Evaluation of Current Scientific Literature on the Impact of Wildlife Rehabilitation on Conservation, Documentation of Knowledge Gaps and Identification of Future Opportunities

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Prepared for:

U.S. Fish and Wildlife Service
Migratory Bird Program

December 2024

Summary

In an effort to qualify the conservation impact of wildlife rehabilitation programs, a literature search for post-release outcomes of rehabilitated avian wildlife was conducted to look at evidence for direct impacts. Thirty-six papers out of 787 returned in the literature search met inclusion criteria, reflecting an overall lack of published data in this field. The majority of the papers (55%) evaluated post-release survival following an oil spill; 36% looked at outcomes after any type of injury; and 8% investigated the survival or success of chicks admitted as "orphans" and hand reared or captive raised before release. Seabirds, waterfowl, and raptors were the most common taxa studied with interspecies variation in outcomes noted. Most studies used survival or reproduction/breeding recruitment as metrics for post-release outcomes. There was a general lack of availability of avian rehabilitation data and no standardized definition(s) for successful outcome.

In addition to the direct impacts, indirect conservation contributions from the wildlife rehabilitation field were summarized, although a full literature search was not done. These included the influence on human-wildlife conflicts; the role of injured and ill wildlife as disease sentinels; the value of wildlife rehabilitation as a data resource and source of rehabilitation science; and the opportunities for public education/outreach. Recommendations for leveraging wildlife rehabilitation as a conservation resource are made based on identified knowledge gaps and potential tools for improved data collection.

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Introduction

Around the world, hundreds of thousands of animals are brought into wildlife rehabilitation centers annually, at a marked amount of personnel, welfare, facility, and equipment costs. With substantial efforts to rehabilitate wildlife and return animals to their native habitat, it raises the question of what impact this work has on the chance of long-term survival of these rehabilitated animals post-release and on larger conservation efforts. In a world of limited time and resources, post-release monitoring studies can often be limited (e.g., limited in number of studies and depth of study), leading to gaps in knowledge about the greater impact of wildlife rehabilitation. The specific aims of this work are to summarize the scope of existing studies regarding avian rehabilitation survival and breeding recruitment, highlight key research gaps, synthesize indirect benefits rehabilitation offers to conservation, and strategize a way forward. We hope to ignite the call and provide support for increased post-release studies, so together, wildlife rehabilitation practitioners and conservationists can strengthen their impact, protecting the planet.

Definitions

Ambassador Animal – An animal whose role includes handling and/or training by staff or volunteers for interaction with the public and in support of institutional education and conservation goals. (Association of Zoos and Aquariums)

Animal Welfare – How an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behavior, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling and humane slaughter/killing. Animal welfare refers to the state of the animal; the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment (World Organization for Animal Health – OIE).

Clinical Wildlife Medicine – Veterinary care and treatment of injured and ill wildlife. (Clinical Wildlife Health Initiative)

Conservation – The protection, care, management and maintenance of ecosystems, habitats, and wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term performance. (International Union for Conservation of Nature)

Wildlife Rehabilitation – The treatment and temporary care of injured, diseased, and displaced indigenous animals, and the subsequent release of healthy animals into appropriate habitats in the wild. (National Wildlife Rehabilitators Association)

Wildlife Rehabilitation Facility or Center – A location at which wildlife rehabilitation is conducted, whether at an individual's home, a triage location, a facility dedicated to wildlife rehabilitation, or a place whose primary activity is not wildlife rehabilitation (such as a nature center, a domestic animal humane society, a veterinary clinic, or a university), but at which wildlife rehabilitation does occur. (National Wildlife Rehabilitators Association)

Wildlife Rehabilitator or "Rehabber" – A person who obtains or works under the current required government permits and pursues ongoing training and education to engage in the practice of wildlife rehabilitation. (National Wildlife Rehabilitators Association)

Literature Search and Review

Methodology

A literature search was conducted on February 16, 2021, to identify post rehabilitation release avian studies. The search was updated on June 11, 2024. Articles were searched from the electronic database, CAB Abstracts, on the OVID search platform using the local server belonging to the University of Minnesota. Articles were selected based on title for relevance and included the keywords and expressions, "rehabilitat* and birds not forest not wetland" in order to limit returns to avian rehabilitation and not include environmental rehabilitation. Abstracts were further scanned for relevance to information occurring post-release; abstracts describing only mortality/morbidity or while the animal was undergoing rehabilitation in the rehabilitation center or release rates were discarded. Only those articles in English were reviewed. Relevant references cited in the retrieved articles were also included in this review. There were no temporal or geographical restrictions placed on article selection. Information from selected publications were recorded in a spreadsheet (Google Sheets) with each row corresponding to an individual article including author(s), species; bird group (raptor, waterfowl, vulture, shorebird, waterbird); injury type (need for rehabilitation); sample size; age of birds (at time of injury); time spent in captivity; duration of study period; location; study design (observational, controlled, case report, etc.); method for detection (telemetry, band recovery or resight); type of data collected, as determined by study authors (survival, behavior, integration, dispersal, breeding); results; upper limit of days followed post-release; and whether cause of death was determined in the study. See summary table below.

Literature Review Results

The literature search returned a total of 787 papers (635 on the first search with an additional 152 on the updated search). Thirty-six articles published between 1978 and 2024 met the inclusion criteria for review. Thirty-three percent (12/36) were published after 2011. The majority of publications reviewed, 55% (20/36), evaluated post-release survival following an oil spill. Thirteen articles reviewed (36%) studied post-release survival for a variety of injuries (trauma, oiled/oil spill, orphan). Three publications (8%) investigated the survival or success of chicks admitted as "orphans" and hand reared or captive raised before release.

Post-release Survival

Joys et al. (2003) assessed the likelihood of rehabilitation success using distance and time elapsed between ringing (banding) and recovery of dead birds of multiple species. Eleven individual species: barn owl (*Tyto alba*), buzzard (*Buteo buteo*), gannet, guillemot, common scoter (*Melanitta nigra*), herring gull (*Larus argentatus*), Eurasian kestrel (*Falco tinnunculus*), little owl (*Athene noctua*), mallard (*Anas platyrhynchos*), mute swan (*Cygnus olor*), Eurasian sparrowhawk (*Accipter nisus*), and tawny owl (*Strix aluco*), and seven bird groups (species with fewer than 20 rehabilitated bird recoveries) were compared to non-rehabilitated ringed birds. Birds were rehabilitated for a variety of reasons, including oil spills. Guillemot and common scoters were found to have such poor survival, the authors concluded the 'majority of the rehabilitated individuals are unlikely to re-enter the wild population.' The authors found large differences in post-release survival within the first two-months post-release compared to non-rehabilitated birds for all species except buzzard, mallard, juvenile common kestrel, and juvenile tawny owls. However, beyond two months, post-release survival was more comparable. Due to small sample sizes for rehabilitated bird recoveries compared to non-rehabilitated recoveries, the authors urged caution when interpreting the results across species (Joys et al., 2003).

Seabirds

Seabirds were the most represented bird group in reviewed literature. A total of 16 publications (44%) addressed seabird survival post-oiling. Species in the seabird group included African penguin (*Sphenicus demersus*), brown pelican (*Pelecanus occidentalis*), Cape gannet (*Morus capensis*), common murre (*Uria aalge*), guillemot, little penguin (*Eudyptula minor*), yellow-eyed penguin (*Megadyptes* antipodes), and western gull (*Larus occidentalis*). Of these species, African penguins, brown pelicans, and western gulls demonstrated the most positive outcomes post-release. Little penguins, Cape gannets, and guillemots demonstrated poor survival rates post-release in the reviewed literature.

Four articles evaluated post-release survival of oiled African penguins. Overall, the studies suggest decontaminated penguins successfully transition back into the wild. In a 10-year study, Whittington (1999) found decontaminated birds had similar long-term survival as non-oiled birds and concluded cleaning the birds is a worthwhile contribution to conservation of the species. However, in a study comparing the breeding success of cleaned, rehabilitated, released African penguins to un-oiled birds, offspring of decontaminated birds averaged 43% fledging success compared to 61% in unoiled birds. The authors advised decontaminated adults cannot be assumed to resume reproductive success similar to non-oiled birds and urged prioritizing the relocation of clean birds prior to exposure (Barham et al., 2007). Similarly, Wolfaardt et al. (2008) found 73% of decontaminated birds were successfully restored to the breeding population, with 45% resighted five years post-release. However, the authors also found a negative correlation between breeding and survival for decontaminated birds over time, suggesting sub-lethal impacts of oil contamination contributing to decreased reproduction (Wolfaardt et al., 2008). All four papers urge measures to prevent bird exposure to oil-spills as the best, most cost-effective route to conserve avian wildlife.

Post-release survival of de-oiled little penguins was evaluated in four papers. Goldsworthy et al. (2000) assessed post-release survival of little penguins for 20 months and found decontaminated birds had significantly lower survival than non-oiled birds. In addition, the study found the degree of oiling had the greatest influence on post-release survival. However, Chilvers et al. (2015) noted that no behavior changes were observed when comparing decontaminated birds and control birds, suggesting rehabilitation efforts were effective and justifiable. Sievwright et al. (2019a) reported that survival rates of little penguins did not differ significantly between decontaminated and control birds. This paper demonstrated the effectiveness of treatment and value of post-release monitoring. The authors evaluated several variables (degree of oiling, body mass, blood parameters, time in captivity), but did not identify any that impacted post-release success. In a second paper, Sievwright et al. (2019b) evaluated breeding success among little penguins released after decontamination compared to non-oiled pairs. The authors found similar egg laying, hatching, and fledging success rates between both groups compared to other little penguin colonies in Australia and New Zealand. Hatching success was found to be significantly lower in the decontaminated birds in the first season after release compared to control birds. The study only monitored birds through the first breeding season post-release. The authors suggest longer evaluation to determine if hatching success improved with subsequent breeding seasons (Sievwright et al., 2019b).

Articles addressing the post-release success of oiled guillemots indicate poor survival and question the conservation value of rehabilitation efforts (Clark, 1978, Sharp, 1996, Wernham et al., 1997, Joys et al., 2003). One study found the median survival rate of de-oiled guillemots was only seven days, with less than 2% surviving one-year post-release (Wernham et al., 1997). In a 2003 study, Joys et al. specifically included a comparison of two periods, pre-1996 and post-1996 rehabilitation survival rates of guillemots (dates chosen based on data available and previous publications) to evaluate if rehabilitation techniques had improved. Unfortunately, survival rates pre-1996 and post-1996 were similar. The authors suggest the poor survival could be related to plumage characteristics and grooming behaviors (Joys et al., 2003). These results support considering the likelihood of species survival when faced with a large number of sick or injured birds requiring rehabilitation.

Two studies evaluating post-release survival of oiled brown pelicans found successful outcomes. Selman et al. (2012) concluded the cleaning, translocation, and soft-release of 182 oiled brown pelicans to be a ‘tentative success’ after six weeks of monitoring found no mortalities and evidence of rehabilitated birds integrating into local flocks (Selman et al., 2012). Most recently, Fiorello et al. (2021) found 75% (9/12) of oiled, rehabilitated pelicans survived six months and some (17%, 2/12) survived over a year. The authors concluded rehabilitated oiled birds can be successfully restored to their environment with a reasonable expectation of survival in both the short- and medium-term (Fiorello et al., 2021).

Cape gannets were found to have relatively poor post-release survival by Joys et al. (2003). However, in a study evaluating the long-term survival of decontaminated gannets, Altwegg et al. (2008) described oiled and rehabilitated gannets as surviving ‘almost as well as’ control birds. The authors support the effort to clean, rehabilitate, and release oiled gannets in the face of an oil spill that could threaten a large portion of the population due to their high site fidelity (Altwegg et al., 2008).

In a study of oiled, rehabilitated common murres, Newman et al. (2004) found the decontaminated birds were four times more likely to die compared to control birds, but survival rates were higher than previous studies. The authors found no difference in survival between the two groups after 34 days post-release (Newman et al., 2004).

One paper evaluated post-release survival of seven oiled and rehabilitated western gulls for nine months. All oiled and rehabilitated birds survived at least 183 days and were observed visiting breeding colonies (Golightly et al., 2002). Due to expiring radio transmitter batteries, resulting in inadequate sample sizes, the authors were unable to determine reproductive success (attempted, unknown success). The authors suggest modern rehabilitation programs, such as California's Oiled Wildlife Care Network (OWCN) have the potential to reduce the impact of marine oil spills on seabird populations.

Alden et al. (2021) used a wildlife rehabilitation database to evaluate outcomes over a 10-year time period in a program for underweight yellow-eyed penguin chicks (an endangered species) brought into captivity for supplemental treatment and feeding, and then released back into a monitored wild population. Although the rehabilitated chicks fledged at a higher weight than the healthy conspecifics fully raised in the wild, their post-fledging survival probability was lower. In addition, intervention with the chicks did not result in improved parent survival or future breeding, providing no support for the conservation strategy of intervention and rehabilitation.

Waterfowl

Four additional publications addressed oiling of waterfowl and other waterbird species (e.g., surf scoter (*Melanitta perspicillata*) and American coot (*Fulica americana*)). Surf scoter behavior post-release demonstrated significant changes compared to controls and did not survive as well as non-oiled rehabilitated birds or control birds (Golightly et al., 2019). De La Cruz et al. (2013) found surf scoters tolerated rehabilitation, but oiling resulted in markedly lower survival compared to non-oiled rehabilitated birds and controls. Oiled and rehabilitated American coots were also found to have significant behavioral changes (i.e., preened more, bathed more, slept less, more frequent feeding and drinking) compared to non-oiled, non-rehabilitated coots (Anderson et al., 2000). Newman et al. (2000) evaluated the hematologic effects of oiling on American coots and determined oiled, rehabilitated coots had shorter survival times if they had very high cholesterol or chloride concentrations two months post-oil exposure. However, rehabilitated coots that survived at least 3.5 months, could not be differentiated hematologically from non-oiled, non-rehabilitated coots.

Raptors

Raptors were the primary bird group investigated in 12 (33%) of the reviewed post-release monitoring publications. Raptors represented in the papers included bald eagle (*Haliaeetus leucocephalus*), Cape vulture (*Gyps coprotheres*), great horned owl (*Bubo virginianus*), griffon vulture (*Gyps fulvus*), peregrine falcon (*Falco peregrinus*), tawny owl, and barn owl. In addition, two articles included data from multiple species of raptors. Seven articles addressed various types of injuries in their data, ranging from trauma, starvation, leg hold trap injuries, and "orphans" (healthy juveniles brought to rehabilitation by well-meaning public). Two articles specifically addressed birds rehabilitated after trauma. Two articles discussed hand-reared fledglings and one captive-raised raptor case study.

Four articles monitoring post-release success of raptors included multiple species. Duke et al. (1981) published an article evaluating 29 raptor species survival post-release. All birds in the study were banded with U.S. Geological Survey (USGS) Bird Banding Laboratory (BBL) bands. Bald eagles were also color marked or tagged with patagial or leg-band streamers, and 4 were radio-tagged. Study inclusion criteria was any resighting or recovery of a bird after release back to the wild. While most resightings or recoveries were opportunistic, the 4 radio-tagged bald eagles were radio tracked by a graduate student. Two color marked bald eagles in the study were observed tending nests and raising young. The authors defined success as surviving six weeks post-release as a mid-sized (~1kg) raptor would die of starvation in 2 to 3 weeks without food and smaller raptors would succumb more rapidly. The study concluded success was not related to severity of injury at the time of admittance to the rehabilitation facility and raptor rehabilitation is worthwhile if just to learn to recognize medical problems or educate the public regarding the value of conservation efforts (Duke et al., 1981). Hamilton et al. (1988) tracked 8 red-tailed hawks (*Buteo jamaicensis*) and one red-shouldered hawk (*Buteo lineatus*) upon release post-rehabilitation using radio tags. Five hawks (55%) survived beyond 2 weeks and were considered acclimated back to the wild, while one hawk was recovered dead after 17 days and three hawks were lost to follow-up (Hamilton et al., 1988).

Martell et al. (2000) reviewed the recoveries and re-sightings of 135 rehabilitated raptors (16 species) over an 18-year period from 1976-1994. The survival time ranged from one to 458 weeks. The authors suggested 85% of birds were successfully rehabilitated because only 14% of birds in the study did not survive six weeks post-release. The authors assumed that birds not recovered within the first six weeks post-release had survived (Martell et al., 2000). A third paper investigated post-release success of 24 raptor species rehabilitated after antebrachial fractures. Success was defined as the return to normal flight ability and no return to the rehabilitation center within one month of release. Forty-seven percent (47%) of birds evaluated had a successful outcome. Red-tailed hawks and great horned owls were less likely to have a successful outcome compared to American kestrels (*Falco sparverius*) (Vergneau-Grosset et al., 2020).

In a study looking at annual survival of rehabilitated and released red-tailed hawks compared to wild-caught and banded ones, post-release survival ranged from 1 day to ($\bar{x} = 147 \pm 81$ days) in 13 radio-tracked red-tailed hawks (Sandberg et al., 2022).

Two articles evaluated the post-release success of hand-reared tawny owl fledglings. The articles defined success in different ways. Leighton et al. (2008) concluded 37% of 16 juvenile tawny owls were successfully tracked more than 6 weeks post-release. Of 18 band returns, 66% (12/18) lived more than six weeks and 39% survived over a year. The study design included a soft release but the authors noted that food provision was not utilized. The authors concluded post-release survival is sufficient to justify resources spent on hand rearing (Leighton et al., 2008). Griffiths et al. (2010) suggested the benchmark for successful release of small raptors be defined as 30 days, rather than the standard 42 days. The authors concluded small raptors would be expected to die of starvation within 8-14 days and monitoring longer would be a waste of resources. In the study, 58% of 57 birds survived to 30 days with a hard release (Griffiths et al., 2010).

Two studies evaluated the post-release survival of rehabilitated peregrine falcons. The majority of injuries in one study resulted from trauma and 77% of birds were less than one year of age. The authors concluded that even falcons with serious injury can be restored to good health and compete successfully in the wild with 20% surviving more than three months post-release and 14% resighted over a year post-release. These survival rates are similar to banded, non-rehabilitated peregrine falcons (Sweeney, 1997). Stauber et al. (2008) provided a case study of an 11-year-old male falcon that had been in rehabilitation for four months due to trauma. The falcon was resighted two years post-release and had produced two broods, totaling five young (Stauber et al., 2008). In another case study, two merlins (*Falco columbarius*) were tracked post-release after treatment of ulnar fractures with one bird surviving for 51 days and the second living at least 2 years and producing 10 young (Warkentin, 1986)

A survey of 42 rehabilitation centers in Spain assessed conservation success of barn owls with traumatic injury as well as captive-bred/released birds. The study found rehabilitated birds had much higher mortality compared to captive-raised birds in the first month. However, after four weeks post-release, the mortality rate between the groups was similar. The authors concluded live prey training had the strongest influence on post-release survival (Fajardo et al., 2000).

Post-release survival of 19 rehabilitated bald eagles with various injuries (fracture, starvation, toe and foot damage from leg hold straps) was evaluated in one reviewed article. The study included juveniles and adults with time in captivity ranging from 23 days to 522 days. The authors concluded rehabilitated bald eagles can integrate back into the wild population, with one bird surviving 835 days and producing two chicks (Martell et al., 1991).

Two articles evaluated post-release success of two species of vultures. The survival rate of 59 captive-raised, soft-released[1] adult and juvenile griffon vultures was monitored for 10 years in France. Adult survival rates were higher than juvenile survival rates. Released birds were documented to produce 59 offspring (Sarrazin et al., 1994).

Breeding Recruitment

Our literature review found 27% (10) of 36 publications noted reproduction or attempted reproduction, of post-released birds. Six of the 10 studies (60%) documenting breeding recruitment were focused on raptors (bald eagles, peregrine falcons, Cape vultures) and four of the 10 studies (40%) focused on seabirds (western gulls, African penguins, and little penguins).

While few studies evaluated breeding success, the studies that documented reproductive activity suggest, at least for several species, integration back into the wild population may be attainable. Bald eagles, peregrine falcons, and little penguins produced offspring post-release. Western gulls and African penguins attempted reproduction. Cape vultures demonstrated breeding recruitment. However, the population growth rate among rehabilitated Cape vultures was not enough to sustain population growth on their own (Monadjem et al., 2014).

Monitoring post-release breeding success of rehabilitated oiled little penguins found egg laying, hatching, and fledgling rates for pairs of rehabilitated birds compared to control penguins similar to ranges reported for other little penguin colonies in Australia and New Zealand. The only significant difference observed was lower success in hatching rate for rehabilitated birds in the first breeding season after release (Sievwright et al., 2019b). Wolfaardt et al. (2008) evaluated breeding restoration of rehabilitated, oiled African penguins for more than a decade and found a substantial proportion were successful. Breeding was documented when a bird was observed incubating eggs, brooding, or guarding chicks. The authors did note a high rate of birds becoming intermittent breeders over time, suggesting the persistence of sub-lethal effects of oiling (Wolfaardt et al., 2008).

While breeding recruitment is a well-accepted metric for post-release success, the indirect influences on breeding populations is less recognized and may complicate evaluation of post-

[1] The gradual process of returning a rehabilitated animal to the wild with continued support/food provided during transition.

release impact of rehabilitated birds. The presence of floaters (non-breeding members of a population) can buffer, regulate and stabilize breeding populations as well as present potential negative intervention with reproduction (Penteriani et al., 2011).

Use of Models

Three studies used annual survival rate models for rehabilitated wild birds. Cape vulture post-release survival was monitored over six years for rehabilitated and non-rehabilitated, wild captured birds (trapped, marked and released as controls). A population dynamics model created by the authors calculated the declining population growth rate over time, which documented the survival rate of rehabilitated birds being significantly lower than non-rehabilitated birds (Monadjem et al., 2014). The authors concluded the survival rate of rehabilitated birds does not recover to wild-bird levels, resulting in a negative impact on long-term population trends.

Sandberg et al. (2022) compared annual survival of rehabilitated and released red-tailed hawks to wild-caught, banded individuals. Building a model using mark-recapture analysis of red-tailed hawk banding data from the USGS BBL between 1970 and 2013, the annual survival of rehabilitated hawks was estimated to be 22% lower than wild-caught, banded individuals, with hatch-year birds being exceptionally vulnerable to early mortality (Sandberg et al., 2022).

Hagen et al. (2024) used wildlife rehabilitation records and bird band recovery data from USGS BBL (1974-2018) to estimate annual survival of both rehabilitated birds and their wild counterparts for 20 raptor species, focusing on whether rehabilitated raptors contributed to populations with potential to replace anthropogenic loss. With a relatively large dataset, they built demographic models looking at both individual and population level effects, concluding that there was adequate information in 17 species to model survival and population contributions. Although survival of rehabilitated birds did not equal their wild counterparts in five species, ten species had equivalent survival to wild birds two to three years post-release (two species were uncertain results). The models also identified a general pattern that K-selected species benefited more from rehabilitation supplementation with a resultant conclusion that rehabilitation can be a modest, yet effective, mitigation offset.

