

**A retrospective insight into the potential effects of parasites on the
eastern loggerhead shrike (*Lanius ludovicianus* spp.)
captive-breeding program in southeastern Canada**

by

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General Abstract

Recovery programs around the globe attempt to mitigate the current biodiversity crisis. Captive breeding programs (CBPs) are one of the tools to attempt conserving diverse threatened or endangered species. This study investigates the CBP of an endangered passerine species in southeastern Canada, the eastern loggerhead shrike (*Lanius ludovicianus* spp.; ELOSH) in the context of one of the most common sanitary challenges in captivity: parasitic infections. Endoparasites can cause damage directly and/or indirectly and may lead to restriction of growth and reproductive functions of their host. This thesis objective is to draw attention to the importance of host-parasite interactions in captive-breeding settings, as well as study the potential effects on breeding success, by collection and analysis of historical data. Two separate datasets were used to conduct the statistical analysis (1) one to describe the parasitic prevalence and abundance, and its effects on the captive population, and (2) another to examine the effects of such parasites in the reproductive output of ELOSH females. Male-biased and juvenile-biased parasitism were observed among the individuals parasitized by *Capillaria* sp. In females, the abundance of *Capillaria* sp. was the only significant factor negatively affecting their reproductive output. Altogether, the results highlight the importance of parasitic management in CBPs, especially for endangered species, where it is essential to prevent any further threats to an already scarce population.

Key Words: parasitology, *Capillaria*, endangered passerines, bird reproduction, zoo research

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List of Abbreviations

AIC	Akaike's information criteria
ALS	African Lion Safari
CBP	Captive Breeding Program
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWHC	Canadian Wildlife Health Cooperative
CWS	Canadian Wildlife Service
ELOSH	Eastern Loggerhead Shrike (<i>Lanius ludovicianus</i> ssp.)
MBCA	Migratory Birds Convention Act
NWRC	National Wildlife Research Centre
SARA	Species at Risk Act
TZ	Toronto Zoo
VIF	Variance Inflation Factor
WPC	Wildlife Preservation Canada
OMNRF	Ontario Ministry of Natural Resources and Forestry

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General Introduction

Captive-breeding

The importance of biodiversity and its continuous loss has been extensively documented (Collen *et al.*, 2010; Bellard *et al.*, 2012). Since 1995, Canada has officially recognized the importance of biodiversity and its conservation, proposing recovery measures, including captive-breeding and the transplanting of wild or captive-bred individuals, for example to their natural areas of occurrence (Environment Canada, 1995).

Captive breeding programs (CBPs) have been used for the conservation of many endangered species and can take place in diverse types of institutions (Philippart, 1995), such as zoos that contribute to conservation actions (Conde *et al.*, 2013). Recent studies have tried to quantify the role of zoos in conservation by examining peer-reviewed publications from accredited zoos and aquariums. The largest number of publications occur in the subject areas of Veterinary Sciences and Zoology, while the share of studies focusing on biodiversity conservation can be considered scarce in comparison (Loh *et al.*, 2018; Lina *et al.*, 2020; Pyott and Schulte-Hostedde, 2020). Although Veterinary Medicine has contributed to biodiversity conservation (e.g., assisting in planning, implementation, and evaluation of conservation projects), a multidisciplinary approach is imperative to achieve the most successful conservation results (Cook and Karesh, 1995).

The primary goal of a captive-breeding program is to reintroduce extinct populations or supplement declining ones within their historical ranges through the release of wild or captive-bred individuals (IUCN, 1998). Captive-breeding also has the potential to maintain targeted populations, until reintroduction into the wild is possible (Conde *et al.*, 2011). Different case studies have illustrated the critical role captive-

breeding can play in preventing species extinction (Cade and Burnham, 2003; