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Wildlife Rehabilitation Datasets as an Underutilized Resource to Understand Avian Threats, Mortality, and Mitigation Opportunities

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WILDLIFE REHABILITATION DATASETS AS AN UNDERUTILIZED RESOURCE TO UNDERSTAND AVIAN THREATS, MORTALITY, AND MITIGATION OPPORTUNITIES

By

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An Abstract of the Thesis Presented
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Wildlife rehabilitation centers collect large datasets that focus on medical care, yet they also collect information more broadly relevant to wildlife conservation. The goal of this study was to demonstrate the potential for these datasets to be used in conservation science to better understand avian threats, mortality, and mitigation opportunities. We quantified the causes of bird admissions to rehabilitation centers within the Northeast and Midwest United States, the mortality rates during rehabilitation by admission cause, and the proportion of anthropogenic-caused admissions. Additionally, we related human population and development metrics to the number of bird admissions to better understand geographic bias in the dataset.

More than 68,000 bird records were organized, reformatted, and reclassified for uniformity. The dataset from this study included five rehabilitation centers from rural environments and five from urban environments. The top five causes of avian admissions to the wildlife rehabilitation centers were orphaning (21% of total admissions), window strikes (13%), vehicle collisions (8%), nest destruction (3%), and encounters with domestic cats (5%). Anthropogenic causes of admission represented 38% of total known admissions and was six times greater than natural causes. Admission number does not relate to

human population and development metrics despite the majority of admissions being sourced from metropolitan environments. Combined datasets from multiple wildlife rehabilitation centers can be used to investigate a variety of conservation questions. In addition, these datasets can support or validate other avian conservation research related to identifying threats and sources of mortality. However, the inconsistencies in record keeping among rehabilitation centers prevent a timely and efficient process for data management and analysis. Adding categorical variables within records and greater utilization of wildlife rehabilitation datasets can facilitate use of wildlife rehabilitation by researchers to inform avian conservation science.

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INTRODUCTION

The loss of over three billion wild birds in North America since 1970 has been the cause of much concern in the conservation community(Rosenberg et al. 2019). This loss is the result of declining population trends for many species across all habitats (Rosenberg et al. 2019). While the reasons for these declines are varied, human activity contributes to this decline by causing direct and indirect bird morality (Loss et al. 2015). The top anthropogenic causes for wild bird death include both direct (e.g. car collisions, wind turbine collisions, window strikes, and predation by domestic animals) and indirect (e.g. habitat loss and ingesting pesticides from prey species) events (Loss et al. 2015). These events result in physical harm and mortality to large numbers of wild birds (Loss et al. 2015). To mitigate these anthropogenic effects, wildlife rehabilitators treat injured birds with the intent of returning them to the wild.

Wildlife rehabilitation is defined by the National Rehabilitators Association and International Wildlife Rehabilitation Council as the treatment of injured and subsequent release of wild animals back to their appropriate habitat (Miller 2012). While the goal of all wildlife rehabilitation is release back into the wild, the facilities of a wildlife rehabilitation center can vary drastically. These facilities range from veterinary clinics that offer wildlife care to non-profit organizations with a large staff to individuals working out of their homes. The variety of centers and different styles of record keeping and reporting make it difficult to compare wildlife rehabilitation admissions among multiple centers and across a large geographical range (Dalton 2016; Hernandez et al. 2018; Schenk 2017). As a consequence, most published studies are from individual bird rehabilitation centers and do not include a large geographic scope.

Among single center studies, trauma is frequently among the top causes of bird admission (Dalton 2016; Hernandez et al. 2018; Komnenou et al. 2005). The source of the trauma is often

unknown. Other reasons for admission include domestic animal encounters, orphaned young, toxicosis, emaciation, and confiscation of protected species (Komnenou et al. 2005; Montesdeoca et al. 2017; Schenk 2017; Tribe et al. 2014). The proportion of direct anthropogenic causes of admission varies across studies. The Wildlife Clinic at the University of Texas found that 30.3% of admissions were anthropogenic while the Wildlife Center of Torreferrussa, Spain had 64% anthropogenic admissions, and the Aristotle University of Thessaloniki in Greece had 85.2% (Komnenou et al. 2005; Montesdeoca et al. 2017; Schenk 2017). This variation of anthropogenic admission rates among centers suggests that different locations have different human impacts on wildlife.

While admission data from rehabilitations are compiled at the individual center scale, these datasets can be combined to examine effects of human activities on wild birds over a greater spatial scope, as well as the mitigation effort of rehabilitation. While the body of research in the veterinary care of wildlife rehabilitation is large, few studies are focused on examining large-scale data patterns of wildlife admissions and outcomes. Most studies focus on one center or a single species (Crandall & Weber 2005; Dalton 2016; Harris et al. 2015; Hernandez et al. 2018; Schenk 2017; Taylor-Brown et al. 2019). Combining datasets from multiple rehabilitation centers allows for understanding large-scale anthropogenic impacts on wild birds as well as the extent to which bird rehabilitation mitigates the mortality rates of wild bird populations.

Impediments to conducting studies involving multiple centers often arise from the lack of standardized record keeping and lack of centralized data repositories. While federal and state reporting of wildlife rehabilitation records requires submission of similar variables across states, the format of these submissions varies among centers. Several databases including Wildlife Rehabilitation MD (https://www.wrmd.org/) and WILD-ONe (https://www.wildlifecenter.org/training-opportunities/WILD-ONe) have been created to improve data sharing among centers and between centers and researchers (The Wild Neighbors Database Project 2020; Wildlife Center of Virginia 2020). The WILD-ONe database,

managed by the Wildlife Center of Virginia (2020), states that medical records from rehabilitations are not in standard format. Issues with lack of record standardization include recording different variables among centers and use of different classification systems to describe admissions and outcomes. The lack of standardization also arises from inconsistent formatting for a variable (Hanson 2019). For example, one center may report a variable as a code and another will use full text.

The goal of this study is to demonstrate the potential for wildlife rehabilitation datasets to be used in conservation science to better understand avian threats, mortality, and mitigation opportunities. The first objective is to determine the proportion of admissions due to each anthropogenic cause and the rate of positive outcomes associated with these causes. The number of anthropogenic admissions is predicted to be greater than 50% of total admissions (Dalton 2016; Tribe et al. 2014). The second objective of the study is to compare bird admission rates and causes of admission among taxa, migratory status, habitat association, and conservation status. Most species admitted are expected to be low conservation priority owing to high representation by abundant species. The greatest number of admissions is expected to be from habitat where birds are readily visible such as in shrubland and agricultural land. The number of migratory bird admissions is expected to increase during migratory periods in the fall and spring. The final objective is to determine whether the number of birds admitted from urban environments exceeds that admitted from rural environments which may represent a geographic bias in the dataset. The admissions are expected to be greater in urban environments, because of higher visibility in developed land use areas and the higher human density in urban environments. This study seeks to demonstrate the potential of an underutilized data resource to address questions about wild bird conservation at large spatial scales.

DATA COLLECTION

The study area was constrained to the Northeast and Midwest regions of the United States so that results were representative of a large geographic area, to ensure there was sufficient time to process the large datasets, and so that the rehabilitation centers had a similar source group of species within the admission area (Fig. 1). To compare admissions from urban and rural environments, each county of admission was classified using the United States Department of Agriculture (USDA) Urban-Rural Continuum codes from 2013 (United States Department of Agriculture 2013). Five rehabilitation centers were chosen from urban towns (from both the metropolitan and urban rural-urban continuum codes) and five rehabilitation centers were chosen from rural towns defined by the US Census Bureau in the table below (Table 1).

Table 1. United States Department of Agriculture Rural-Urban Continuum Codes (US Department of Agriculture 2013)

	Code	Description
Metropolitan	1	Counties in metro areas of 1 million population or more
	2	Counties in metro areas of 250,000 to 1 million population
	3	Counties in metro areas of fewer than 250,000 population
Urban	4	Urban population of 20,000 or more, adjacent to a metro area
	5	Urban population of 20,000 or more, not adjacent to a metro area
	6	Urban population of 2,500 to 19,000, adjacent to a metro area
	7	Urban population of 2,500 to 19,999, not adjacent to a metro area
Rural	8	Completely rural or less than 2,500 urban population, adjacent to a metro area
	9	Completely rural of less than 2,500 urban population, not adjacent to a metro area

Centers were identified through lists of licensed rehabilitators on websites, through state Departments of Natural Resources or Fish and Wildlife, within the study area. Rehabilitation centers that admit wild birds were identified, and not-for-profit organizations with multiple staff were contacted, as these centers were predicted to have larger datasets. Bird admission data for 2009-2018 were requested from 25 centers in the study area via email. Data were submitted electronically by

cooperating centers in the form of Microsoft Excel, Microsoft Access or Google Sheets. For each bird admission, we requested attributes on bird species, date of admission, cause of admission, outcome (i.e., final status) of the bird, town were the bird was found, and the date of the outcome (Table 1). These records and attributes must be maintained and reported annually in order to be a licensed rehabilitator by the federal government and thus represented consistently collected attributes among rehabilitation centers (Miller 2012).

In addition to requests to individual rehabilitation centers, data were obtained from the WILD-ONe database managed by The Wildlife Center of Virginia (Wildlife Center of Virginia 2020). Seven centers were selected from this database that met the following criteria: 1) located within the study area, 2) admission number over 1,000 per year, 3) the required years for the study were in the database, and 4) clear representation of either an urban or rural location based on census definitions.

The Partners in Flight Species Assessment Database provided data for the attributes of migratory status, conservation status, vulnerability metric, and major habitat type for each bird species in the compiled admissions database (Partners in Flight 2020; Table 2). The migratory status had three categories; migrants, partial migrants, and residents (Flight, 2020). Migratory species complete a yearly migration while resident species remain in the same location year-round. Partial migrants are species with both migrant and resident populations (Panjabi et al. 2019). Endangered or threatened species were determined using the International Union for Conservation of Nature (IUCN) Red List (International Union for Conservation of Nature 2020).

Table 2. Variables within the compiled dataset from bird rehabilitation centers including definitions and sources.

Variable	Definition	Variable Source
Wildlife Rehabilitation Center	The rehabilitation where the admission record was sourced	Rehabilitation submission
Species Common Name	The common name of the bird	Rehabilitation submission
Species Scientific Name	The scientific name of the bird	Rehabilitation submission

Table 2 Continued.

Variable	Definition	Variable Source
Species Family	What family of bird the species belongs to	Rehabilitation submission
Vulnerability Metric	A metric determined by Partners in Flight that determines the vulnerability of the species	Partners in Flight Avian Conservation Assessment Global Database (Partners in Flight 2020)
Conservation Status	The presence of the bird species on any species watchlist	Partners in Flight Avian Conservation Assessment Global Database
IUCN Status	The IUCN status of the species	IUCN Redlist 2020
Major Habitat	The primary habitat of the bird species	Partners in Flight Avian Conservation Assessment Global Database
Migratory Status	Whether the bird is migratory, a partial migrant or resident	Partners in Flight Avian Conservation Assessment Global Database
Date of admittance	The date the bird entered into the care of the rehabilitation	Rehabilitation submission
Cause of Admittance	The cause of injury to the bird requiring rehabilitative care (e.g.. orphaning, window strike, domestic animal encounter)	Rehabilitation submission
Injury	The injury sustained from the cause of admittance	Rehabilitation submission
Anthropogenic	Whether the cause of admission was related to human activity or structures (ex. hit by vehicle is classified as human-caused)	Classified based on the cause of admission
Town	The town where the bird in need of rehabilitation was found	Rehabilitation submission
County	Same as above	Classified based on town found
State	Same as above	Classified based on town found
Urban-rural Code	The rural urban continuum code of the county the bird was found in	USDA urban-rural continuum code, year 2016
Outcome	Result of an admission with the options being dead on arrival, died in care, released, kept in captivity, euthanized or escaped	Rehabilitation submission
Date of outcome	The date on which the outcome occurred	Rehabilitation submission

DATA ANALYSIS

We selected submitted data from 2014-2018 because some centers did not keep electronic records or had different data collection methodology prior to 2014. As each rehabilitation center had its own method of record keeping, the submitted data were reclassified in order to create consistent categories for cause of admission and rehabilitation outcomes. Cause of admission categories were chosen based on frequent reoccurring comments within the dataset. The cause of admission data submitted were separated into cause and resulting injury fields. Dates, outcomes, and location found were reformatted for uniformity. State and county of injury were additional metrics generated based on the town where each bird was injured (Table 2). The urban-rural codes (Table 1) were assigned based on the county where the bird was found.

Rehabilitation outcomes were separated into positive and negative categories. Negative outcomes were defined as any outcome that led to the death of the bird including transport to the rehabilitation center, death in care, or euthanasia. Positive outcomes were defined as any outcome leading to the bird's survival including release to the wild, escape, or permanent residency in captivity.

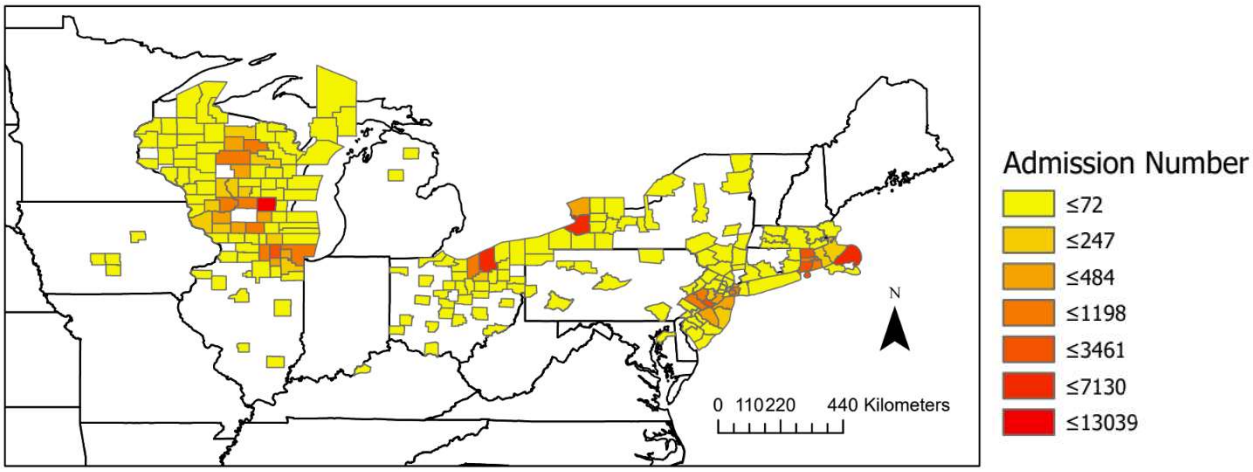
All spatial analyses were conducted in ArcGIS Pro(Version 2.6.3). Center locations were obscured to protect confidentiality. County shapefiles used in the analysis were the 2017 US county file from the US Census Bureau (United States Census Bureau 2017). The Euclidean distance from the rehabilitation center was calculated from the centroid of the county where the admitted bird was found to the centroid of the county where the rehabilitation center was located. The proportion of developed land cover for each county was calculated using the 2016 National Land Cover Database (Multi-Resolution Land Characteristics (MRLC) Consortium 2016). Human population data were obtained from the US Census Bureau shapefile (United States Census Bureau 2017) and were log transformed for analysis.

The following analyses were conducted in Microsoft Excel using the Analysis Toolpak add-in. We compared anthropogenic and natural admissions using a chi-square test. We performed a one-way ANOVA on the average admission number per county using the USDA urban-rural continuum codes (Table 2) as groups. To understand the relationship between admission number per county and human population, proportion of developed land cover, and distance from rehabilitation center, we used a linear regression. Unknown causes of admission and outcomes are assumed to be proportionally distributed among categories and would not change statistical inferences if known. Statistical significance was based on $\alpha = 0.05$.

RESULTS

Twenty-five centers were contacted and five contributed data (20%). Of the five submitted datasets, we removed one urban rehabilitation center as more urban rehabilitation centers submitted data than rural rehabilitation centers. The urban rehabilitation center with the lowest number of admissions was removed. Additional data from six centers in the WILD-ONe database were included in the study dataset. The final dataset included 68,524 individual avian rehabilitation admissions representing 383 bird species from the 10 centers (Fig. 1; Appendix A). While 19 near threatened and 6 vulnerable bird species were represented within the admission dataset, most species (96%) are listed as least concern on the Red List (International Union for the Conservation of Nature 2020). Fifty-five bird species were listed as species of conservation concern in the Avian Conservation Assessment Database through Partners in Flight (2020; Appendix B). Twenty-one species were listed as common but in steep decline, 26 species were listed on the watch list as vulnerable but not in decline, six species were on the watch list and in decline, and three species were on the red watch list that are experiencing range-wide decline.

Figure 1. Bird admission numbers by county for 10 wildlife rehabilitation centers within the study area from 2014-2018.



The ten species with the greatest number of rehabilitation admissions account for 52% of total admissions (Table 3). These ten species are not limited to one family but rather represent a diversity of taxa including three species introduced from Europe and Asia, the House Sparrow (*Passer domesticus*), Rock Dove (*Columba livia*), and European Starling (*Sturnus vulgaris*), and one western North American species, the House Finch (*Haemorhous mexicanus*) not native to the midwestern and northeastern US (House Finch) (York et al. 1948). Fifty-six avian families were present in the dataset with 69% of all admissions represented by the top ten families (Table 4, Appendix A).

The top ten species were similar among the 10 centers analyzed. American Robin (*Turdus migratorius*) and Mourning Dove (*Zenaida nacroura*) were present on all individual rehabilitation centers' list of top admitted species. Other species identified among multiple rehabilitation centers' top admitted species included the Mallard (admitted by 9 of 10 centers), House Sparrow (8), Canada Goose (8), European Starling (7) and Rock Dove (5).

Table 3. The ten bird species with the largest number of rehabilitation admissions from 2014-2018 from ten rehabilitation centers in the Northeast and Midwest United States.

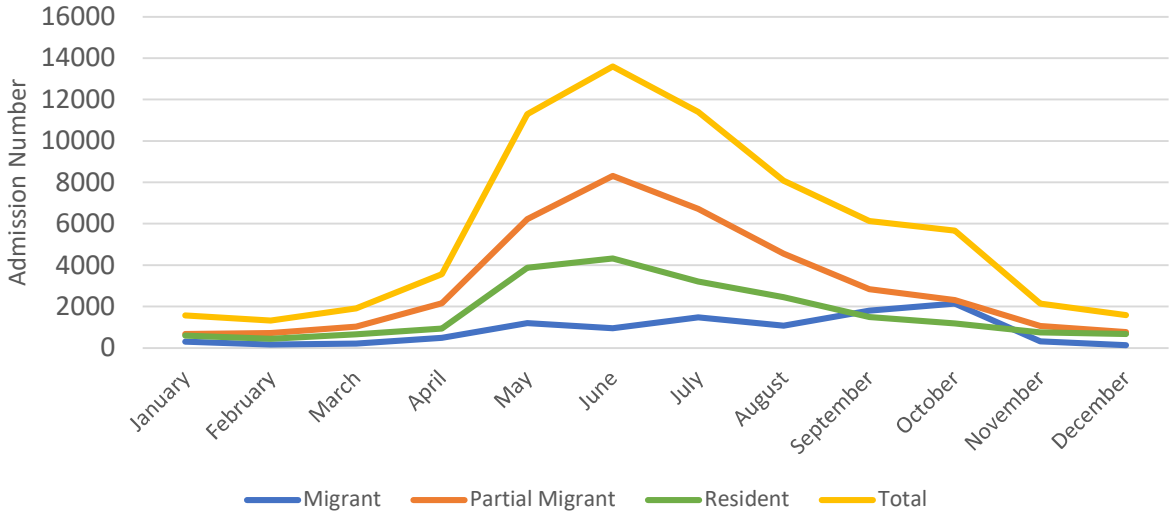
Species	Number of Admissions	Percent of Total Admissions
American Robin *(Turdus migratorius)*	6987	10.2
Rock Dove *(Columbia livia)*	5572	8.1
Mallard *(Anas platyrhynchos)*	5081	7.4
House Sparrow *(Passer domesticus)*	4646	6.8
Mourning Dove *(Zenaida nacroura)*	3426	5.0
European Starling *(Sturnus vulgaris)*	2544	3.8
Canada Goose *(Branta canadensis)*	2250	3.3
Red-tailed Hawk *(Buteo jamaicensis)*	2039	3.0
House Finch *(Haemorhous mexicanus)*	1628	2.4
Common Grackle *(Quiscalus quiscula)*	1447	2.1

Table 4. The ten bird families with the highest number of rehabilitation admissions from 2014-2018 from ten rehabilitation centers in the Northeast and Midwest United States.

Family	Number of Admissions	Percent of Total Admissions
Anatidae	9241	13.5
Columbidae	9028	13.2
Turdidae	7570	11.0
Passeridae	4647	6.8
Accipitridae	3762	5.5
Fringillidae	2718	4.0
Corvidae	2696	4.0
Passerellidae	2642	3.9
Sturnidae	2544	3.7
Strigidae	2447	3.6

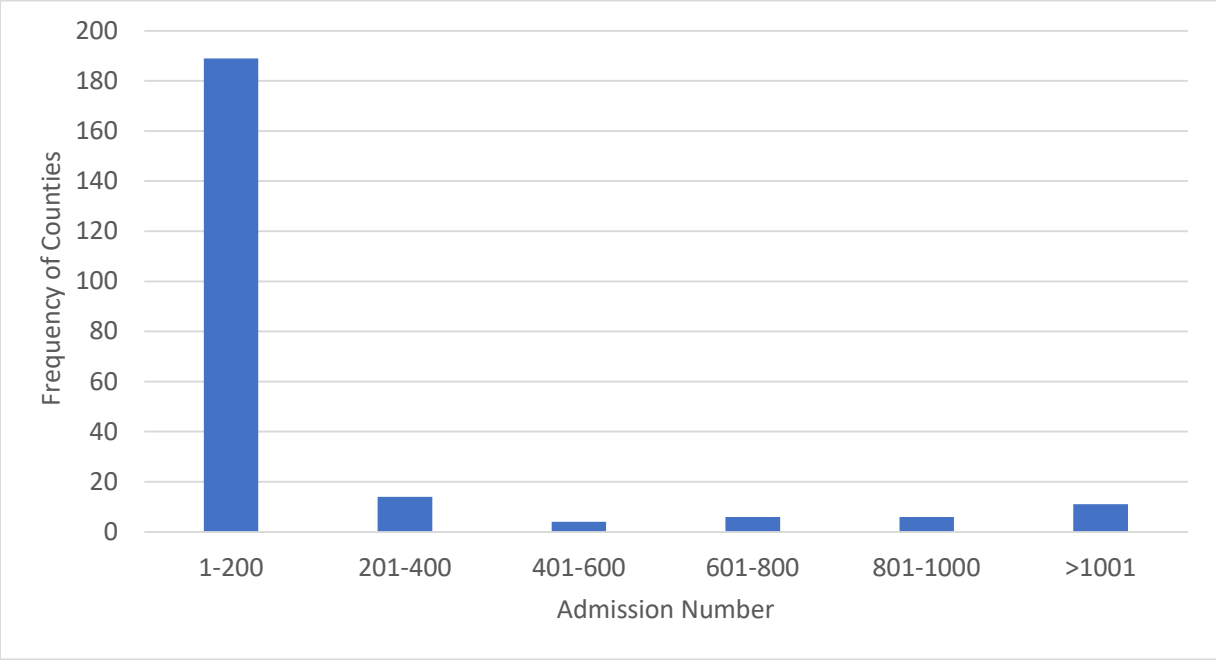
Total admission numbers were highest in late spring and summer, peaking in June coincidental with the breeding season (Figure 2). Partial migrants had the highest admission numbers overall. Unlike residents and partial migrants, migrant birds have the highest admission rate during September and October which coincides with fall migration.

Figure 2. Bird admission number by date and migratory status (migrant, partial migrant, and resident), 2014-2018.



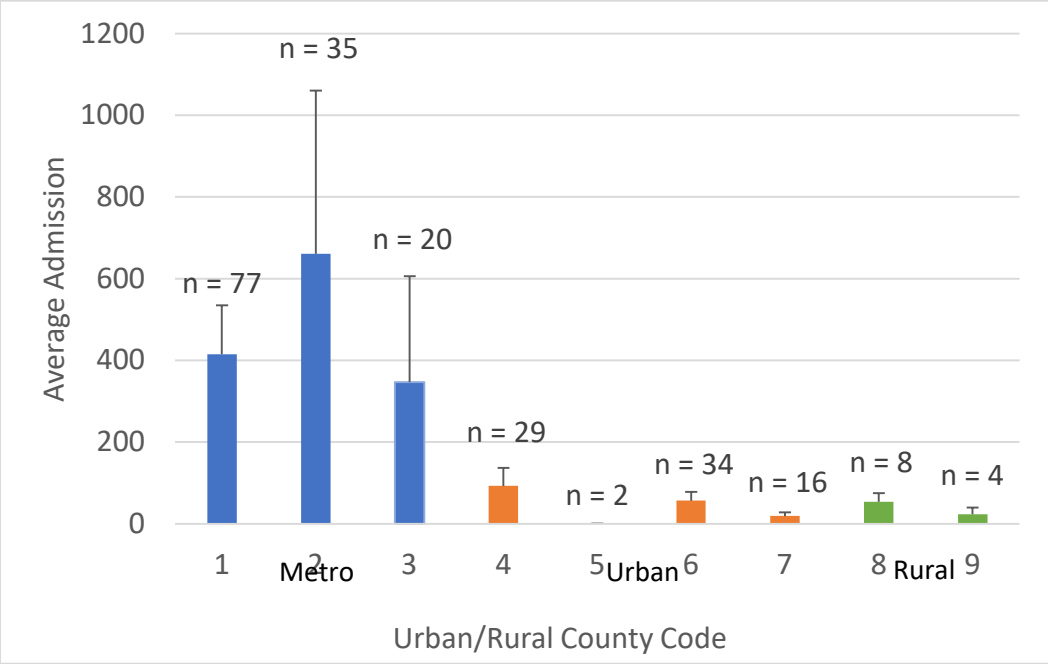
The admission data were analyzed by the county where the birds were found to determine the relationships of urban environments and rural environments to bird admission number. Sixteen states and 251 counties were represented within the dataset (Figure 3).

Figure 3. Frequency of counties by quantity of bird admissions, 2014-2018.



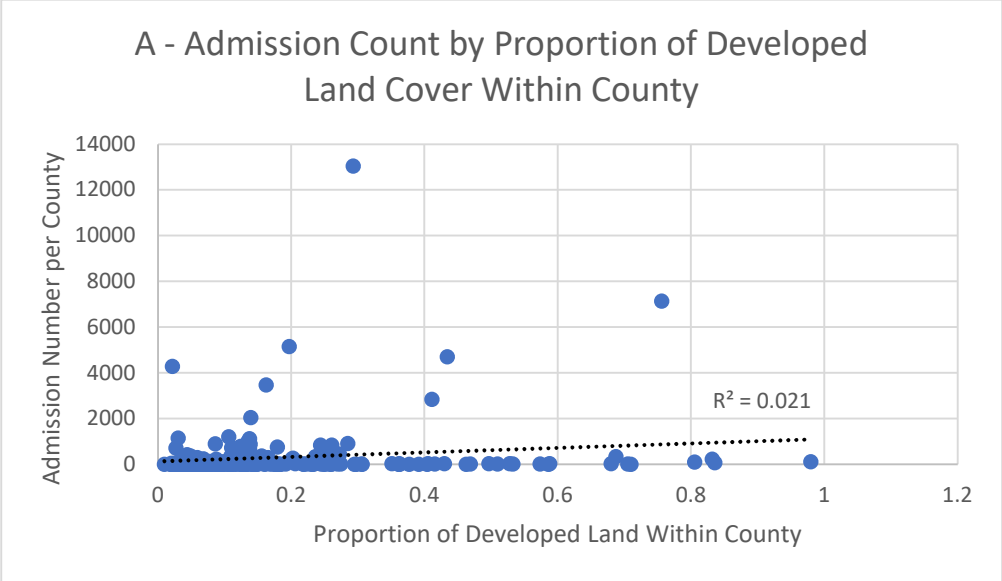
The average admission rehabilitation number by US census urban-rural code (Figure 4) was not significantly different (one-way analysis of variance (ANOVA) test; $F(8, 216) = 0.9981$, $p < 0.4384$). The counties in metropolitan areas had high variation in admission number. Birds from twenty-three major habitat types were represented in the dataset (Appendix C). Birds that were habitat generalists had the highest admission number at 40% followed by second-growth scrub (17%), freshwater lakes (11%), and pastures/agricultural lands (7%) habitat associations.

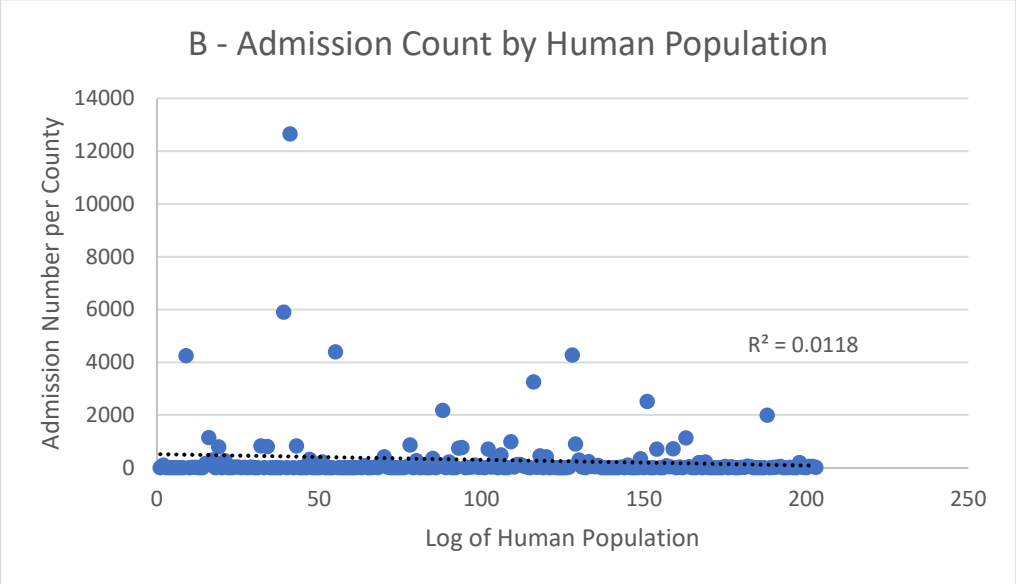
Figure 4. The average rehabilitation admission number by US census urban-rural code to ten rehabilitation centers, 2014-2018. The code definitions are listed in Table 1.