Limitations of Study

Availability of Avian Rehabilitation Data

While all United States federal rehabilitation permit holders are required to keep records subject to inspection, the method of data collection is not standardized allowing for aggregation across rehabilitators and facilities. These records must be accurate and contain information on each bird in possession, its disposition, and outcome (whether the bird was released, euthanized, died, or still undergoing rehabilitation), or information related to bird transfer elsewhere (U.S. Fish and Wildlife Service, 2022). Unfortunately, when collected in a manner that is non-retrievable, this data is not useful to inform survivability studies, conservation studies, or ecosystem health initiatives. In addition, there is no widely accepted standardized terminology or data collection in wildlife rehabilitation. Without the ability to fully capture and integrate the scope of existing rehabilitation practitioners and their work, it is difficult to infer a collective conservation benefit.

Defining Post-Release Success

Most studies included in the literature review discussed factors that may influence post-release success. These include, but are not limited to, species, injury type, body condition score, time of year, release habitat, and release type (hard vs soft). In addition, many studies evaluated survival post-release by re-sighting over time, distance traveled, breeding recruitment, band recovery, or integration back into the wild population. However, the vast majority of literature reviewed did not specifically define "success" in their methods.

Only eight publications (22%) provided specific criteria to measure a successful outcome post-release. Six of these used temporal metrics. Three studies defined success based on days-survived post-release. Leighton et al. (2008) and Duke et al. (1981) defined success for various raptors as surviving greater than six weeks post-release, while Warkentin (1986) used survival past four weeks as a metric. Goldsworthy et al. (2000) considered the rehabilitation of oiled little penguins successful if the bird was captured or resighted at least once 30 days or more post-release, while others considered rehabilitation successful if the bird was not re-sighted or recovered within a certain period of time (Vergneau-Grosset et al., 2020, Martell et al., 2000).

Another two articles defined success based on breeding outcomes in seabirds. Wolfaardt et al. (2008) defined the success of decontaminated African penguins as being restored into the breeding population. Birds were determined to be breeding only if they were observed incubating eggs, brooding, or guarding chicks. Sievwright et al. (2019b) defined reproductive success as similar breeding outcomes of decontaminated little penguins compared to control birds in the first breeding season post-release.

Indirect Benefits of Wildlife Rehabilitation on Conservation

The rediscovery of 'One Health', the interconnectedness of human, animal and environmental health, speaks to the need to promote biodiversity, sustainability, and environmental stewardship for both human and non-human animals. Only by maintaining an intact ecosystem for all species, can we also conserve those species that are threatened and endangered.

Human-Wildlife Conflict (HWC) can be defined as 'negative interactions between people and wild animals, with consequences for both people and their resources, and wildlife and their habitats' (IUCN, 2020). HWC poses a significant risk: to the survival of many threatened and endangered species; to the integrity of ecosystems and protected areas, and the services they provide; and, erodes people's appreciation of the value of wildlife and their support for associated conservation and resource-management measures (IUCN, 2020).

Conflicts at the human-wildlife interface continually occur resulting in injured, orphaned, and/or sick animals. Trauma from collisions, trappings, shootings, companion animal attacks, oiling, and primary or secondary poisonings are common inciting causes requiring rehabilitation among birds (Redig and Arent, 2008; Kelly et al., 2013; Saito et al., 2007). These conflicts are indiscriminate and can affect populous as well as threatened and endangered species. Depending upon species and timing, many of these activities are considered illegal. These activities are reflected on the annual report of activities completed by permitted avian wildlife rehabilitators at the end of each calendar year and submitted to the oversight agencies.

While avian wildlife rehabilitation serves to directly restore the health and welfare of individual animals, indirect impacts reverberate to conservation as well. These indirect impacts include: ecosystem monitoring; scientific research; contributions to knowledge bases of avian veterinary medicine, disease, biology and ecology; advance clinical wildlife medicine and wildlife rehabilitation; inform changes in avian wildlife management; and, advise public and public health policies.

Avian Wildlife as Sentinels

Surveillance or monitoring pathogen activity among wildlife is resource intensive and logistically challenging. Animals entering rehabilitation facilities may serve as an accessible source for sample and data collection, serving as environmental indicators, or biosentinels, for toxin or microbial threats to animals and people (Redig and Arent, 2008). The novel Coronavirus Disease 2019 (COVID-19) pandemic, being the most recent example, highlights the reality that most emerging infectious diseases originate from a wildlife reservoir (Jones et al., 2008). Birds, of particular note, given their ability for wide distance travel and forage capacity in urban environments may circulate pathogens into human or other animal populations (Camacho et al., 2016a). Examples in the literature utilizing avian species as biomonitors include: lead poisoning, mercury and rodenticide poisonings; diseases such as avian influenza, West Nile virus (WNV), and SARS-CoV-2; energy industry impacts such as power lines and wind turbines; contributions to antimicrobial resistance patterns; illegal take such as shooting and trapping; and the impact of free-roaming cats on birds.

Lead Poisoning

Lead has been well documented in the literature to cause morbidity and mortality among a range of scavenging and predatory birds (Fisher et al., 2006; Kelly et al., 2013; Pain et al., 2019; Manning et al., 2019). Much of what is known or published on lead toxicity has come out of work associated with wildlife rehabilitation centers. In raptors, especially bald eagles, golden eagles (*Aquila chrysaetos*), and California condors (*Gymnogyps californianus*), lead is the most common cause of intoxication (Redig and Arent, 2008). Poisoning occurs through the ingestion of prey, carcasses, or viscera containing lead-based ammunition (Redig and Arent, 2008; Hunt et al., 2006). Poisoning from lead fishing tackle has been identified as the leading cause of mortality in adult common loons (*Gavia immer*) with population level impacts (Grade et al., 2018). Recently, an evaluation of lead exposure and eagle population level consequences at a continental scale was completed. The study estimated that lead exposure reduced the annual population growth of bald eagles by 4% and golden eagles by 1% (Slabe et al., 2022).

Recognition of lead toxicosis among avian species has provided the impetus for public policy to protect animals, the environment, and public health. In 1991, lead birdshot was banned for waterfowl hunting in the United States to protect waterfowl from lead toxicity, as well as endangered bald eagles that prey on poisoned waterfowl. In 2008, because of mounting evidence demonstrating mortality among the California condor population, lead ammunition was banned within the condor range in California for big game and non-game hunting (California

Department of Fish and Game, 2008). In 2013, California expanded this ban, requiring non-lead ammunition when taking wildlife with a firearm anywhere in the state (California State Assembly, 2013).

Anticoagulant Rodenticide Poisonings

Avian wildlife rehabilitation also serves as environmental biomonitors detecting rodenticide poisoning in non-target animals. Like lead, identifying rodenticides in wildlife called current mitigation strategies into question and contributed to public policy change. For nearly 40 years anticoagulant rodenticides have been well documented in the literature for non-target species (Murray, 2011; Murray, 2017; Murray, 2020). In the U.S., from 2006-2016, 96% of 94 birds of prey admitted to a Massachusetts wildlife clinic had detectable anticoagulant rodenticides in postmortem liver samples (Murray, 2017). In 2008, the U.S. EPA initiated regulatory action to protect non-target animal species, including wildlife and pets, by banning the sale of certain rodenticides to the public under the Risk Mitigation Decision for Ten Rodenticides (Murray, 2020; U.S. Environmental Protection Agency, 2008). Despite the regulation taking full effect in 2015, a follow-up study conducted again by Murray from 2017-2019 revealed continual widespread exposure to these rodenticides (Murray, 2020). This work highlights the importance for continued wildlife monitoring at wildlife rehabilitation clinics to provide data necessary to inform and evaluate conservation and public health mitigation strategies and legislation.

