# USING WILDLIFE REHABILITATION AND POSTMORTEM DATA TO IDENTIFY KEY CAUSES OF MORBIDITY AND MORTALITY IMPACTING THE HEALTH AND WELFARE OF FREE-LIVING WILD ANIMALS IN CANADA

Authors: King, Meagan, Giacinti, Jolene, Dubois, Sara, Lair, Stéphane, Parmley, E. Jane, et al.

Source: Journal of Wildlife Diseases, 59(1) : 93-108

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/JWD-D-21-00178

DOI: 10.7589/JWD-D-21-00178

*Journal of Wildlife Diseases*, 59(1), 2023, pp. 93–108


# USING WILDLIFE REHABILITATION AND POSTMORTEM DATA TO IDENTIFY KEY CAUSES OF MORBIDITY AND MORTALITY IMPACTING THE HEALTH AND WELFARE OF FREE-LIVING WILD ANIMALS IN CANADA

**Meagan King,[1,2,8] Jolene Giacinti,[1,3] Sara Dubois,[4,5] Stéphane Lair,[6] E. Jane Parmley,[3,7] and Claire M. Jardine[1,3]**

[1] Department of Pathobiology, Ontario Veterinary College, University of Guelph, 50 Stone Road E, Guelph, Ontario N1G 2W1, Canada
[2] Department of Animal Science, Faculty of Agricultural and Food Sciences, University of Manitoba, 12 Dafoe Rd., Winnipeg, Manitoba R3T 2N2, Canada
[3] Canadian Wildlife Health Cooperative, Ontario Veterinary College, University of Guelph, 50 Stone Road E, Guelph, Ontario N1G 2W1, Canada
[4] Faculty of Land and Food Systems, University of British Columbia, 2357 Main Mall, Vancouver, British Columbia V6T 1Z4, Canada
[5] British Columbia Society for the Prevention of Cruelty to Animals, 1245 East 7th Ave., Vancouver, British Columbia V5T 1R1, Canada
[6] Canadian Wildlife Health Cooperative, Faculté de médecine vétérinaire, Université de Montréal, St. Hyacinthe, Quebec J2S 2M2, Canada
[7] Department of Population Medicine, Ontario Veterinary College, University of Guelph, 50 Stone Road E, Guelph, Ontario N1G 2W1, Canada
[8] Corresponding author (email: meagantmking@gmail.com)

ABSTRACT: The health and welfare of wild animals are of increasing concern, yet there are very few large-scale data syntheses examining how causes of wildlife morbidity and mortality vary across time, space, and taxa. Records for 18,540 animals submitted to the Canadian Wildlife Health Cooperative (CWHC) (2009–19) and 144,846 animals admitted to 19 wildlife rehabilitation centers (WRCs) (2015–19) were evaluated to 1) identify the main causes of morbidity and mortality for Canadian wildlife and 2) assess the utility and complementarity of these two data sources to further our understanding of wildlife health. The CWHC cases (mortality) were examined by pathologists and grouped by the presence or absence of five diagnostic categories: trauma, emaciation, infection or inflammation, toxicity, and other. These CWHC animals were also classified as "killed due to real or perceived human-wildlife conflict" based on finder history. The WRC admissions were categorized by health issue (according to intake records) and based on reported or observed situational reasons for admission: parental loss, unsafe or unsuitable location, nest or habitat disturbance, illegal possession, and abnormal behavior. For both datasets, the main reason for submission or admission was trauma (44 and 48%, respectively), especially vehicle collisions (7 and 11%) and window or building strikes (5 and 7%). Many other WRC admissions were due to parental loss (28%), cat attacks (6%), and immature animals being found in unsafe or unsuitable locations (6%). Most other CWHC mortalities were caused by infections (27%) and emaciation (23%). Relatively few birds, amphibians, and reptiles submitted to CWHC were killed due to human-wildlife conflict, but 22% of mammals were killed for this reason, highlighting the taxonomic differences in the perceived threat of wildlife to finders, and therefore their response. Together, these data sources highlight key issues impacting the health and welfare of wild animals in Canada.

*Key words:* Disease, human-wildlife conflict, trauma, wildlife health, wildlife rehabilitation, wildlife welfare.

## INTRODUCTION

Wildlife health and welfare may be affected by naturally occurring stressors such as hunger, thirst, disease, injury, predation, and parasitism (Soryl et al. 2021). Human activity may indirectly influence wildlife through habitat destruction, introductions of invasive species, pollution, and climate change. Humans also directly impact wildlife morbidity and mortality through intentional activities (e.g., legal harvesting, illegal poaching), unintentional events (e.g., window strikes), and activities (e.g., poisoning) that may fall into both of these categories (Fraser and MacRae 2011). Previous studies have demonstrated that anthropogenic activities, especially vehicle and window collisions and predation by domestic animals, are responsible for the deaths of billions of birds and mammals each year in North America (Calvert et al. 2013; Loss et al. 2013, 2015). The effects of human activity on the health and welfare of free-living wild animals are of increasing concern worldwide for many people, including the public, animal welfare scientists, and conservation biologists (Walker et al. 2014; JWD Wildlife Welfare Supplement Editorial Board 2016; Beausoleil et al. 2018).

There are very few large-scale data syntheses looking at causes of wildlife morbidity and mortality and how they vary across time, space, and taxa (Calvert et al. 2013; Loss et al. 2015; Kwok et al. 2021). Multiscale analyses (e.g., national, provincial, regional) can help identify the scale of a particular anthropogenic impact and at what level coordination and mitigation may be most strategic. Data within and between taxa and across seasons may help elucidate patterns and processes relevant for mitigation and management of anthropogenic impacts on wildlife health. Although many sources of wildlife morbidity and mortality data exist, different organizations have different mandates, priorities, and capabilities. Some surveillance systems are passive, whereas others actively target certain species or areas. Each source may collect different types of data that, if looked at in isolation, may miss crucial information. Integrating multiple data sources may allow us to generate new knowledge and gain a more complete understanding of wildlife health.

Existing frameworks to study wildlife health in Canada, such as the Canadian Wildlife Health Cooperative (CWHC), which rely on the submission of dead or diseased animals for pathologic examination, are primarily focused on injury and disease related to cause of death. By contrast, wildlife rehabilitation centers (WRCs), which take in live animals, may collect more information about wildlife morbidity related to sublethal disease and human-wildlife interactions; these data have been identified as an underused resource for understanding wildlife health and welfare (Taylor-Brown et al. 2019). Kelly et al. (2021) recently used reasons for admission and "prediagnostic clinical data" (health or syndromic data from physical examinations before diagnoses are confirmed and officially reported) from WRCs in California to predict clinical diagnoses and to detect morbidity and mortality events. The combination of pathologic and toxicologic examinations of dead animals from the CWHC with situational reasons for admission or hospitalization from WRCs may help develop a more complete understanding of how wildlife is impacted by human activity (Mariacher et al. 2016).

Using passively collected data from the CWHC and WRCs across Canada, our objectives were to 1) describe and compare the major causes of wildlife morbidity, mortality, and WRC admittance across time, space, and taxa; 2) assess the use and complementarity of CWHC and WRC data to further our understanding of the impacts of human activities on wildlife health; and 3) propose steps to improve integration and sharing of information to use limited resources more effectively.

## MATERIALS AND METHODS

Data were collected from two main sources: 1) the CWHC Wildlife Health Intelligence Platform and 2) WRC intake records. No animal use or human ethics approvals were needed for this study.

### CWHC data

The CWHC is a national network of wildlife health experts offering diagnostic services at six regional centers across Canada. Animals submitted to the CWHC are examined by a veterinary pathologist to determine the cause(s) of death. Postmortem examination data for all wild animals submitted through the core passive surveillance component 2009–19 were extracted from the CWHC national database and provided by the CWHC national office; animals submitted as part of targeted surveillance or research projects were excluded. The following demographic data were extracted: date, species, age category, and location. Reports included date of death, date found, date received, and date of necropsy. Whichever came first was the ultimate date of death we considered.