Admission number by county correlates with the log of human population (R^2=0.03, F(1, 206)=7.19, p<0.01); however, the model had low predictive power. Admission number by county also correlates with the proportion of developed cover for the county, but also had little predictive power (R^2=0.02, F(1, 206)=4.48, p<0.04). (Figure 5). Data were zero inflated and clustered at the x-axis for both variables (Figure 5).

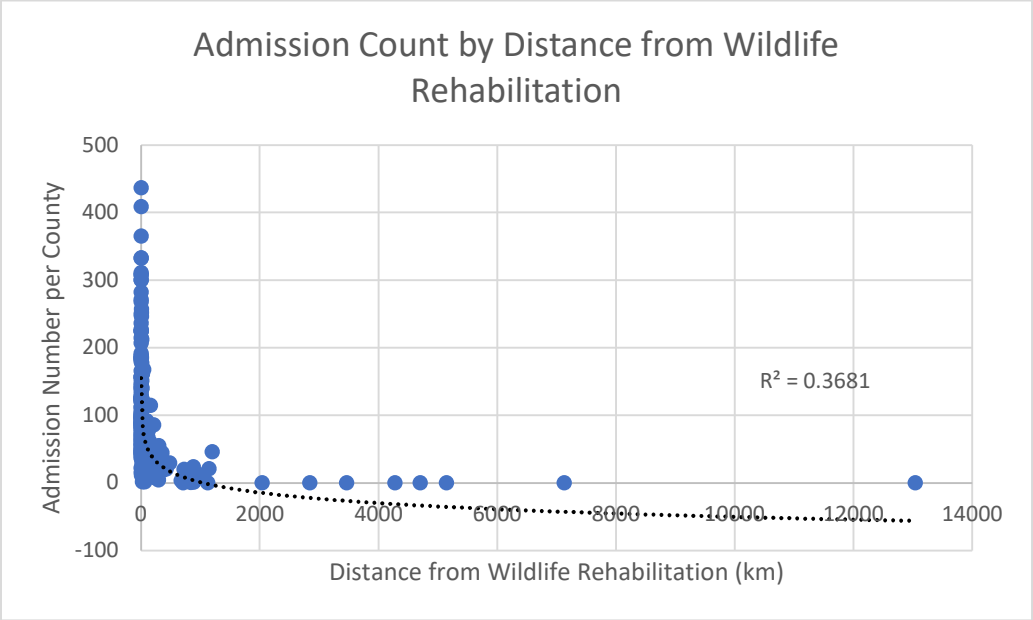
Figure 5. Bird admissions by county for two metrics of human presence. The majority of counties represented had few admissions, causing clustering near the x-axis.





Admission number correlates with the Euclidian distance to rehabilitation center, but the model has little predictive power (R^2=0.06, F(1, 206)=13.58, p<.01)) Rehabilitation centers received the majority of their admissions from within the same county as the rehabilitation center. Data were zero inflated and thus were clustered around the x axis (Figure 6).

Figure 6. Bird Admissions by the distance from the rehabilitation center.



The reasons that birds were admitted to rehabilitation centers were as varied as the species present in the dataset. We grouped causes of admission into thirty-three cause categories. The top cause of admission was unknown representing 35% of all admissions. Orphaning was the top cause of known admission. The orphaning category included all birds that were unable to be cared for by their parents. This included cases where the parent died or was missing for unknown reason. Four of the five top reasons with known cause of admission were due to anthropogenic agents (Table 5). Asterisks denote the anthropogenic admissions.

Table 5. The most common causes of bird admission to rehabilitation centers.

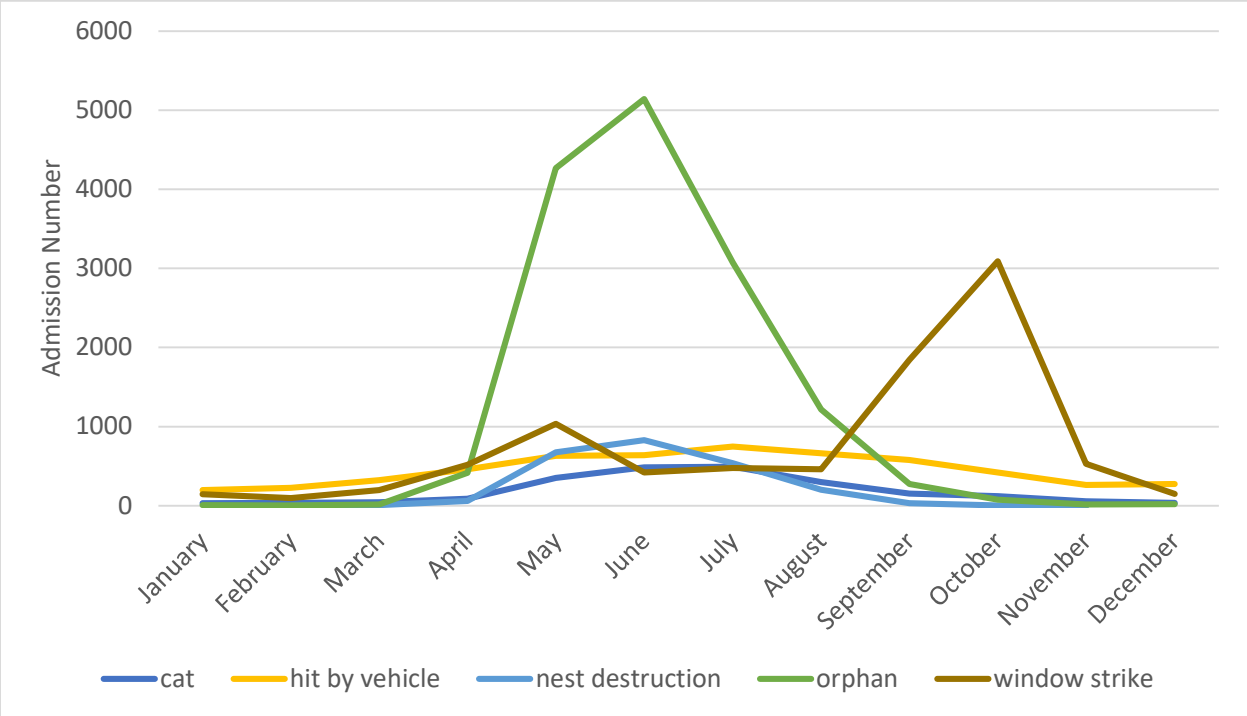
Cause of Admission	Number of Admissions	Percent of Total Admissions
Orphaning	14545	21
Window strike*	8961	13
Hit by vehicle*	5425	8
Nest destruction*	2351	3
Attacked by cat*	3155	5

Table 5 Continued.

Cause of Admission	Number of Admissions	Percent of Total Admissions
Unlicensed possession*	1312	2
Storm	1178	2
Stranding	1162	2
Fell	1123	2
Attacked by dog*	1072	2

Window strikes for migrant birds peaked during spring and fall migration with a higher peak during the fall migration (Figure 7). The higher peak for fall occurs when hatch year birds make their first migration to the wintering grounds. Additionally, when considering the full annual cycle, population sizes are near their peak just before fall migration and are at their lowest just before the breeding season.

Figure 7. The top five causes of admission by date, 2014-2018.



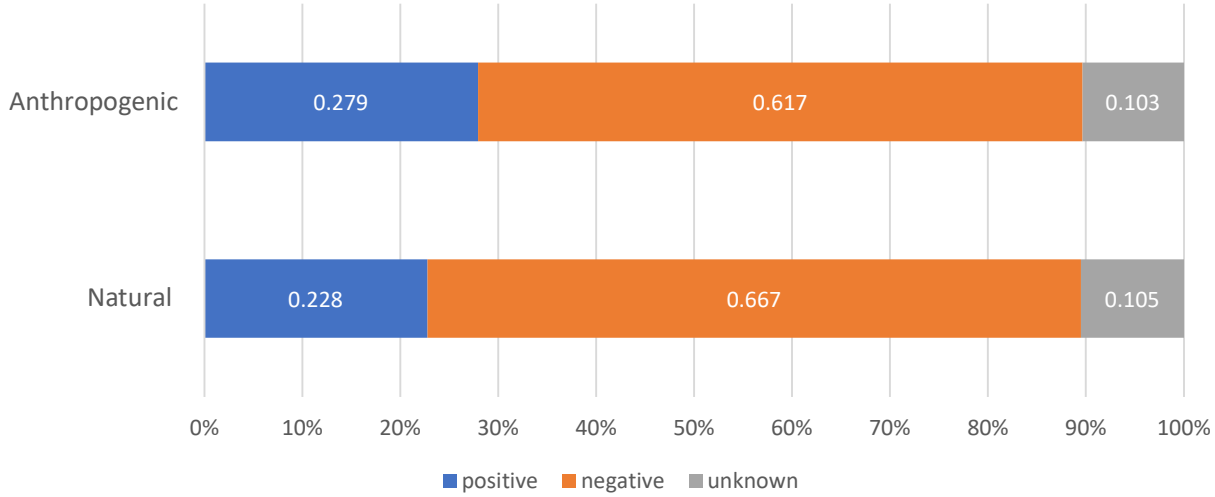
The injuries of birds admitted to the rehabilitation centers were categorized into 101 categories. Forty two percent of admissions had no injury identified and 11% of the admissions were physically healthy (Table 6). Birds that were admitted as physically healthy were orphans, or imprints. Three of the top 10 injuries were associated with poor body condition (emaciation, thin, and lethargic; Table 6).

Table 6. The most common injuries of bird admission to rehabilitation centers.

Injury	Number of Admissions	Percent of Total Admissions
Emaciated	4691	7
Wound	2827	4
Broken wing	2818	4
Wing injury	2646	4
Neuro	2134	3
Lethargic	1961	3
Thin	1937	3
Eye injury	1474	2
Internal injury	1365	2
Pelvic injury	1305	2

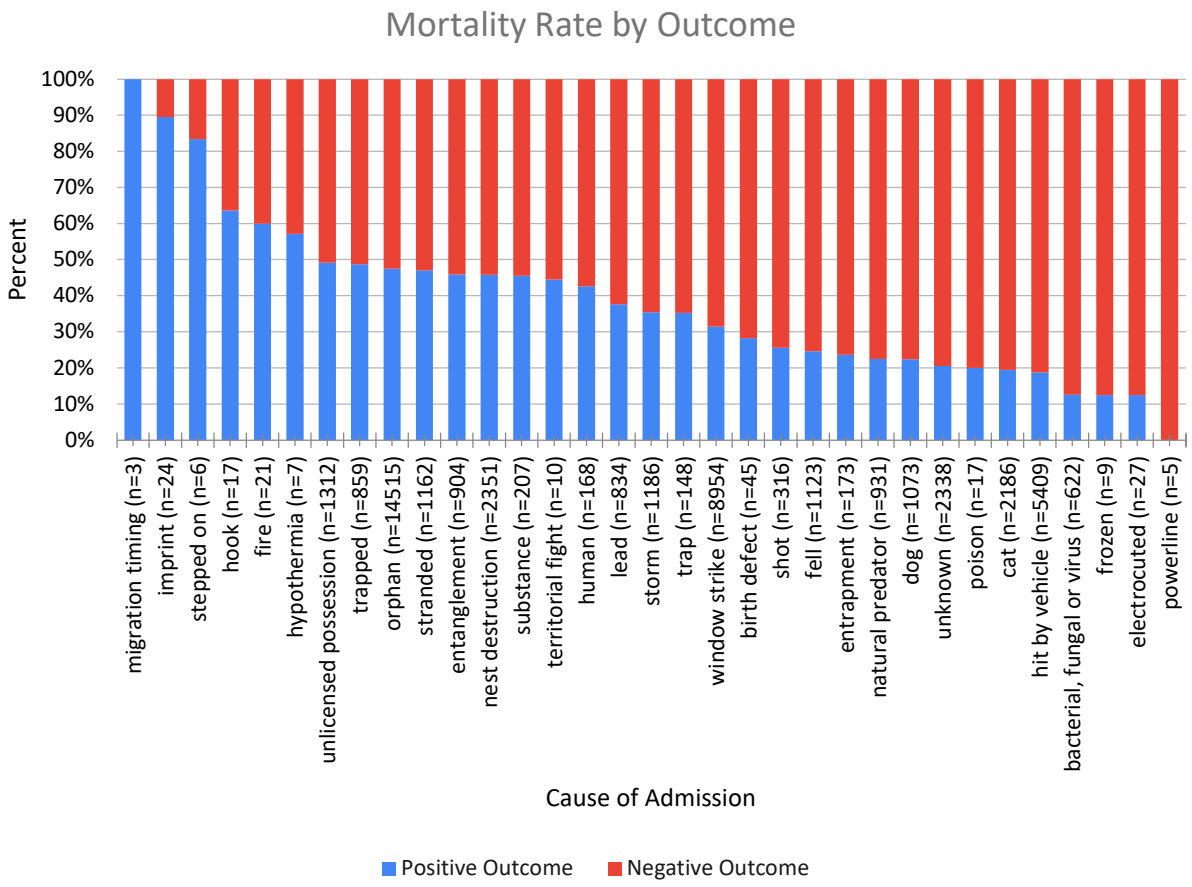
The largest proportion of admissions were unknown to be anthropogenic of natural (56%). This proportion included admissions of unknown cause and admission causes such as orphaning that may be anthropogenic or natural. Known anthropogenic admissions (38%) were more than six times greater than natural-caused admissions (6%). Fourteen percent of admissions had an unknown outcome primarily due to ongoing active cases and transfers to other facilities. Birds admitted from an injury occurring from human causes had a higher likelihood of survival than those injured by natural agents, $\chi 2(2, N = 68{,}608) = 173845.8$, $p = 0.001$ (Figure 8).

Figure 8. Anthropogenic causes of admissions have significantly lower mortality rates than natural and higher mortality rates than unknown admissions.



Birds hitting powerlines or electrocuted had the highest mortality rate while birds that missed migration, imprinted on humans, or were stepped on had the highest survival rates (Figure 4).

Figure 9. Relative rates of a positive outcome and negative outcome based on the cause of admission. The cause of admission with the highest mortality percentage is on the right and the highest chance of survival on the left. Birds with unknown outcomes were not included in the chart.



DISCUSSION

Wildlife rehabilitators treat a high diversity of bird species and injuries. The species with the greatest number of individuals admitted represent different families, habitat type, and cause of admission. Injuries showed a high range of diversity with 101 categories of injury present within the dataset. The diversity of admissions creates opportunities for datasets such as this one to address a variety of conservation questions.

Despite the high diversity of species admitted, the species with the greatest number of admissions were consistent among rehabilitation centers. While the species were not in the same rank order, other studies have reported these species to have high admission numbers (Dalton 2016; Hanson 2019). Hanson (2019) included all of the bird species from this study's top ten in the top twenty admitted species in New York State (Hanson 2019). This similarity in species admitted supports previous studies asserting that wildlife rehabilitation centers treat high proportions of common and generalist species (Dalton 2016; Hanson 2019; Montesdeoca et al. 2017; Schenk 2017). The top ten species admitted to wildlife rehabilitation centers have low conservation concern. Other studies also reported treating mostly common species of least conservation concern (Hanson 2019). Bird species admitted to the rehabilitations are likely found through random chance because of their high abundance or association with humans and human structures (e.g. Rock Dove, European Starling, and House Sparrow).