WNV and Other Novel and Emerging Pathogens

West Nile virus has affected thousands of birds since its 1999 detection in North America. In 2002, wildlife practitioners across 12 states reported an increasing number of dying raptors. Diagnostic evaluation on carcasses revealed a positivity rate of 71% (40/56) for WNV, which was determined to be the cause of widespread death (Saito et al., 2007). In order to test the utility of small-scale avian wildlife WNV biomonitoring, researchers at an Iowa Rehabilitation facility evaluated 29 serum samples from birds brought to the facility between 2002 and 2007. While results of infection were non-comparable between submitted birds and free-range birds, Randall et al. (2012) concluded this was likely attributable to small-scale sampling over a short time period with a low prevalent disease. The authors suggested increased sampling spanning a larger spatial scale would be more informative and useful (Randall et al., 2012). With a larger sample size, monitoring over 13,000 raptor samples between 1990 and 2014, Alba et al. (2017) demonstrated the usefulness of WNV syndromic surveillance from routine collection of data from admitted raptors to The Raptor Center (TRC; St. Paul, Minnesota). Study investigators were able to demonstrate the temporality of WNV circulation among admitted raptors and free-range raptors, concluding that this information may be useful for efficient allocation of financial and human resources (Ana et al., 2017).

Kelly et al. (2021) integrated pre-diagnostic clinical data in near real-time from a network of 30 wildlife rehabilitation organizations in California, for early and enhanced detection of unusual wildlife morbidity and mortality events. The project demonstrated the effectiveness and efficiency of the system in alerting to events associated with both common and emerging diseases, adding value to existing wildlife disease surveillance programs through a relatively efficient, low-cost strategy.

There are numerous other examples in the literature demonstrating the utility of using wildlife rehabilitation centers to monitor micro-organisms, including novel and emerging pathogens. Avian examples include viruses such as Avian Influenza A virus and Newcastle disease virus, bacteria including *Mycoplasma gallisepticum* (Wellehan et al., 2001a/b), *Escherichia coli* and Salmonella spp., and parasites (Michael et al., 2010; Bueno-Padilla et al., 2012). In all, researchers concluded that testing admitted wildlife is useful to measure overall prevalence on a large scale with an abundant sample size but cautioned differences may not be detectable in local populations for certain pathogens and host species (Camacho et al., 2016b, Redig and Goyal, 2012).

Antimicrobial Resistance Patterns

Antimicrobial resistance (AMR) constitutes a high proportion of emerging infectious disease. While AMR is often looked at in wildlife, particularly in avian wildlife, wild animals are not a driver of AMR. Nor does AMR appear to reduce the survival of 'infected' animals, although this has not been tested. Theoretically, AMR could compromise the treatment of individual wild animals in captivity such as wildlife exhibits, hospitals, or other highly managed populations (Arnold et al., 2016; Kock and Caceres-Escobar, 2022).

The most significant issue for wildlife populations is the management response should they be considered a source of AMR for humans or livestock (Arnold et al., 2016). Wildlife are 'spillover' hosts, becoming exposed to resistomes in the environment. This spillover allows bacteria, fungi, viruses, and parasites to evolve in response to antimicrobials which could then 'spillback' to humans (if used as a food source) and/or transference into domestic animal populations in proximity. Of particular concern are wildlife species that have the capacity for long-range movements, such as migratory birds. The control of wildlife infections transmissible to humans and livestock relies on three main approaches: separation - reducing contact with the wildlife source; vaccination - not possible for AMR; and wildlife population control - often by culling. For many reasons, culling is often the management response despite any controversy regarding the efficacy and efficiency of such an approach (Arnold et al., 2016).

Projectiles in Birds of Prey

The protection of birds of prey species began with the Migratory Bird Treaty Act in 1918 and has been strengthened over the decades by this and other acts to protect all birds of prey. However, birds of prey are still being shot, either on purpose or accidentally. Numerous papers from avian rehabilitation facilities have looked at projectile injuries in avian wildlife (Durham, 1981; Richards et al., 2005; Cummings et al., 2022). However, as the admission process of a bird to a wildlife rehabilitation center is not standardized, the data collected (e.g., cause for admission) could vary widely. Some reports showed reduced gunshot findings in raptors (Desmarchelier et al., 2010; Richards et al., 2005), but birds may not have been radiographed if there was no suspicion of gunshot, and not all rehabilitation centers have the resources to radiograph every bird that is brought to their center. Thus, incidental gunshot wounds (i.e., gunshots unrelated to reasons for admission) may have gone undetected. The Raptor Center's admission protocol does include whole body radiographs for all birds admitted. The Center is currently performing a retrospective review of the digital radiographs to determine how many gunshot findings are incidental findings, to evaluate how often projectiles might be missed throughout the admission process, and therefore how many illegal shootings are missed and unreported.

Free-roaming Cats

A free-roaming cat is defined as a cat living outdoors at least part of the time. This may be a pet cat that is allowed to spend time outdoors, a lost or abandoned owned cat, a tame un-owned cat, or a feral cat. Free roaming cats continue to be one of the most challenging animal welfare issues facing our communities. This is a multifaceted ‘wicked problem’, and many organizations have policy statements regarding the issues and potential solutions. For the purposes of this report, we will limit the discussion to the impact of free-roaming cats on birds. The American Veterinary Medical Association policy states that “Free-roaming cats are non-native predators and cause considerable wildlife destruction and ecosystem disruption, including the deaths of hundreds of millions of birds, small mammals, reptiles, amphibians, and fish (AVMA 2024).” Avian wildlife rehabilitation centers have contributed to the scientific literature regarding this issue, and we have included two such papers and their results.

McRuer et al. (2017) found cat interactions were the fourth greatest cause of wild bird admissions (13.7%), and the second greatest cause of wild avian mortality (80.8%). Adult birds were documented most frequently admitted (42.7%), followed by juveniles (37.2%), then nestlings (20.1%). The ten most common species admitted were mourning dove (*Zenaida macroura*), blue jay (*Cyanocitta cristata*), Carolina wren (*Thryothorus ludovicianus*), American robin (*Turdus migratorius*), gray catbird (*Dumetella carolinensis*), European starling (*Sturnus vulgaris*), northern cardinal (*Cardinalis cardinalis*), unknown sparrow sp., common grackle (*Quiscalus quiscula*), and unknown finch sp. and were more likely to be from a rural area. Their findings indicate that free-roaming cats substantially contribute to admissions in a wildlife rehabilitation hospital and even with veterinary intervention, release potential is limited.

Demezas and Robinson (2021) found cat interactions to be the second-most reported cause of admission, representing 12.3% of 6,345 admissions. The authors concluded that cats most often interact with regionally common near-ground-dwelling bird species in both urban and rural habitats. Wildlife rehabilitation centers can provide valuable sources of data for cat-bird interactions but potential sources of uncertainty and bias in their data need to be considered carefully.

Wildlife Rehabilitation Datasets and Databases

A related indirect benefit of wildlife rehabilitation is the development of standardized datasets and databases. Individual centers have long reported annual reports or annual reports over time, but the usefulness of this data is limited. The potential utility of data from wildlife rehabilitation and rescue efforts to provide management and conservation data has been demonstrated (Pyke and Szabo, 2018a; Pyke and Szabo, 2018b). Combining datasets from multiple rehabilitation centers allows for better: assessment of trends in wildlife; evaluations of large-scale anthropogenic impacts; alert systems for novel and re-emerging issues; determination of the extent to which wildlife rehabilitation mitigates mortality rates; and data access for wildlife managers and conservation research (Duffy, 2020; McNamara et al., 2013). One of the first attempts at aggregating wildlife rehabilitation data from multiple wildlife rehabilitation centers was Russell and Harden (2011) of Wildlife Rescue, Inc in New Mexico. Funded by a New Mexico state wildlife grant, the study involved 13 out of 15 permitted wildlife rehabilitation centers in New Mexico (Harden et al., 2006). The pilot project utilized a new acquisition log with standardized data fields and terminology and collected statewide data for one year.

Concurrently, in 2009 the Clinical Wildlife Health Initiative, a cross section of wildlife rehabilitation centers, met and developed a standardized dataset with terminology and descriptions (CWHI, n.d.). Subsequently this standardized terminology was integrated into the Wildlife Incident Log/Database and Online Network (WILD-One, 2024). WILD-ONe is a free, online patient management and data analysis program developed by the Wildlife Center of Virginia and designed for wildlife rehabilitators and wildlife health professionals. WILD-ONe itself grew out of a Homeland Security funded project called Project Tripwire, an effort to track zoonotic diseases that could be used for bioterrorism. A Google Scholar search referencing the WILD-ONe database returned numerous peer-reviewed papers. Articles include multiple studies involving dog and/or cat interactions with wildlife, human-wildlife conflicts (Timm and Kime, 2020), impacts on outcome of wildlife (Kelly and delBarco-Trillo, 2020) and welfare impacts of inappropriate human possession of wildlife (Frink, 2020).

Duffy (2020) used the WILD-ONe database to examine avian threats, mortality, and mitigation opportunities. The final dataset included 68,524 individual avian rehabilitation admissions, representing 383 bird species from 10 centers located in the Northeast and Midwest. While most species admitted (96%) were generalist species and listed as least concern on the International Union for the Conservation of Nature Red List in 2020, 19 near-threatened and 6 vulnerable bird species were included in the dataset. An additional 55 species were listed as species of conservation concern in the Avian Conservation Assessment Database through Partners in Flight in 2020. Duffy felt that wildlife rehabilitation center datasets are underutilized in bird conservation science. Stated advantages include their diversity of species, causes of admissions and broad scope of locations. A passive approach to monitoring wildlife, these datasets can be used to address conservation questions or support hypotheses for single species or broad taxonomic groups. By looking at spatial patterns to bird threats, avian wildlife managers can target local conservation activities and/or mitigation efforts (Duffy, 2020). That said, there are still many issues that need to be considered when using wildlife rehabilitation data including bias sampling and the lack of validity of some data types.

Besides RAVEN Wildlife Rehabilitation Records System, sold through the International Wildlife Rehabilitation Council (RAVEN, 2022), and WILD-ONe, offered by the Wildlife Center of Virginia, other database programs available to wildlife rehabilitators include Wildlife Rehabilitation MD (WRMD, n.d.), which was utilized for the aforementioned study in California (Kelly et al., 2021), and RaptorMed, out of the Carolina Raptor Center (RaptorMed, 2010). In addition, the CWHI standardized datasets with terminology and descriptions are free to download and utilize with any database program.

Some rehabilitators also have a banding permit through the USGS BBL. These encounters provide information on dispersal, behavior, survival, longevity, productivity, and the effects of natural and anthropogenic factors such as trauma, toxins and disease on survival and productivity (Scott, 2013; Martell et al., 1991; Bystrak et al., 2012). For example, banding records of rehabilitated raptors have increased dramatically since the 1960's with BBL having records for over 43,000 birds, which represents a significant resource for data mining (Bystrak et al., 2012;

Hagen et al. 2024). Lutmerding et al. (2012) demonstrated that compared to raptors banded and released in normal operations, the proportion of encounters for rehabilitated raptors within the first year of banding for all decades was higher. However, over time, the difference in time between banding and encounters for rehabilitated raptors as compared to raptors banded and released in normal operations, became progressively smaller. A significant finding for these relatively long-lived birds.

Science of Wildlife Rehabilitation

The number of birds admitted to rehabilitation facilities continues to grow, along with the number and scope of avian threats, both 'natural' and anthropogenic. The steady rise of professionalism and wildlife rehabilitation science has many short and long-term benefits. First and foremost, it improves overall avian welfare, of significance to the wildlife community and society as a whole (Willette et al., 2023; Mullineaux and Pawson, 2023). Advanced diagnostics result in broadening biosentinel science, further informing public policies and actions. Ongoing development of best management practices, especially for those challenging species, should improve release percentages (Hagen et al., 2024; Paul, 2024). Progressive avian medicine benefits individual birds and species, including threatened and endangered species, both captive and free-ranging (Kozlov, 2023).

Clinical Wildlife Medicine

Historically, wildlife rehabilitation has been driven by extremely dedicated lay people. For a variety of reasons, most wildlife admitted for rehabilitation are not seen by a veterinarian (Partners 4 Wildlife, unpublished data). Increasingly however, veterinarians are becoming involved, driving the sub-discipline of clinical wildlife medicine, the veterinary medical component of wildlife rehabilitation (Sleeman and Clark, 2003; Innis et al., 2019).

Wildlife hospitals, especially those accompanying Veterinary Medical Colleges, have high, diverse caseloads, with extensive research capacity and rigorous academic programs. The field of wildlife veterinary medicine has significantly advanced, as evidenced by an extensive portfolio of publications and textbooks, improving diagnostics methods and treatment protocols. One example, Dr. Pat Redig, director emeritus and founder of TRC has contributed over 75 publications in the field of raptor medicine and revolutionized avian orthopedic fracture repair in the mid-1990s with the introduction of a tie-in fixator technique (Bueno et al., 2019). This innovative technique allowed for fracture reduction, preserving survival of the animal. Further, since the mid-1980s, TRC has hosted hundreds of veterinarians from nearly 30 countries training them in raptor medicine and surgery enabling them to share learned knowledge to the next generation of veterinary professionals.

A second example is the California Raptor Center and the Companion Zoological Animal Research Laboratory at the University of California Davis School of Veterinary Medicine under Dr. Joanne Paul-Murphy. The focus of their work is anesthesia, analgesia, and critical patient care for avian species, including raptors, with the goal of improving pain management, wellness, and welfare. Since the early 2000's, this group has published dozens of articles looking at the types and distribution of opioid receptors of various species of birds, evaluating the pharmacokinetics and pharmacodynamics of analgesic drugs for use in the treatment of avian pain, and the assessment of clinicopathologic changes in birds associated with specific diseases.

Most avian wildlife rehabilitation centers, especially those with full- or part-time veterinarians have contributed to the knowledge base through peer-reviewed publications, book chapters, or professional presentations. The Raptor Center is currently conducting a literature review to determine the extent of contributions of wildlife rehabilitation to the scientific literature. Preliminary results show an increasing number of articles year over year, in a wide variety of disciplines - primarily within veterinary medicine and biology fields, over a broad range of animal orders, including many orders of birds.

Wildlife Rehabilitation

The community of wildlife rehabilitators is quite diverse in terms of knowledge and skills, professional training, funding, and available resources. Avian wildlife rehabilitation requires a federal permit and a corresponding state permit. Although most states issue permits for wildlife rehabilitation, eligibility criteria and reporting requirements vary widely. Most states do not have significant systems for accountability and oversight.

In addition to contributing to the veterinary medical knowledge, the wildlife rehabilitators are at the forefront of establishing best practices for management of wildlife temporarily in captivity for rehabilitation as well as optimizing techniques for rescue, reconditioning, and release. Wildlife rehabilitators are increasingly establishing relationships with local universities, exhibitors, departments of fish and game, researchers, and conservationists. Based on experience and expertise developed through working in wildlife rehabilitation, one of this paper's authors (J. Ponder) has worked extensively with the Galapagos National Park and others on protecting endemic species from non-target impacts during efforts to eradicate invasive, destructive mammals from island ecosystems.