Additional fields completed by pathologists included necropsy notes, diagnostic text, and interpretation. The history field was provided by the finder. From these, we extracted the cause(s) of mortality for each individual and coded this in a new field. If an animal died in the care of a veterinarian or WRC and was later submitted to CWHC, the cause of death was coded as the diagnosis with which the animal was admitted; issues that arose during hospitalization (typically infections) were not included in analyses because we were focused on causes of morbidity and mortality in animals in their original, respective environments. Major categories of diagnosis included primary and secondary emaciation (based on fat stores or body condition); dehydration; trauma; infectious or inflammatory disorders; poisoning, toxicity, soiling, or contamination of fur or feathers; and orphaning. Animals with undetermined diagnoses and those described as exhibiting threatening or strange behavior with no identifiable cause were coded as "open." Animals described as acting appropriately with nonthreatening, species-specific behavior with no identifiable pathologic process were coded as "normal." Major categories of diagnosis were further subdivided (see the Supplementary Table). All remaining diagnoses were coded as "other."

If the animal was recorded as purposely euthanized or killed, the specific method used was coded (e.g., chemical and physical methods; see the Supplementary Table). Animals euthanized using a projectile or gunshot were not categorized as trauma. Based on the history, we also determined whether each animal had been euthanized or killed due to human-wildlife conflict, defined as a real or perceived threat to humans or property or because of nuisance behavior according to the finder. This classification was based on a systematic evaluation of the contextual information provided in the history, specifically the description of behavior, clinical signs, and proximity to humans (see the Supplementary Table). Development of this definition was guided by existing descriptions of human-wildlife conflict (Messmer 2009; Peterson et al. 2010; Nyhus 2016; Grande et al. 2018).

Four researchers (two authors and two research assistants) coded portions of CWHC data. After training sessions, we independently coded a random sample of 50 records to ensure acceptable intercoder reliability. Compared with the primary coder (MK), we achieved kappas of 0.86, 0.87, and 0.90, which indicate "almost perfect agreement" according to Viera and Garrett (2005).

### WRC data

Using contact information available online, 101 licensed WRCs across Canada were contacted by phone or email to inquire about their interest in participating in the study. Participants were offered the chance to win one of two Can$150 gift cards as an incentive to participate. Inclusion criteria were simply that the rehabilitator or facility must have 1–5 yr of records available from 2015 to 2019, regardless of center size or species accepted. In addition, the Fatal Light Awareness Program (FLAP) Canada provided data that are presented separately due to their active surveillance strategy to search for injured and dead birds. Participating WRCs submitted all intake records including date; species; age; location; diagnosis, reason for admission, or both; and final disposition.

Using health and situational information in the records, animals were grouped into four categories: 1) recorded health issue(s); 2) recorded situational issue(s); 3) recorded health and situational issues; or 4) unknown or unrecorded situation, location, and diagnosis. Health issues were coded following the same general categorization described for the CWHC, with the caveat that many diagnoses in WRC intake records were suspected or presumed causes of morbidity upon examination at admittance, but not yet confirmed by a veterinarian or diagnostic test at the point of data entry. Furthermore, WRC admission could be due to starvation (as opposed to emaciation).

Admission due to situational circumstances included illegal or inappropriate human possession (animals kept as pets, confiscated, or rehabilitated without a license), nest or habitat disturbance or destruction, in unsuitable locations, or showing "abnormal behavior" (see below). Animals found in unsafe or unsuitable locations were often immature animals that "fell from the nest" or they were interpreted by the finder to be stranded or in unsuitable or nuisance locations, whereas adults that fell from the nest or were on the ground uninjured were coded as open. If none of these situations occurred and the entry included abnormal behavior or was for a hibernating species found awake in winter, this was considered abnormal behavior.

Final dispositions were classified as released (by rehabilitators or the animal escaped); died (dead on arrival, died in care), euthanized, in care (still at the WRC because it was admitted close to the end of the data collection period, was overwintering, or was kept for flight training), transferred (to another facility), or placed (permanent resident or kept as an education animal).

### Statistical analyses

Statistical analyses were conducted using SAS 9.4 (2002–12; SAS Institute Inc., Cary, North Carolina, USA). Provinces were grouped into the following regions: Pacific (British Columbia), Prairies (Alberta, Saskatchewan, and Manitoba), Ontario, Quebec, Atlantic (Prince Edward Island, New Brunswick, Nova Scotia, Newfoundland, and Labrador), and Northern Canada (Yukon, Northwest Territories, and Nunavut). Animals were categorized by taxonomic group as either birds, mammals, reptiles, amphibians, or fish. Birds and mammals were further categorized according to their behavioral niches and significance to humans (see the Supplementary Table). Animals were classified by age as immature or mature. We also classified animals based on their protection status under the Species at Risk Act (2002) and the Migratory Birds Convention Act (1994). Descriptive statistics were calculated in SAS, stratified by region, species group, age group, and month. Differences in proportions of each diagnosis category (CWHC) and reason for admission (WRCs) were assessed using chi-square tests. Bonferroni corrections were used where multiple pairwise comparisons were performed.

## RESULTS

### General intake trends

Supplementary Material Figure S1 describes the total number of records received, reviewed, and excluded for the CWHC and WRCs. The total number of complete records for CWHC (2009–19) was 18,540 and for 19 WRCs (2015–19) was 144,846 (see the Supplementary Table). Three WRCs focused on birds of prey, two focused on birds in general, and one treated reptiles and amphibians; the others did not have a specific species focus. From FLAP Canada, we obtained records for 14,486 birds from 2015 to 2019. Table 1 contains the breakdown of submissions by vertebrate class, conservation status, age category, region, and final disposition.

Annual admissions to WRCs peaked in June and CWHC submissions peaked in August. Mostly birds and mammals were submitted; there were relatively few reptiles, amphibians, and fish (Table 1 and Fig. 1). Most birds collected by FLAP were protected under the Migratory Birds Convention Act (Government of Canada 1994), with smaller proportions classified as such from CWHC and WRCs. Just over 3,000 animals (Table 1) were defined as threatened or endangered according to the Species at Risk Act (Government of Canada 2002). For all regions, songbirds were the most common species group submitted, followed by birds of prey. There were more immature than mature animals in CWHC and WRC datasets (Table 1). The most common outcome for animals in WRCs or FLAP datasets was death; the remaining FLAP birds and WRC animals were released. We present overall diagnostic trends for CWHC, WRC, and FLAP data, stratified by region, month, age category, and species group.

### Trauma

Trauma was the leading cause of death and of WRC admission (Tables 2–4). The proportion of animals affected by trauma was higher in WRC (47.9%) than CWHC (44.1%) data ($P<0.001$). Of the known sources of trauma in CWHC and WRC data, 92 and 93% of cases, respectively, were caused by anthropogenic factors (see the Supplementary Table for details), particularly collisions with vehicles in summer and windows or buildings in spring, summer, and fall (see Supplementary Material Figs. S2 and S3 and the Supplementary Table). Within the WRC dataset (see Supplementary Fig. S3A), vehicle collisions were more frequent for mature than immature animals, whereas mortality due to vehicle collisions was relatively equal between age categories in the CWHC dataset. For adult birds admitted to WRCs, window or building strikes were most common during the April–May and September–October migration periods and for immature birds during June–September (see Supplementary Fig. S3B). The FLAP collisions mirrored the spring and fall migration periods (see Supplementary Fig. S3B). Window or building strikes were more common for immature individuals sent to CWHC throughout the year. Cat attacks were most common during May–August and more so for immature individuals than adults (see Supplementary Fig. S3C) and were a top-ranking issue for songbirds, hummingbirds, and aerial insectivores.