The habitat associations also support that birds are found by random chance as generalist species comprise 40% of admissions. Other habitats may have high admission numbers because of bird visibility to humans, such as agricultural lands. With 17% of admissions, second-growth scrub had the highest number of admissions from a specific habitat association. This is significant as many birds associated with second-growth scrub are experiencing declines (American Bird Conservancy 2020; King & Schlossberg 2014).

The majority of bird admissions were sourced from the county where the rehabilitation center was located resulting in zero-inflated results for distance between county of collection and the county of the rehabilitation center. Several factors may cause low admission rates from outside the county were the rehabilitation center is located. First, the time and expense of transporting a bird may limit the distance a person is willing to drive a bird to a rehabilitation center. Second, knowledge of the rehabilitation center may be localized or, in some cases, there may be a closer rehabilitation center not in this study. In addition, there may be concern that a bird may not survive a long trip. This final reason needs further study to determine if travel distance is positively correlated with the likelihood of mortality on the way to the rehabilitation center and affects a bird's chance of survival following admission. Finally, many social factors influence the likelihood that a person will bring an injured bird to rehabilitation. More research is needed on the social influence on bird admissions.

While the analysis of bird admission location suggested that there were higher admissions in urban settings, evaluating admission numbers based on county-scale human population metrics may be too coarse to discern a relationship. Within a county, there can be diverse land use characteristics and variable human population densities. Ideally, the data would be analyzed at the town or a point location level to provide greater resolution on potential patterns of geographic bias. This would require additional data reclassification and organization to improve the resolution of the location analysis. For example, rehabilitation centers inconsistently reported the location where a bird was found. Most likely a result of limited information conveyed by the person bringing in the injured bird, the location found column included towns, addresses, and bodies of water.

We were unable to account for human bias and detectability of injured birds for admission to rehabilitation centers. Many different factors can affect bird admissions to rehabilitations centers. Urban environments may facilitate detection simply by having a higher human population density available to find an injured bird. The social factors associated with wildlife rehabilitation may influence

the number of admissions. Attitudes and behavior around wild birds may differ based on the rurality of the area, contributing to different admission numbers (Clucas & Marzluff 2012). Other examples of relevant social factors that may relate to admission numbers include the number of hunters within a community, or access to transportation suitable for transporting birds. Although the birds admitted include both large and small-bodied birds, injured birds of larger size are easier to detect than smaller birds (Borner et al. 2017; Santos et al. 2016). Causes of admission with high mortality rates are likely underrepresented in the dataset because birds may die before reaching a rehabilitation center. All of these factors in human bias and detectability of injured birds require further study.

While most admissions were of unknown cause, the number of admissions due to anthropogenic causes was 38%, six times that of the known natural causes. Previous studies from individual rehabilitation centers outside of the study area predict the number of anthropogenic admissions to be 30.3%, 64% and 85.2% (Komnenou et al. 2005; Montesdeoca et al. 2017; Schenk 2017). The variation in percentages suggests that anthropogenic admission rates vary by geographic location. The anthropogenic admission rate of this study was likely much higher given that data entries with suspected causes of admissions (examples include admissions listed as “possible window strike,” “likely hit by a car” etc.) were categorized as unknown. This suggests that many of the unknown causes were likely anthropogenic. The high number of admissions from urban locations suggested that urban environments had higher rates of bird injury and mortality. However, this may be due to detection bias. While there were more admissions with anthropogenic causes than natural causes, the birds associated with anthropogenic-caused injury had higher survival rates. The proximity to humans during an anthropogenic-related event or as the direct cause of injury may account for this higher survival rate due to higher and faster detection rates.

The top causes for admission in this study were orphaning, vehicle strikes, window strikes, cat predation, and nest destruction, and were consistent with results from single-center studies of wildlife

rehabilitations. A recent paper on admissions from the Ohio Wildlife Center also shows the top causes of admission to be orphaning, domestic animal attacks, and car collisions (Long et al. 2020). Large scale, multi-center studies can provide context and corroboration for the more common single-center or single-taxon studies.

Rehabilitation data can independently validate the patterns of bird mortality found in other studies and can inform wild bird conservation. Similarities were found between the top causes of admission to rehabilitation centers and the top causes of mortality identified in other North American studies. High numbers of admissions from cat predation, window strikes, and vehicle strikes are consistent with the top three anthropogenic causes of bird mortality in the US as identified by Loss et al (2015). Causes of mortality included in the Loss et al (2015) paper that were present but do not have high admission numbers included power line and wind turbine collisions and electrocution. These causes of admission had high mortality rates among admitted birds suggesting that many birds may die instantly or not survive transport to the rehabilitation center.

Continuity between this study and previous studies also occurred in temporal aspects of admission numbers. Admissions from the dataset were highest during the spring as other studies have shown (Long et al. 2020; Taylor-Brown et al. 2019). Admissions due to window collisions peaked during the months of October and September as found in other studies (Kahle et al. 2016; Ocampo-Peñuela et al. 2016).

When looking at morality rates, the admission causes with the highest and lowest mortality rates were based on a small number of cases. The mortality rates of rare causes of admission were likely prone to random outcomes than causes with large sample sizes. For example, the five birds that ran into powerlines all died, resulting in a 100% mortality rate. This high rate may be because hitting a powerline has high fatality rates, or conversely, it may be due to random chance given the small sample size.

Important variables not captured by this study's dataset include the long-term survival and success of the bird after release. For a bird returned to the wild, the long-term success or survival of the individual was unknown. While this may be a lower concern for adult animals that previously lived in the wild, the long-term survival of orphaned young animals returned to the wild is a needed area of study.

Even with this lack of knowledge in long-term survival, wildlife rehabilitation mitigates negative human impact through the care and release of individual birds. This study shows that most known causes of admission are anthropogenic. Therefore, the treatment of injured birds and their subsequent release represents a mitigation effort to counter negative anthropogenic activities. The majority of birds in the wildlife rehabilitations were not considered high conservation concern. However, rehabilitation centers have great potential to conserve species in the "common but in steep decline" category as identified by Partners in Flight (2020). For example, the Common Grackle is "common but in steep decline" and the tenth most common admission in this study. This high occurrence may be due to the relatively large numbers of grackles found near humans or the habitat with which grackles associate. Regardless, rehabilitation potentially can aid in reversing the decline of this species and others in the "common but in steep decline" category.

Wildlife rehabilitation datasets can inform both targeted and broad conservation efforts. Most studies of wildlife rehabilitation records focus on one center, single species, or broad conservation issues such as domestic animal attacks, vehicle collisions and window strikes that affect many different species and locations (Dalton 2016; Hanson 2019; Montesdeoca et al. 2017; Smith et al. 2018). Combining location data with known threats to wild birds can address the complexities of avian conservation and help to target mitigation efforts. For example, reducing lead poisoning in wildlife is a goal in many states. Rehabilitation data could be used to target outreach efforts to communities and user groups where there is high local admittance of raptors and waterbirds with lead poisoning.

The effect of human activity, and therefore the importance of wildlife rehabilitation as a way to mitigate negative human impact, becomes increasingly important in the context of climate change. Although categorized in this study as natural, causes of admission such as migration timing, extreme weather events, and diseases such as West Nile Virus could be affected by human-driven climate change. Past studies connected climate change to changes in fecundity (Sillett et al. 2000), range of disease (Van Hemert et al. 2014), and phenology (Doxa et al. 2012; Hurlbert & Liang 2012). In this context, few, if any, causes of admission identified in this study were free of human influence.