Public Education and Outreach

Most states across the country allow wildlife rehabilitation services. These facilities provide public education and outreach through visitorship (guided tours), intake of wildlife for veterinary care and rehabilitation, and field calls regarding nuisance wildlife, providing the direct opportunity for public education and outreach. A public education impact survey, conducted over 30 years ago representing over 400 New York State rehabilitators, revealed one-to-one communication with people directly delivering an animal to the facility for care was the most common type of public interaction (Siemer et al., 1991). Each of the over half a million wild animals (about 50% of which are birds) seen in wildlife rehabilitation each year are brought in for help by an individual represents a potential and likely teaching moment between a wildlife rehabilitator and the public. Educational opportunities include presentations, media, written material, and conversations with donors while dropping off an injured animal (Tribe and Brown, 2000). Today, while rehabilitation centers continually have high annual animal intakes and phone calls, the addition of informative websites provides an expanded opportunity for public education and outreach.

Releasing a rehabilitated animal back to the wild is the goal and desired outcome of wildlife rehabilitation. However, behavioral and health reasons may prohibit an animal's return to the wild. Nonreleasable animals may then become "ambassador" animals (with obtainment of proper authorizations and permits), representing their wild counterparts. Considered "the most important members of their species," these animals may stimulate engagement and appreciation among the public. In return, ambassador animals may foster empathy towards a particular species, creating the impetus for overall wildlife stewardship.

There is an abiding philosophy that the informal science education provided by wildlife rehabilitators has the potential to foster interest in wildlife, generate awareness and empathy, and support for their conservation issues and other environmental threats (Tribe and Brown, 2000; Dubois, 2003). Unfortunately, this is not well documented in the literature (Feck and Hamann, 2013; Luhrmann, 2017). While live animal interactions may help visitors to retain information about threats to animals and conservation messages better, there is little evidence to support influence on their long-term behavior change (Ballantyne et al., 2009; Ballantyne et al., 2011; Clifford-Clarke et al., 2021).

Data Gaps and Future Recommendations

Data Gaps

Ultimately, in order to understand the impact of avian rehabilitation on conservation, a series of outcomes need to be investigated such as post-release survivorship, the impact of released birds on species, populations and ecosystems, and subsequent reproductive and recruitment success. There may also be conservation impacts from the indirect benefits of wildlife rehabilitation, including more robust ecosystem health policies, wildlife rehabilitation science applied to threatened and endangered species, and human behavior change as a result of public outreach/education. Fully recognizing the tall order of reaching this level of understanding, it is unsurprising why most studies end at acquiring survivorship data.

At a high level, we identified multiple data gaps reflected in the literature:

- There is a general lack of conservation data given the number of wild birds rehabilitated in the United States each year. This includes overall numbers of birds studied, scope of species represented, and number of publications. This likely reflects the lack of follow-up post-release as well as failure to publish.
- Given species variations and the numbers of birds treated in wildlife rehabilitation, the available literature reflects a very small cross-section of wildlife rehabilitation with a strong bias towards oiled wildlife. This bias may be the result of the U.S. Oil Pollution Act of 1990 which mandates a response to oiled wildlife in the United States. The cost of the entire spill response, including recovery and treatment of oiled wildlife, is borne by the responsible party (Henkel and Ziccardi, 2018).
- There are minimal reported metrics or information beyond survivorship of released rehabilitated animals. All studies included in our search included survival data, while few included information on breeding and even fewer included information on potential

population impacts from situations such as release of unfit animals or disease translocation.

- There is a lack of consistent terminology and metrics for both pre- and post-release monitoring, which creates barriers to collating data and allowing for robust information.
- Species ecology can be expected to influence outcomes and the success and conservation contributions of rehabilitated and released wild birds, which limits the ability to make broad conclusions. Initial target population size, causes of admission for rehabilitation and life strategies can impact contributions (Newton, 2010; Paterson et al., 2021; Hagen et al., 2024). In addition, the contribution of non-breeding individuals to overall avian species conservation has not been well-explored (Brown, 1969; Penteriani et al., 2011).

Recommendations

Determining the direct and indirect contributions of wildlife rehabilitation to avian conservation requires multiple disciplines. Below the authors provide suggestions to address data gaps directly involved with wildlife rehabilitation.

Standardization of Terminology and Data Collection for Wildlife Rehabilitation

As noted earlier, all United States federal rehabilitation permit holders are required to keep records subject to inspection. The lack of ability to retrieve this data and/or aggregate across rehabilitators and facilities means that critical information useful for conservation studies, mitigation planning, and ecosystem health initiatives is lost. Without the ability to fully capture and integrate the scope of existing rehabilitation practitioners and their work, it is difficult to infer a collective conservation benefit.

> *Recommendation: Promote data collection method standardization across United States rehabilitation facilities and individual rehabilitation practitioners to allow for an online database that supports data aggregation. Promote consistent use of standardized terminology and adopt standard practices across all reporting.*

> *Recommendation: Conduct a review of data currently collected by United States Fish and Wildlife Service for reporting and what would be most helpful for migratory bird conservation and management.*

Standardization of Terminology and Data Collection for Post-release Monitoring

Standardized terminology and study parameters: A significant challenge when reviewing post-release monitoring studies is the lack of standardized terminology or parameters related to avian rehabilitation. The terms recovery, resighting, restoration, success, survival, and breeding success are used differently depending on the author(s). Often these terms, while of significant importance in the methods and analysis of results, were not defined by the authors. For example, one author may use the term “recovery” to indicate a live bird return, while another used the term to indicate a carcass. In addition, some authors assumed birds were dead if not resighted within a particular time period, while others would classify those birds as alive. These differences may occur based on geographic location of the study, species evaluated in the article, and injury type. The lack of standardized definitions for these terms leads to conflicting outcomes, challenges when comparing studies, and ambiguity leading to assumptions about the methods and results. Standardization of these terms would lead to data and outcomes that could be evaluated on a larger scale and add clarity to rehabilitation success.

> *Recommendation: Develop standardized definitions for key terms related to rehabilitation and post-release monitoring. The definitions could be determined on a species level, by bird group, injury type, etc.*

Tools for Post-release Monitoring

Essential to survival studies is the ability to identify released birds in the wild following rehabilitation. While there are a number of systems for monitoring wild bird movements, they can be expensive and technically challenging, putting them beyond the reach of most wildlife rehabilitators. One tool, bird banding, has been used for over 100 years and continues to be practiced despite technological advances in techniques, likely owing in part to its low invasivity and relative simplicity (Jackson et al., 2008; Bildstein and Peterjohn, 2012). Banding permits require the submission of a "complete research proposal documenting the goals, purpose and project in detail" (U.S. Geological Survey, 2017). This requirement may be suitable for those in high resource and/or academic settings, but is restrictive to others. Without the potential to identify previously released birds, especially aggregating data from different rehabilitators intermittently releasing single or low numbers of birds across a large spatial scale, retrospective studies are challenging if not impossible to perform. Submitting a research proposal prior to banding individual or a small number of birds is time and resource intensive and likely prohibitive for individuals without a research background. Additionally, this requirement, by inherently selecting relatively larger resource intensive rehabilitation centers in certain geographic regions, disproportionally biases available information. Despite these limitations, bird banding has strong potential as a tool to assess the short and long-term impacts of avian rehabilitation and effects on conservation (Hagen et al., 2024).

> *Recommendation: Adapt the bird banding permit requirements to allow routine banding of rehabilitated/released birds in order to increase the amount and representation of available information related to rehabilitation efforts and post-release survivability. This could also be accomplished by creating a large-scale research project with conservation scientists or wildlife managers crossing multiple wildlife rehabilitation centers with standardization of rehabilitation and data collection methods.*

Determination of Cause of Mortality

Cause of death information is typically absent in post-release monitoring studies. Success or survival post-release is evaluated primarily based on days-lived post-release with a few studies including breeding/recruitment as metrics. While this benchmark provides important information, it omits potentially useful data to evaluate the effectiveness of rehabilitation. Information generated from necropsies, particularly, can provide valuable information related to unapparent co-morbidities on gross examination that contributed to an animal's mortality. Literature suggests raptors can have a sublethal level of rodenticides, which predisposes them to fatal injuries or events such as predation, trauma, and reduced hunting ability (Redig and Arent, 2008; Murray, 2020; Kelly et al., 2013). Further, without investigation it may not be possible to know if the animal was ill prepared for release, released at an inappropriate location, released at an inappropriate time of year, etc. Understanding the circumstances leading to the death of a released bird, in conjunction with the bird's demographic factors (taxa, age, time spent in captivity, type of injury), may help both wildlife rehabilitation practitioners and conservation scientists achieve their shared goal of preserving animal welfare and conservation.