TABLE 1. Characteristics of wildlife submissions received by the Canadian Wildlife Health Cooperative (CWHC), wildlife rehabilitation centers (WRCs), and the Fatal Light Awareness Program (FLAP Canada) in Canada.

| | CWHC (2009–19), No. (%) | WRCs (2015–19), No. (%) | FLAP Canada (2015–19), No. (%) |
|---|---|---|---|
| Vertebrate class | | | |
| Birds | 12,089 (65.2) | 96,648 (66.7) | 14,486 (100) |
| Mammals | 5,825 (31.4) | 41,202 (28.4) | NA[a] |
| Reptiles | 279 (1.5) | 6,802 (4.7) | NA |
| Fish | 250 (1.3) | 0 (0) | NA |
| Amphibians | 97 (0.5) | 149 (0.10) | NA |
| Unknown or unrecorded | 0 (0) | 45 (0.03) | NA |
| Species status | | | |
| Species at risk[b] | 1,009 (5.4) | 2,064 (1.4) | 59 (0.4) |
| Migratory birds[b] | 3,588 (19.4) | 51,538 (35.6) | 10,154 (70.1) |
| Age category | | | |
| Immature | 8,853 (47.8) | 86,148 (59.5) | NA |
| Mature | 6,691 (36.1) | 46,639 (32.2) | NA |
| Unknown age | 2,996 (16.2) | 12,059 (8.3) | NA |
| Region[c] | | | |
| Pacific | 356 (1.9) | 38,747 (26.8) | NA |
| Prairies | 5,112 (27.6) | 22,747 (15.7) | NA |
| Ontario | 3,884 (20.9) | 71,323 (49.2) | 14,486 (100) |
| Quebec | 5,384 (29.0) | 12,029 (8.3) | NA |
| Atlantic | 3,477 (18.8) | NA | NA |
| Northern | 327 (1.8) | NA | NA |
| Final disposition | | | |
| Released | NA | 55,270 (38.2) | 3,298 (22.7) |
| Died[d] | 18,540 (100) | 83,331 (57.6) | 11,006 (76.0) |
| In care | NA | 642 (0.4) | NA |
| Placed | NA | 365 (0.3) | NA |
| Transferred | NA | 3,495 (2.4) | 182 (1.3) |
| Unknown | 0 (0) | 1743 (1.2) | 0 (0) |
| Total | 18,540 (100) | 144,846 (100) | 14,486 (100) |

[a] NA = not applicable.

[b] According to classification outlined by the Species at Risk Act (2002) and Migratory Birds Convention Act (1994).

[c] Regions are as follows: Pacific (British Columbia); Prairies (Alberta, Saskatchewan, and Manitoba); Ontario; Quebec; Atlantic (Prince Edward Island, New Brunswick, Nova Scotia, Newfoundland, and Labrador); and Northern Canada (Yukon, Northwest Territories, and Nunavut).

[d] Died included euthanized and animals that died on their own. Animals that were killed and sent to CWHC ($n = 5{,}172$) or euthanized at WRCs ($n = 47{,}052$).

Cat attacks were also the greatest source of trauma for bats overall as well as for hares and rabbits in WRC data; dog attacks were major sources of trauma for CWHC skunks, raccoons, and opossums and WRC hares and rabbits, opossums, weasels and otters, canids, rodents, and ungulates. WRC waterfowl were often entrapped or entangled. For CWHC felids, bears, canids, ungulates, gamebirds, and waterfowl, projectiles were a top-ranking source of trauma. Within the CWHC dataset, a greater proportion of birds ($P<0.001$) were affected by trauma compared to mammals and others, with the latter two not differing from each other ($P=1.00$). In contrast, the proportion of WRC animals affected by trauma differed for all taxa ($P<0.001$) with all pairwise comparisons being significant (others>birds>mammals).

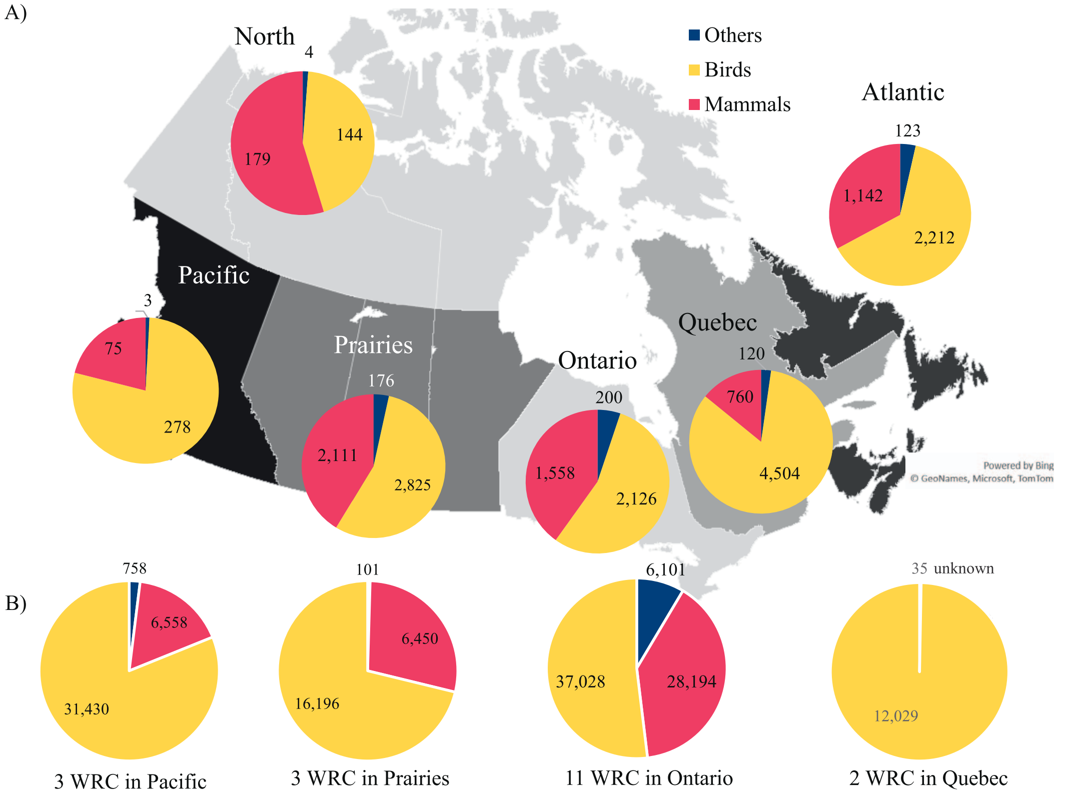


FIGURE 1. Number of complete records for birds, mammals, and others (reptiles, amphibians, fish, and unknown species) representing (a) six regions contributing Canadian Wildlife Health Cooperative data and (b) four regions contributing wildlife rehabilitation center data.

#### Infection or inflammation

Overall, infectious and inflammatory disorders were a leading cause of mortality in animals within the CWHC dataset (Table 2). Most infections were viral (see the Supplementary Table). Across all CWHC regions, infection or inflammation was most common in mammals and was the most common cause of death for bats (mostly white nose syndrome and rabies), raccoons (canine distemper virus [CDV], parvovirus), skunks (CDV, rabies), and ungulates (meningeal worm, chronic wasting disease; Table 5). The proportion of animals affected by infection and inflammation was significantly higher in CWHC (27.3%) than in WRC (2.8%) animals ($P<0.001$). Within the CWHC dataset, a greater proportion of mammals ($P<0.001$) were affected by infection or inflammation compared to birds and others, with the latter two not differing from each other ($P=0.57$). In contrast, the proportion of WRC animals affected by infection or inflammation differed for all taxa ($P<0.001$) with all pairwise comparisons being significant (birds>mammals>others).