Wildlife rehabilitation data have potential to address numerous questions in conservation science; however, lack of consistency in record keeping between centers leads to challenges when combining datasets. Organization and standardization of submitted data were time-consuming steps prior to analysis. Data attributes such as species, rehabilitation outcome, or dates were easy to process and standardize for analysis. Possibly as a response to the quick organization time, research papers consistently analyze these variables (Dalton 2016; Long et al. 2020; Schenk 2017; Tribe et al. 2014). The records concerning type of injury and cause of admission required substantial time to standardize and reclassify. This is most likely due to the innumerable reasons that a bird can be admitted to a rehabilitation center. The WILD-ONe database structure helped with uniformity of record submission. However, in the absence of data validation measures and pre-established categories within fields, the rehabilitation center staff entered data in a way that required review and reclassification.

Recording data using consistent attributes, categories, and formats would improve the usability of these data for analysis among centers and for addressing research questions at large spatial scales. More rehabilitation centers participating consistently in centralized data repositories such as WILD-ONe or WRMD would increase the usability of these databases. However, if centers choose not to participate in these databases, separating injury and cause of admission into separate fields and adding categorical columns for these fields would increase usability for researchers. All rehabilitation centers recorded

spatial data but they did so using a mix of addresses, towns and location descriptions listed in the same location field. Rehabilitation center staff likely report the location information as described by the person who found the bird resulting in inconsistencies in record keeping. These spatial data were the most time consuming to reclassify for uniformity. As a result, this study was unable to resolve locations smaller than the county level. By creating multiple location fields (for example, state, county, town, street address, etc.) and using the same data format consistently within these fields would improve spatial resolution of the records. This will allow researchers to more easily address questions at different spatial scales.

Wildlife rehabilitation center datasets are an underutilized resource in bird conservation science. The strengths of these datasets are their diversity of species, causes of admission, and locations that can address questions for single species or for broad taxonomic groups. Rehabilitation datasets are a passive approach to gain information for research. They can be utilized to address conservation questions or support hypotheses. Spatial analysis of these data can help identify spatial patterns to bird threats and to target local conservation activities or mitigation efforts.

CONCLUSION

Wildlife rehabilitation serves as a mitigation tool to counter anthropogenic bird fatalities and thus provides unique insight into anthropogenic impact through their records. Wildlife rehabilitation centers and programs serve many populated areas of the United States and thus have the potential for large-scale impact on birds to survive both anthropogenic and natural sources of injury and abandonment. However, the variability in record-keeping and need to reclassify them creates difficulties when pooling data among rehabilitation centers. A balance between preserving the details and variability of cases and standardizing record keeping is needed to increase the usability of these data.

Compiling bird admission, injury, and outcome data from multiple rehabilitation centers can inform conservation issues by addressing scientific questions that include large geographic areas, multiple species, and diverse taxa. This study demonstrated the potential to use rehabilitation data to corroborate anthropogenic causes of wild bird injury and mortality identified as the primary drivers of population declines in other studies.

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APPENDIX A: FAMILY ADMISSION NUMBERS

Table 7. The Admission Numbers of the Represented Families within the Dataset.

Family	Admission Number
Anatidae	9241
Columbidae	9028
Turdidae	7570
Passeridae	4647
Accipitridae	3762
Fringillidae	2718
Corvidae	2696
Passerellidae	2642
Sturnidae	2544
Strigidae	2447
Parulidae	2433
Laridae	2428
Icteridae	2343
Picidae	1581
Cardinalidae	1344
Hirundinidae	1000
Mimidae	819
Bombycillidae	758
Troglodytidae	685
Phasianidae	665
Paridae	650
Apodidae	523
Scolopacidae	520
Regulidae	516
Trochilidae	475
Falconidae	472
Ardeidae	454
Cathartidae	333
Gaviidae	331
Tyrannidae	327
Phalacrocoracidae	284
Gruidae	277
Sittidae	275
Certhiidae	189
Alcidae	186
Caprimulgidae	143
Podicipedidae	133
Charadriidae	126
Rallidae	115

Table 7 Continued.

Family	Admission Number
Sulidae	112
Vireonidae	97
Pandionidae	90
Cuculidae	81
Alcedinidae	78
Procellariidae	73
Pelecanidae	30
Odontophoridae	28
Polioptilidae	11
Tytonidae	10
Alaudidae	5
Hydrobatidae	4
Calcariidae	2
Threskiornithidae	1
Turnicidae	1
Motacillidae	1
Oceanitidae	1

APPENDIX B: SPECIES OF CONSERVATION CONCERN

Table 8. The Species of Conservation Concern as Determined by the Avian Conservation Assessment Database through Partners in Flight.

Conservation Status	Species Common Name	Admission Number
CBSD-Common but in steep decline	American Tree Sparrow	35
	Blackpoll Warbler	165
	Black-throated Blue Warbler	3
	Chuck-will's-widow	3
	Common Grackle	1447
	Common Nighthawk	136
	Eastern Meadowlark	14
	Field Sparrow	12
	Glaucous Gull	4
	Grasshopper Sparrow	6
	Green Heron	85
	Herring Gull	921
	Horned Lark	5
	Least Flycatcher	19
	Long-tailed Duck	22
	Northern Bobwhite	11
	Pine Siskin	139
	Short-eared Owl	7
	Varied Thrush	1
	Wilson's Warbler	25
	Yellow-billed Cuckoo	54
Watch List - Red	Band-rumped storm Petrel	2
	Golden-winged Warbler	2
Watch List - Red	Piping Plover	7
Watch List - Yel-D	Allen's Hummingbird	1
	American Woodcock	472
	Black Skimmer	1
	Black Tern	1
	Black-billed Cuckoo	27
	Canada Warbler	21
	Chimney Swift	523
	Cinnamon Teal	2
	Connecticut Warbler	16
	Evening Grosbeak	4
	Franklin's Gull	4
	Harris's Sparrow	1
	Henslow's Sparrow	1

Table 8 Continued.

Watch List - Yel-D	Kentucky Warbler	2
	Least Tern	1
	Lesser Yellowlegs	1
	Long-eared Owl	19
	Manx Shearwater	4
	Olive-sided Flycatcher	3
	Prairie Warbler	1
	Red-headed Woodpecker	20
	Roseate Tern	4
	Snowy Owl	62
	Whip-poor-will	5
	Willet	3
	Wood Thrush	68
Watch List - Yel-R	American Oyster Catcher	1
	Brant	9
	Cory's Shearwater	31
	Kirtland's Warbler	2
	Purple Sandpiper	1
	Yellow Rail	3

APPENDIX C: THE MAJOR HABITAT ASSOCIATION OF ADMISSIONS

Table 9: The major habitat association of admissions.

Major Habitat	Admission Number	Proportion of Admissions	Number of Species
Generalist	27166	0.40	132
Second-growth scrub	11662	0.17	12
Freshwater lakes	7608	0.11	13
Pastures/agricultural lands	4821	0.07	8
Tropical deciduous forest	3706	0.05	8
Coastal sand beaches/mudflats	2266	0.03	13
Secondary forest	2042	0.03	11
Tropical lowland evergreen forest	1725	0.03	26
Freshwater marshes	1326	0.02	18
Montane evergreen forest	1262	0.02	4
Riparian thickets	1116	0.02	2
Pine forest	1050	0.02	10
Coastal waters	695	0.01	10
Northern temperate grassland	590	0.01	7
Arid lowland scrub	482	0.01	4
Mangrove forest	468	0.01	8
Pine-oak forest	333	0.00	5
Pelagic waters	86	0.00	11
Gallery forest	61	0.00	8
Semihumid/humid montane scrub	25	0.00	1
Saltwater/brackish marshes	24	0.00	5
Rivers	8	0.00	2
Coastal rocky beaches	1	0.00	1

BIOGRAPHY OF THE AUTHOR

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