Recommendation: Encourage inclusion of cause of death with necropsies within post-release monitoring studies.

Conclusions

The authors recommend creating a collaborative working group across key United States rehabilitation centers, including rehabilitators, veterinarians, conservation scientists and wildlife managers to develop rehabilitation protocols for avian groups/species with the highest likelihood of successful outcomes. Beyond this literature review, a deeper evaluation (systematic review) of the literature as well as looking to conservation organizations such as IUCN and species-specific recovery plans and reintroduction protocols will help with the development of science-based protocols and hypothesis-driven research and modeling to further the conservation impacts of wildlife rehabilitation.

Limitations of Literature Search

Only one database, CAB Abstracts, was used for the literature search. While CAB Abstracts is a broad database, these articles are still assumed to be an underrepresentation of the total number of articles in the scientific literature. Including other databases and sources (‘gray literature’) that are not indexed in electronic databases, would yield more articles and additional information.

While some indirect benefits of wildlife rehabilitation were outlined in this paper, an in-depth literature search on the conservation benefits of each of these topics was not undertaken. In addition, the authors recognize that wildlife rehabilitation techniques and best practices vary greatly among geographical areas and have also changed dramatically over the time covered by the literature search. The literature search was not limited geographically and intentionally included available sources from all countries in order to find as much information as possible to address the underlying question of the conservation impacts of wildlife rehabilitation. When specifics about wildlife rehabilitation are mentioned or recommendations are made, the focus is the United States region.

Table 1 Summary of the selected 36 articles meeting search criteria for post-release from wildlife rehabilitation

Year	Author(s)	Geographical Location	Bird Group	Species	Injury Type	Method	Time	Type of data	Cause of death
1978	Clark	United Kingdom	Seabird	Guillemots	Oil spill	Resight	<6w	Survival	No
1981	Duke et al.	United States	Raptors	Multiple	Trauma, various	Telemetry, band resight	>6w	Survival	Yes
1986	Warkentin	Canada	Raptors	Merlins	Trauma	Telemetry, nest surveys	>6w	Survival, breeding	No
1988	Hamilton et al.	United States	Raptors	Multiple	Trauma, various	Telemetry	<6w	Survival	No
1991	Martell et al.	United States	Raptor	Bald eagles	Trauma	Telemetry, band resight	>6w	Survival, breeding, behavior	Yes
1996	Sharp	North America	Seabird	Guillemots, various	Oil spill	Band recovery, band resight	>6w	Survival	No
1997	Sweeny	United States	Raptor	Peregrine falcon	Trauma		>6w	Survival, breeding	No
1997	Wernham et al.	Britain	Seabird	Guillemots	Oil spill	Band resight	>6w	Survival	No
1999	Underhill et al.	South Africa	Seabird	African penguins	Oil spill	Band recovery, band resight	>6w	Survival, breeding	Yes
1999	Whittington	South Africa	Seabird	African penguins	Oil spill	Band recovery,	>6w	Survival	No

Year	Author(s)	Geographical Location	Bird Group	Species	Injury Type	Method	Time	Type of data	Cause of death
						band resight			
2000	Goldsworthy et al.	Australia	Seabird	Little penguins	Oil spill	Band resight	>6 w	Survival	Yes
2000	Anderson et al.	United States	Waterfowl	American coots	Oil spill	Band resight	>6w	Survival, Behavior	Yes
2000	Newman et al.	United States	Waterfowl	American coots	Oil spill	Soft release	>6w	Survival	Yes
2000	Fajardo et al.	Spain	Raptor	Wild barn owls	Trauma, hand-reared, other	Band recovery, band resight	>6w	Survival, dispersal	Yes
2000	Martell et al	United States	Raptor	Multiple	Trauma	Patagial markers and telemetry	>6w	Survival, breeding	No
2002	Golighty et al.	United States	Seabird	Western gulls	Oil spill	Telemetry	>6w	Survival, breeding	No
2003	Joys et al.	Britain	Multiple	Multiple	Various, trauma, oil spill	Band recovery	>6w	Survival	No
2004	Newman et al.	United States	Seabird	Common murre	Oil spill	Telemetry, band resight	>6w	Survival, behavior	Yes
2007	Barnham et al.	South Africa	Seabird	African penguins	Oil spill	Band resight	>6w	Survival, breeding	No

Year	Author(s)	Geographical Location	Bird Group	Species	Injury Type	Method	Time	Type of data	Cause of death
2008	Stauber et al.	United States	Raptor	Peregrine falcon	Trauma	Telemetry	>6w	Survival, breeding	No
2008	Leighton et al.	United Kingdom	Raptor	Tawny owls	Juvenile - hand-reared	Telemetry, band resight	>6w	Survival	Yes
2008	Altwegg et al.	South Africa	Seabird	Cape gannets	Oil spill	Band Recovery	>6w	Survival	No
2008	Wolfaardt et al.	South Africa	Seabird	African penguins	Oil spill	Band recovery, band resight, restoration, breeding	>6w	Survival, breeding	No
2010	Griffiths et al.	United Kingdom	Raptor	Tawny owls	Juvenile - hand-reared	Telemetry	>6w	Survival	No
2012	Selman et al.	United States	Seabird	Brown Pelican	Oil spill	Band resight	6w	Survival, Integration	Yes
2013	De La Cruz et al.	United States	Waterfowl	Surf Scoters	Oil spill	Telemetry	>6w	Survival	?
2014	Monadjem et al.	South Africa	Raptor	Cape vultures	Poisoning, trauma, other	Band resight	>6w	Survival	No
2015	Chilvers et al.	New Zealand	Seabird	Little blue penguins	Oil spill	Telemetry	>6w	Survival, behavior	No
2019	Golightly et al.	United States	Waterfowl	Surf scooters	Oil spill	Telemetry	>6w	Survival, behavior	No

Year	Author(s)	Geographical Location	Bird Group	Species	Injury Type	Method	Time	Type of data	Cause of death
2019a	Sievwright et al	New Zealand	Seabird	Little blue penguins	Oil spill	Telemetry	>6w	Survival, breeding	No
2019b	Sievwright et al	New Zealand	Seabird	Little blue penguins	Oil spill	Telemetry	>6w	Survival	No
2020	Vergneau-Grosset et al.	Canada	Raptor	Multiple	Trauma	Band Recovery	1 Month	Survival	Yes
2021	Fiorello et al.	United States	Seabird	Brown Pelicans	Oil spill	Telemetry	>6w	Survival	No
2021	Alden et al	New Zealand	Seabird	Yellow-eyed penguins	Juvenile -Starvation	Mark resight		Survival	No
2022	Sandberg et al.	United States	Raptor	Red-tailed hawks	Trauma	Telemetry	N/A	Survival	No
2024	Hagen et al.	North America	Raptor	Multiple	Trauma	Band recover		Survival	No

Data in this table includes information interpreted from a literature search that met the criteria described above. Columns include the year of publication; the bird group and species; injury cause or event necessitating rehabilitation; the method the study authors utilized post-release to identify released birds; upper limit of time birds were identified post-release, which was categorized for simplicity as less than 6 weeks (<6w), 6 weeks (6w), or greater than 6 weeks (>6w); type of data authors included in their publication; and whether authors mentioned a cause of death in any birds in their studies.

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