#### Emaciation or starvation

Emaciation ranked as the third most common cause of mortality in animals from the CWHC dataset (Table 2). Emaciation was a cause of mortality for roughly one third of CWHC birds of prey, shore or groundbirds, and seabirds. Only 3% of all animals were admitted to WRCs due to starvation. The proportion of animals affected by emaciation was significantly higher ($P<0.001$) for CWHC (23.4%) than WRC (3.2%) animals, as well as within each dataset taxonomically ($P<0.001$) with all pairwise

TABLE 2. Top reasons[a] for mortality in 18,540 Canadian Wildlife Health Cooperative (CHWC) submissions and 144,846 admissions to intake records from 19 wildlife rehabilitation centers (WRCs).

| Species class | Total | No. 1 reason | No. (% of species class) | No. 2 reason | No. (% of species class) | No. 3 reason | Number (% of species class) |
|---|---|---|---|---|---|---|---|
| CWHC overall | 18,540 | Trauma | 8,183 (44.1) | Infection or inflammation | 5,062 (27.3) | Emaciation | 4,329 (23.4) |
| Birds | 12,089 | Trauma | 6,238 (51.6) | Emaciation | 3,285 (27.2) | Infection or inflammation | 2,643 (21.9) |
| Mammals | 5,825 | Infection or inflammation | 2,296 (39.4) | Trauma | 1,753 (30.1) | Emaciation | 1,021 (17.5) |
| Reptiles | 279 | Trauma | 144 (51.6) | Open | 69 (24.7) | Infection | 54 (19.4) |
| Fish | 250 | Open | 140 (56.0) | Infection or inflammation | 59 (23.6) | Trauma | 21 (8.4) |
| Amphibians | 97 | Open | 51 (52.6) | Trauma | 27 (27.8) | Infection or inflammation | 10 (10.3) |
| WRC overall | 144,846 | Trauma | 69,434 (47.9) | Parental loss | 39,835 (27.5) | Unsuitable location | 8,678 (6.0) |
| Birds | 96,648 | Trauma | 49,944 (51.7) | Parental loss | 20,681 (21.4) | Unsuitable location | 7,398 (7.7) |
| Mammals | 41,202 | Parental loss | 19,027 (46.2) | Trauma | 14,513 (35.2) | Nest disturbed | 1,915 (4.6) |
| Reptiles | 6,802 | Trauma | 4,882 (71.8) | Nest or habitat disturbed | 844 (12.4) | Illegal possession | 127 (1.9) |
| Amphibians | 149 | Trauma | 78 (52.3) | Nest or habitat disturbed | 16 (10.7) | Unsuitable location | 7 (4.7) |

[a] Note that the available categories differed between CWHC and WRC datasets. WRC had additional situational reasons to explain why animals were admitted, which were not applicable to CWHC specimens. Unknown WRC species are not included in this table.

TABLE 3. Top reasons[a] for known sources of trauma in 18,540 Canadian Wildlife Health Cooperative (CHWC) submissions and 144,846 admissions to intake records from 19 wildlife rehabilitation centers (WRCs).

| Species class | Total | No. 1 source | No. (% of species class) | No. 2 source | No. (% of species class) | No. 3 source | No. (% of species class) |
|---|---|---|---|---|---|---|---|
| CWHC overall | 18,540 | Vehicle collision | 1,314 (7.1) | Unknown collision | 949 (5.1) | Window or building strike | 498 (2.7) |
| Birds | 12,089 | Unknown collision | 837 (6.9) | Vehicle collision | 785 (6.5) | Window or building strike | 497 (4.1) |
| Mammals | 5,825 | Vehicle collision | 446 (7.7) | Unknown predator | 167 (2.9) | Unknown collision | 108 (1.9) |
| Reptiles | 279 | Vehicle collision | 68 (24.4) | Unknown predator | 39 (14.0) | Fishing gear | 4 (1.4) |
| Fish | 250 | Fishing gear | 5 (2.0) | Natural predator | 3 (1.2) | Target species capture | 1 (0.01) |
| Amphibians | 97 | Vehicle collision | 15 (15.5) | Natural predator | 5 (5.2) | Unknown predator | 2 (2.1) |
| WRC overall | 144,846 | Vehicle collision | 16,127 (11.1) | Window or building strike | 10,138 (7.0) | Cat attack | 8,720 (6.0) |
| Birds | 96,648 | Window or building strike | 10,083 (10.4) | Vehicle collision | 9,098 (9.4) | Cat attack | 5,527 (5.7) |
| Mammals | 41,202 | Vehicle collision | 2,631 (6.4) | Cat attack | 3,167 (7.7) | Dog attack | 1,910 (4.6) |
| Reptiles | 6,802 | Vehicle collision | 4,389 (64.5) | Unknown predator | 96 (1.4) | Fishing gear | 40 (0.6) |
| Amphibians | 149 | Vehicle collision | 19 (12.8) | Yard gear | 10 (6.7) | Unknown predation | 9 (6.0) |

[a] Note that the available categories differed between CWHC and WRC datasets. WRC had additional situational reasons to explain why animals were admitted, which were not applicable to CWHC specimens. Unknown WRC species are not included in this table.

TABLE 4. Causes of trauma for animals submitted to the Canadian Wildlife Health Cooperative (CWHC) from 2009 to 2019 or admitted to 1 of 19 wildlife rehabilitation centers (WRCs) from 2014 to 2019.

| Trauma subcategory | CWHC (no.) | CWHC (% of all cases) | WRCs (no.) | WRCs (% of all cases) |
|---|---|---|---|---|
| Collision | | | | |
| Overall | 2,989 | 16.1 | 30,096 | 20.8 |
| Vehicle[a] | 1,314 | 7.1 | 16,127 | 11.1 |
| Window or building strike | 498 | 2.7 | 10,138 | 7.0 |
| Natural event[b] | 90 | 0.5 | 174 | 0.1 |
| Fell from nest or dropped | 69 | 0.4 | 1,688 | 1.2 |
| Other structure[c] | 62 | 0.3 | 88 | 0.1 |
| Unknown collision | 956 | 5.2 | 1,882 | 1.3 |
| Entanglement or entrapment | | | | |
| Overall | 608 | 3.3 | 4,076 | 2.8 |
| Trap or snare | 413 | 2.2 | 601 | 0.4 |
| Nontrap or space[d] | 120 | 0.6 | 1,497 | 1.0 |
| Fishing gear | 59 | 0.3 | 175 | 0.1 |
| Natural or organic source[e] | 15 | 0.1 | 72 | 0.05 |
| Unknown | 1 | 0.0 | 1,731 | 1.2 |
| Animal interaction | | | | |
| Overall | 970 | 5.2 | 16,705 | 11.5 |
| Wild animals | 137 | 0.7 | 1,088 | 0.8 |
| Domestic cat | 302 | 1.6 | 8,720 | 6.0 |
| Domestic dog | 112 | 0.6 | 2,688 | 1.9 |
| Captive or other domestic | 16 | 0.1 | 87 | 0.06 |
| Unknown animal | 403 | 2.2 | 4,123 | 2.8 |
| Projectile or gunshot | 415 | 2.2 | 351 | 0.2 |
| Abuse or neglect[f] | 22 | 0.1 | 93 | 0.06 |
| Electrocution | 242 | 1.3 | 140 | 0.1 |
| Burns | 65 | 0.4 | 95 | 0.07 |
| Yard gear | 2 | 0 | 219 | 0.15 |
| Farm gear | 0 | 0 | 21 | 0.01 |
| Other[g] | 23 | 0.1 | 19 | 0.01 |
| Unknown[h] | 2,906 | 15.7 | 17,800 | 12.3 |
| Total[i] | 8,183 | 44.1 | 69,434 | 47.9 |

[a] Vehicles include car, truck, boat, plane, and train.
[b] Includes collisions with trees and cliffs or due to storms and extreme weather events.
[c] Includes collisions with other artificial structures, such as wind turbines, powerlines, fences, or fans.
[d] Includes entrapment in artificial spaces or buildings, vents, or pipes or in materials such as litter, string, rope, or netting.
[e] Includes entrapment in any material or space that is not artificial.
[f] Animals being hit by humans with objects such as bats or rocks.
[g] Other includes foreign body, being stepped on or crushed.
[h] Luxation, traumatic hemorrhages, and fractures with nonmetabolic causes were coded as unknown trauma.
[i] Total number of animals with trauma is not a perfect sum of the total due to multiple accounts of trauma for some animals (both within and between trauma types).

comparisons being significant (birds>mammals>others for CWHC data, mammals>birds>others for WRC data). Emaciation (CWHC) and starvation (WRCs) were more common in the winter and late summer or fall (see Supplementary Fig. S4). Both datasets showed more impact on immature animals in late summer and fall. The CWHC emaciation data in winter peaked for mature and immature animals; WRCs witnessed more starvation in winter for mature animals only.

TABLE 5. Major causes of mortality[a] by species grouping for 18,540 animals submitted for necropsy to the Canadian Wildlife Health Cooperative (CWHC) between 2009 and 2019.

| Vertebrate class and species subgroup | Health issue[b] | | | | | | Normal | Open | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Total health issue | Infection or inflammation | Trauma | Emaciation or starvation | Toxicity or contamination | Parental loss | | | |
| Birds | 10,852 (89.8) | 2,643 (21.9) | 6,238 (51.6) | 3,285 (27.2) | 840 (6.9) | 117 (1.0) | 5 (0.04) | 1,232 (10.2) | 12,088 |
| Aerial insectivores | 122 (77.2) | 11 (7.0) | 77 (48.7) | 30 (19.0) | 3 (2.0) | 0 (0) | 0 (0) | 36 (22.8) | 158 |
| Birds of prey | 4,535 (94.5) | 898 (18.7) | 2,866 (59.7) | 1,805 (37.6) | 128 (2.7) | 30 (0.6) | 2 (0.04) | 263 (5.5) | 4,800 |
| Gamebirds | 635 (88.6) | 175 (24.4) | 279 (38.9) | 108 (15.1) | 133 (18.5) | 23 (3.2) | 0 (0) | 82 (11.4) | 717 |
| Hummingbirds | 8 (47.1) | 2 (11.8) | 3 (17.6) | 4 (23.5) | 0 (0) | 0 (0) | 0 (0) | 9 (52.9) | 17 |
| Seabirds | 1,099 (83.8) | 441 (33.6) | 475 (36.2) | 422 (32.2) | 83 (6.3) | 1 (0.1) | 0 (0) | 213 (16.2) | 1,312 |
| Shore or groundbirds | 374 (92.6) | 31 (7.7) | 239 (59.2) | 133 (32.9) | 29 (7.2) | 1 (0.2) | 0 (0) | 30 (7.4) | 404 |
| Songbirds | 2,874 (87.7) | 862 (26.3) | 1,807 (55.1) | 511 (15.6) | 167 (5.1) | 41 (1.3) | 2 (0.06) | 401 (12.2) | 3,277 |
| Waterfowl | 1,205 (85.8) | 223 (15.9) | 492 (35.0) | 272 (19.4) | 297 (21.2) | 21 (1.5) | 1 (0.07) | 198 (14.1) | 1,404 |
| Mammals | 4,540 (74.7) | 2,296 (37.8) | 1,753 (28.9) | 1,021 (16.8) | 137 (2.3) | 202 (3.3) | 266 (4.4) | 1,019 (16.8) | 5,825 |
| Aquatic | 175 (63.4) | 59 (21.4) | 56 (20.3) | 63 (22.8) | 0 (0) | 25 (9.1) | 0 (0) | 101 (36.6) | 276 |
| Bats | 986 (70.0) | 511 (36.3) | 409 (29.0) | 310 (22.0) | 2 (0.1) | 2 (0.1) | 123 (8.7) | 300 (21.3) | 1,409 |
| Bears | 92 (79.3) | 17 (14.7) | 58 (50) | 10 (8.6) | 0 (0) | 9 (7.8) | 4 (3.4) | 20 (17.2) | 116 |
| Canids | 655 (84.7) | 270 (34.9) | 339 (43.9) | 193 (25.0) | 52 (6.7) | 10 (1.3) | 31 (4.0) | 87 (11.3) | 773 |
| Felids | 54 (69.2) | 8 (10.3) | 27 (34.6) | 23 (29.5) | 0 (0) | 2 (2.6) | 13 (16.7) | 11 (14.1) | 78 |
| Hares or rabbits | 165 (88.7) | 47 (25.3) | 113 (60.8) | 29 (15.6) | 0 (0) | 9 (4.8) | 0 (0) | 21 (11.3) | 186 |
| Opossums | 19 (61.3) | 10 (32.3) | 16 (51.6) | 4 (12.9) | 0 (0) | 2 (6.5) | 2 (6.5) | 10 (32.3) | 31 |
| Raccoons | 872 (83.6) | 655 (62.8) | 182 (17.4) | 60 (5.8) | 20 (1.9) | 89 (8.5) | 57 (5.5) | 114 (10.9) | 1,043 |
| Rodents | 490 (77.8) | 152 (24.1) | 262 (41.6) | 81 (12.9) | 42 (6.7) | 24 (3.8) | 9 (1.4) | 131 (20.8) | 630 |
| Skunks | 120 (81.1) | 65 (43.9) | 40 (27.0) | 15 (10.1) | 9 (6.1) | 11 (7.4) | 9 (6.1) | 19 (12.8) | 148 |
| Ungulates | 843 (80.7) | 485 (46.4) | 208 (19.9) | 223 (21.3) | 11 (1.1) | 15 (1.4) | 10 (1.0) | 192 (18.4) | 1,045 |
| Weasels or otters | 69 (76.7) | 17 (18.9) | 43 (47.8) | 10 (11.1) | 1 (1.1) | 4 (4.4) | 8 (8.9) | 13 (14.4) | 90 |
| Amphibians | 46 (47.4) | 10 (10.3) | 27 (27.8) | 2 (2.1) | 0 (0) | 0 (0) | 0 (0) | 51 (52.6) | 97 |
| Reptiles | 210 (75.3) | 54 (19.4) | 144 (51.6) | 20 (7.2) | 0 (0) | 0 (0) | 0 (0) | 69 (24.7) | 279 |
| Fish | 110 (44) | 59 (23.6) | 21 (8.4) | 1 (0.4) | 5 (2) | 0 (0) | 0 (0) | 140 (56) | 250 |
| Total[c] | 15,758 (85.0) | 5,062 (27.3) | 8,183 (44.1) | 4,329 (23.4) | 982 (5.3) | 319 (1.7) | 271 (1.5) | 2,511 (13.5) | 18,540 |

[a] Raw number (percentage within that species category).

[b] Other minor categories of mortality not in the table include drowning ($n = 197$); blockages, impactions, or perforations ($n = 138$); research, management, or pest control accidents ($n = 126$); nephrosis and/or gout of unknown origin ($n = 119$); exposure ($n = 87$); neoplasia ($n = 46$); anemia of unknown origin ($n = 33$); dental issues ($n = 30$); hypoxia ($n = 27$); metabolic disorders ($n = 26$); grain overload ($n = 24$); atelectasis ($n = 21$); parturition complications ($n = 13$); and others ($n = 146$).

[c] Total number of animals with various issues is not a perfect sum of the total due to multiple diagnoses for some animals.

### Parental loss

Situational reasons, the majority of which were presumed parental loss, accounted for more than one third of the animals admitted to WRCs (see the Supplementary Table). Parental loss was the second most common reason for WRC admission (Table 2). For many mammals and waterfowl (Table 6), parental loss was the number one reason for admission. It ranked as one of the top three most common reasons for admission for all bird subgroups. More than 50% of aquatic mammals, skunks, weasels and otters, rodents, raccoons, opossums, and bears and 47% of ungulates were admitted as orphans to WRCs. In CWHC data, <2% of deaths were attributed to parental loss. Therefore, the proportion of animals affected by parental loss was significantly higher ($P<0.001$) for WRC (27.5%) than CWHC (1.7%) animals and differed between taxa within each dataset ($P<0.001$), with all pairwise comparisons being significant. Within WRC animals, parental loss affected 46.2% of mammals compared with 21.4% of birds and 1.8% of other taxa.

### Other situational reasons for WRC admission

Being in an unsuitable location was the third major reason for admission for amphibians and birds, particularly songbirds (Table 2). The proportion of WRC animals found in an unsuitable location differed by taxon ($P<0.001$), with all pairwise comparisons being significant (birds>mammals>others). Many rodents were also found in unsafe or unsuitable locations (Table 6). Nest or habitat disturbance or destruction was a high-ranking reason for reptiles, amphibians, and mammals (especially hares and rabbits, rodents, and bats). Illegal or inappropriate possession was more common for mammals, reptiles, and amphibians compared with birds (Table 2). Although many rodents brought to WRCs were held illegally, proportionately ungulates, amphibians, and reptiles were the taxa most commonly admitted due to illegal or inappropriate human possession (Table 6). Abnormal behavior (being awake in winter) was the second most common reason for WRC admission for bats, after trauma (Table 6).

### Human-wildlife conflict in CWHC data

Of the 5,172 CWHC animals euthanized or killed, 1,518 (29%) were due to human-wildlife conflict. Of those, 1,015 (67%) were diagnosed with health disorders, 251 (17%) were given open diagnoses, and 253 (17%) were deemed normal. Although 22% (1,291) of mammals were killed due to conflict, only 2% (222) of birds were killed for this reason. Proportionally, wild felids were the most common subgroup killed due to conflict: 28 (36%) wild felids were killed due to conflict (22 mountain lions, 5 lynx, 1 bobcat), and of those felids, 12 (43%) were diagnosed as clinically and behaviorally normal. However, wild felids contributed to <2% of all conflicts. Raccoons, bats, ungulates, and wild canids 95 coyotes (*Canis latrans*), 73 foxes (*Vulpes vulpes*), and 22 wolves (*Canis lupis*) collectively contributed to >70% of all conflicts, and 23–31% of each subgroup were classified as normal (see the Supplementary Table).

## DISCUSSION

The main causes of wildlife morbidity and mortality identified by the CWHC were trauma, infection or inflammation, and emaciation. Admission to WRCs was also commonly caused by trauma as well as parental loss and various other scenarios relating to human-wildlife conflicts. Although many issues were common across datasets, seasons, taxa, and region, this study also identified some key differences.

### Trauma

Across Canada, trauma was the most common cause of CWHC mortality and WRC admission, overwhelmingly due to vehicle and window collisions and attacks by cats (Tables 2 and 3). This was expected given that numerous studies have also identified collisions and cats as the main sources of trauma for North American wildlife (Hartup 1996; Dubois 2003; Loss et al. 2015; Long et al. 2020; Pandit et al. 2021). Cats have been shown to have devastating effects on bird and mammal populations (Loss et al. 2013). In our

TABLE 6. Main reasons for admission[a] by species grouping for animals admitted to 19 wildlife rehabilitation centers (2015–19).

| | Health issue[b] | | | | Situational issue | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species subcategory | Trauma | Starvation | Infection or inflammation | Toxicity or contamination | Parental loss | Unsafe location | Nest or habitat | Illegal possession | Total |
| Birds | 49,944 (51.7) | 2,724 (2.8) | 2,993 (3.1) | 1,270 (1.3) | 20,681 | 7,398 (7.7) | 1,869 (1.9) | 514 (0.5) | 96,648 |
| Aerial insectivores | 649 (38.2) | 19 (1.1) | 5 (0.3) | 14 (0.8) | 463 (27.3) | 318 (18.7) | 151 (8.9) | 2 (0.1) | 1,699 |
| Birds of prey | 5,345 (63.1) | 713 (8.4) | 216 (2.5) | 113 (1.3) | 485 (5.7) | 124 (1.5) | 37 (0.4) | 23 (0.3) | 8,472 |
| Gamebirds | 7,847 (53.6) | 649 (4.4) | 1,022 (7.0) | 270 (1.8) | 2,395 (16.3) | 460 (3.1) | 305 (2.1) | 91 (0.6) | 14,649 |
| Hummingbirds | 1,091 (75.2) | 14 (1.0) | 11 (0.8) | 22 (1.5) | 58 (4.0) | 126 (8.7) | 9 (0.6) | 5 (0.3) | 1,450 |
| Seabirds | 4,357 (60.3) | 258 (3.6) | 227 (3.1) | 170 (2.4) | 299 (4.1) | 792 (11.0) | 18 (0.2) | 8 (0.1) | 7,226 |
| Shore or groundbirds | 971 (60.1) | 101 (6.3) | 24 (1.5) | 16 (1.0) | 172 (10.7) | 110 (6.8) | 3 (0.2) | 2 (0.1) | 1,615 |
| Songbirds | 25,610 (58.9) | 695 (1.6) | 1,382 (3.2) | 293 (0.7) | 8,114 (18.6) | 2,606 (6.0) | 1,318 (3.0) | 273 (0.6) | 43,516 |
| Waterfowl | 4,074 (22.6) | 275 (1.5) | 106 (0.6) | 372 (2.1) | 8,695 (48.2) | 2,862 (15.9) | 28 (0.2) | 110 (0.6) | 18,021 |
| Mammals | 14,513 (35.2) | 1,937 (4.7) | 1,044 (2.5) | 211 (0.5) | 19,027 (46.2) | 1,199 (2.9) | 1,915 (4.7) | 439 (1.1) | 41,202 |
| Aquatic | 5 (18.5) | 2 (7.4) | 1 (3.7) | 1 (3.7) | 19 (70.4) | 2 (7.4) | 0 (0.0) | 0 (0.0) | 27 |
| Bats | 754 (36.3) | 66 (3.2) | 25 (1.2) | 27 (1.3) | 80 (3.9) | 89 (4.3) | 93 (4.5) | 4 (0.2) | 2,075 |
| Bears | 2 (50.0) | 1 (25.0) | 0 (0.0) | 0 (0.0) | 2 (50.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 4 |
| Canids | 203 (32.2) | 59 (9.4) | 178 (28.2) | 1 (0.2) | 195 (30.9) | 6 (1.0) | 0 (0.0) | 6 (1.0) | 631 |
| Felids | 1 (100.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 |
| Hares or rabbits | 6,515 (50.4) | 346 (2.7) | 43 (0.3) | 11 (0.1) | 4,588 (35.5) | 199 (1.5) | 891 (6.9) | 167 (1.3) | 12,934 |
| Opossums | 553 (40.5) | 72 (5.3) | 3 (0.2) | 1 (0.1) | 706 (51.7) | 12 (0.9) | 3 (0.2) | 9 (0.7) | 1,365 |
| Raccoons | 1,162 (22.3) | 255 (4.9) | 443 (8.5) | 21 (0.4) | 2,743 (52.6) | 116 (2.2) | 95 (1.8) | 58 (1.1) | 5,218 |
| Rodents | 4,479 (27.4) | 994 (6.1) | 279 (1.7) | 130 (0.8) | 9,234 (56.4) | 731 (4.5) | 826 (5.0) | 170 (1.0) | 16,374 |
| Skunks | 375 (26.3) | 75 (5.3) | 58 (4.1) | 16 (1.1) | 889 (62.3) | 20 (1.4) | 0 (0.0) | 4 (0.3) | 1,426 |
| Ungulates | 322 (46.6) | 28 (4.1) | 6 (0.9) | 2 (0.3) | 325 (47.0) | 17 (2.5) | 1 (0.1) | 20 (2.9) | 691 |
| Weasels or otters | 134 (32.0) | 39 (9.3) | 8 (1.9) | 1 (0.2) | 227 (54.2) | 7 (1.7) | 6 (1.4) | 1 (0.2) | 419 |
| Unknown mammals | 8 (21.6) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 19 (51.4) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 37 |
| Amphibians | 78 (52.3) | 2 (1.3) | 1 (0.7) | 0 (0.0) | 1 (0.7) | 7 (4.7) | 16 (10.7) | 3 (2.0) | 149 |
| Reptiles | 4,882 (71.8) | 8 (0.1) | 27 (0.4) | 124 (1.8) | 118 (1.7) | 71 (1.0) | 844 (12.4) | 127 (1.9) | 6,802 |
| Unknown species | 17 (37.8) | 0 (0.0) | 1 (2.2) | 1 (2.2) | 8 (17.8) | 3 (6.7) | 0 (0.0) | 0 (0.0) | 45 |
| Total[c] | 69,434 | 4,671 | 4,066 | 1,606 | 39,835 | 8,678 | 4,644 | 1,083 | 144,846 |

[a] Raw number (percentage within that species category).

[b] Other health issues ($n=1,606$) include exposure ($n=940$); congenital ($n=208$); metabolic bone disease ($n=156$); research or mist net accidents ($n=126$); possible drowning ($n=39$); deformities or tumors ($n=35$); blockages, impactions, or perforations ($n=25$); migration exhaustion ($n=22$); and other ($n=57$).

[c] Total number of animals with various issues is not a perfect sum of the total due to multiple diagnoses for some animals.

study and those of others, songbirds, aerial insectivores, and hummingbirds were particularly affected by cats, as were mammals such as bats, hares and rabbits, and rodents, especially immature animals in spring and summer (Wimberger and Downs 2010; Loyd et al. 2017; Long et al. 2020). Because Loss et al. (2013) estimated that 70–90% of fatal cat attacks in the US were by unowned cats, future studies investigating population sizes of unowned cats and their predation rates would help to inform models to better estimate the impacts of cats on wildlife (Loss et al. 2013; McRuer et al. 2017).

### Parental loss

Parental loss accounted for 28% of WRC admissions in this study, falling between previous estimates of 20–51% (Loyd et al. 2017; Taylor-Brown et al. 2019; Long et al. 2020; Kwok et al. 2021). By comparison, parental loss was far less common in CWHC records, but those were instances where animals were lethally affected. Parental loss was the leading cause of WRC admission for mammals, songbirds, waterfowl, and gamebirds in Ohio (Long et al. 2020) and for mammals and waterfowl in the current study. Unfortunately, most records of confirmed orphans lacked detailed reasons, and many others were unknown, unconfirmed, or deemed as "unnecessary interference by humans" causing the animal to be an "unnecessary orphan." Enhanced screening protocols and standardized data entry across WRCs would improve our understanding of the reasons why wild animals are orphaned (Long et al. 2020).

### Other situations and human-wildlife conflict

Conflicts leading to killing of wildlife (CWHC) and admission to WRCs were most common in the Prairies and Ontario (see the Supplementary Table). Although the population density, disease status, or behavior of wildlife may differ across Canada, the driving factors of most human-wildlife conflicts are related to the human element (Peterson et al. 2010), such as human population densities, attitudes, and behaviors. The social aspects of human-wildlife conflict were beyond the scope of this study, but we systemically captured many complex and nuanced situations that led to conflict, determining that 22% of mammals from CWHC data were killed due to conflict; of those animals, 19% were diagnosed as clinically and behaviorally normal, indicating that there were no identified health issues or abnormal behaviors to justify killing those animals as a management approach. By contrast, only 2% of CWHC birds were killed due to conflict, perhaps because they are perceived to be less threatening based on their size, behavior, or perceived ability to transmit disease. Alternatively, parental loss accounted for far more mammalian WRC admissions than birds and other species. Those admitted because they were found in unsuitable locations were most commonly birds as well as amphibians and mammals, as reported by others (Dubois 2003; Wimberger and Downs 2010; Pandit et al. 2021). Nest or habitat disturbances were common for hares and rabbits, reptiles, and amphibians. Bats, however, were often admitted because they were found awake during winter or had their habitat or roosts disturbed, and many were killed because the public was concerned about disease. Therefore, people seem to deem close proximity to adult mammals (regardless of their health or behavior) as more threatening, risky, or bothersome, whereas a bird, amphibian, reptile, or young or orphaned mammal in the same situation generally provokes the finder to rescue it.

There are also differences in perceived threats among mammalian groups, and tolerance of mammals may be taxonomically biased, with carnivores being the least tolerated mammalian subgroup (Kansky et al. 2014). This was seen in the current dataset, because felids, bears, and canids ranked among the top five mammalian subgroups killed due to conflict, with the others being raccoons and skunks. Although carnivores are often associated with threats to human safety and mesomammals are thought to pose a danger to property, it is smaller, noncharismatic species of low conservation interest that are associated with more expensive damage in both urban and rural areas (Peterson et al. 2010). As we continue to encroach upon the habitat of wildlife, there will be more interactions between people and wild animals. To facilitate development and adoption of methods for sustainable and positive human and wildlife coexistence, there is a need to understand the beliefs and attitudes of the general public toward wildlife, because they may overestimate the risks of wildlife and may base their opinions on negative interactions with wildlife or inaccurate perceptions (Buttke et al. 2015).

#### Complementarity and importance of WRC and CWHC data

The strengths of WRC data are the large number of submissions and information about nonlethal stressors to wildlife and specific causes of trauma. CWHC data provided detail and confidence regarding causes of infectious disease and toxicity and animals killed due to human-wildlife conflicts. Combining these two data sources allowed us to better understand the various threats to wildlife and how they may lead to impaired welfare, mortality, or both. The value of examining both postmortem examinations and WRC intake records is gaining appreciation in the fields of animal welfare, conservation biology, wildlife health surveillance, and environmental policy (Stitt et al. 2007; Mariacher et al. 2016; Long et al. 2020). Wildlife rehabilitators encounter numerous animals (Duncan et al. 2008) and also are increasingly connected with each other through networks and are adopting more modern systems for record-keeping. Examining CWHC data alone underrepresents many nonlethal situations such as orphaning, nest or habitat disturbances, animals in unsuitable locations, and those with sublethal trauma. WRC records alone do not capture animals killed due to direct human-wildlife conflict. Therefore, together, these data sources provide a more complete understanding of the factors affecting wildlife health, especially those that are anthropogenic. Moving beyond these two sources and including data from hunters and anglers, citizen science applications (e.g., iNaturalist) and other observational data may further improve our wildlife health surveillance system and ability to make predictions about small- and large-scale morbidity and mortality events (Kelly et al. 2021) and develop evidence-based mitigation strategies to improve and protect wildlife health.

#### Limitations of WRC and CWHC data

The current study used a laborious, but necessary, manual approach to coding data because of many unpredictable inconsistencies between data sources. By contrast, supervised machine learning–based approaches with standardized data, such as that used by Kelly et al. (2021), would make such data analyses much more efficient. Together, these methods can capture unique and nuanced situations and improve the efficiency and accuracy of these analyses, but only with access to trained personnel and standardized data. Also, although our study covered a large geographic area, WRC data were not represented from all regions and CWHC data were limited in certain regions. Future studies could include provincial and territorial wildlife health databases and prospectively implement shared data collection methods across organizations. Furthermore, public participation is crucial for the CWHC and WRCs that rely on wildlife agencies and private citizens to report and submit injured, sick, or dead animals (MacDonald et al. 2016). Thus, there are limitations to the data, such as the potential skew toward species living near human activity (Wimberger and Downs 2010) or those of interest to humans (Trocini et al. 2008). There may be an overrepresentation of chronic diseases, injuries, or emaciation that animals live with for months, as opposed to injuries and acute health disorders that cause immediate death (MacDonald et al. 2016). Because many animals are injured or die in nature and are not submitted, these two data sources underrepresent the actual number of deaths and injuries. Finally, although more than 3,000 animals were identified as species at risk, this is still a relatively small proportion of total submissions; passive surveillance techniques only may not be adequate to collect information about these species.

Our study evaluated spatial trends at the regional level, but future studies could use much higher resolution data to understand the effects of human activity, habitat modification, and natural processes across the country. Analysis of animal outcomes at WRCs was beyond the scope of this study, but Kwok et al. (2021) reported that animals found abandoned, orphaned, or in unsuitable environments were much more likely to survive than those admitted due to trauma; this information may help rehabilitators decide which animals to rehabilitate with limited resources. Of the animals that were killed and sent to CWHC, at least 3% (166/5,172) were killed using questionable methods by untrained private individuals ($n$=116 animals) or using methods that are not considered humane ($n$=51), most notably by freezing, drowning, beating, thoracic compression, decapitation, and bleeding without stunning or anesthesia (Canadian Council on Animal Care 2003; American Veterinary Medical Association 2020). This highlights the need for 1) proper training of professionals regarding whether, when, and how to humanely euthanize wildlife; and 2) accessible information for the public about who to call when they see an issue.

The process of combining wildlife-related data could be improved through better communication and data sharing across organizations. Grants or technical support made available to WRC networks for the purposes of standardization of data collection may increase the ability to combine these data across facilities and with CWHC data through ongoing wildlife health surveillance efforts.

## ACKNOWLEDGMENTS

We thank Tonia Von Hugo and Afreeda Mahesaniya for assistance coding data. We are extremely grateful to the many WRCs and rehabilitators, FLAP Canada, and the CWHC for supporting this project by sharing data with us. Funding for MK was provided by Animal Ethics.

## SUPPLEMENTARY MATERIAL

Supplementary material for this article is online at http://dx.doi.org/10.7589/JWD-D-21-00178.

## LITERATURE CITED

American Veterinary Medical Association. 2020. *AVMA guidelines for the euthanasia of animals: 2020 edition*. https://www.avma.org/sites/default/files/2020-02/Guidelines-on-Euthanasia-2020.pdf. Accessed March 2022.

Beausoleil NJ, Mellor DJ, Baker L, Baker SE, Bellio M, Clarke AS, Dale A, Garlick S, Jones B, et al. 2018. "Feelings and fitness" not "feelings or fitness" – the raison d'être of conservation welfare, which aligns conservation and animal welfare objectives. *Front Vet Sci* 5:296.

Buttke DE, Decker DJ, Wild MA. 2015. The role of one health in wildlife conservation: A challenge and opportunity. *J Wildl Dis* 51:1–8.

Calvert AM, Bishop CA, Elliot RD, Krebs EA, Kydd TM, Machtans CS, Robertson GJ. 2013. A synthesis of human-related avian mortality in Canada. *Avian Conserv Ecol* 8:11.

Canadian Council on Animal Care. 2003. Guidelines on: the care and use of wildlife. https://ccac.ca/Documents/Standards/Guidelines/Wildlife.pdf. Accessed March 2022.

Dubois S. 2003. *A survey of wildlife rehabilitation goals, impediments, issues, and success in British Columbia, Canada*. MS Thesis, University of British Columbia, Vancouver, Canada, 166 pp.

Duncan C, Backus L, Lynn T, Powers B, Salman M. 2008. Passive, opportunistic wildlife disease surveillance in the Rocky Mountain region, USA. *Transbound Emerg Dis* 55:308–314.

Fraser D, MacRae AM. 2011. Four types of activities that affect animals: Implications for animal welfare science and animal ethics philosophy. *Anim Welf* 20:581–590.

Government of Canada. 1994. *Birds protected in Canada*. https://www.canada.ca/en/environment-climate-change/services/migratory-birds-legal-protection/list.html. Accessed January 2021.

Government of Canada. 2002. *Species at Risk Act*. https://laws-lois.justice.gc.ca/PDF/S-15.3.pdf. Accessed November 2022.

Grande JM, Zuluaga S, Marchini S. 2018. Casualties of human-wildlife conflict. *Science* 360:1309.

Hartup BK. 1996. Rehabilitation of native reptiles and amphibians in DuPage County, Illinois. *J Wildl Dis* 32:109–112.

JWD Wildlife Welfare Supplement Editorial Board. 2016. Advances in animal welfare for free-living animals. *J Wildl Dis* 52 (2 Suppl):S4–S13.

Kansky R, Kidd M, Knight AT. 2014. Meta-analysis of attitudes toward damage-causing mammalian wildlife. *Conserv Biol* 28:924–938.

Kelly TR, Pandit PS, Carion N, Dombrowski DF, Rogers KH, McMillin SC, Clifford DL, Riberi A, Ziccardi MH, et al. 2021. Early detection of wildlife morbidity and mortality through an event-based surveillance system. *Proc R Soc B* 288:20210974.

Kwok ABC, Haering R, Travers SK, Stathis P. 2021. Trends in wildlife rehabilitation rescues and animal fate across a six-year period in New South Wales, Australia. *PLoS One* 16:e0257209.

Long RB, Krumlauf K, Young AM. 2020. Characterizing trends in human-wildlife conflicts in the American Midwest using wildlife rehabilitation records. *PLoS One* 15:e0238805.

Loss SR, Will T, Marra PP. 2013. The impact of free-ranging domestic cats on wildlife of the United States. *Nat Commun* 4:1396.

Loss SR, Will T, Marra PP. 2015. Direct mortality of birds from anthropogenic causes. *Annu Rev Ecol Evol Syst* 46:99–120.

Loyd KAT, Hernandez SM, McRuer DL. 2017. The role of domestic cats in the admission of injured wildlife at rehabilitation and rescue centers. *Wildl Soc Bull* 41: 55–61.

MacDonald AM, Jardine CM, Campbell GD, Nemeth NM. 2016. Mortality and disease in wild turkeys (*Meleagris gallopavo silvestris*) in Ontario, Canada, from 1992 to 2014: A retrospective review. *Avian Dis* 60:644–648.

Mariacher A, Gherardi R, Mastrorilli M, Melini D. 2016. Causes of admission and outcomes of long-eared owl (*Asio otus*) in wildlife rescue centers in Italy from 2010 to 2014. *Avian Biol Res* 9:282–286.

McRuer DL, Gray LC, Horne LA, Clarke EE. 2017. Free-roaming cat interactions with wildlife admitted to a wildlife hospital. *J Wildl Manage* 81:163–173.

Messmer TA. 2009. Human–wildlife conflicts: Emerging challenges and opportunities. *Human-Wildlife Conflicts* 3:10–17.

Nyhus PJ. 2016. Human–wildlife conflict and coexistence. *Annu Rev Environ Resour* 41:143–171.

Pandit PS, Bandivadekar RR, Johnson CK, Mikoni N, Mah M, Purdin G, Ibarra E, Tom D, Daugherty A, et al. 2021. Retrospective study on admission trends of Californian hummingbirds found in urban habitats (1991–2016). *PeerJ* 9:e11131.

Peterson MN, Birckhead JL, Leong K, Peterson MJ, Peterson TR. 2010. Rearticulating the myth of human–wildlife conflict. *Conserv Lett* 3:74–82.

Soryl AA, Moore AJ, Seddon PJ, King MR. 2021. The case for welfare biology. *J Agric Env Ethics* 34:7.

Stitt T, Mountifield J, Stephen C. 2007. Opportunities and obstacles to collecting wildlife disease data for public health purposes: Results of a pilot study on Vancouver Island, British Columbia. *Can Vet J* 48:83–90.

Taylor-Brown A, Booth R, Gillett A, Mealy E, Ogbourne SM, Polkinghorne A, Conroy GC. 2019. The impact of human activities on Australian wildlife. *PLoS One* 14:e0206958.

Trocini S, Pacioni C, Warren K, Butcher J, Robertson I. 2008. Wildlife disease passive surveillance: The potential role of wildlife rehabilitation centres. In: *Proceedings of the sixth Australian wildlife rehabilitation conference*. Canberra, Australia, 22–24 July, pp. 1–5.

Viera AJ, Garrett JM. 2005. Understanding interobserver agreement: The kappa statistic. *Fam Med* 37:360–363.

Walker M, Díez-León M, Mason G. 2014. Animal welfare science: Recent publication trends and future research priorities. *Int J Comp Psychol* 27:80–100.

Wimberger K, Downs CT. 2010. Annual intake trends of a large urban animal rehabilitation center in South Africa: A case study. *Anim Welf* 19:501–513.

*Submitted for publication 11 November 2021. Accepted 3 August 2022.*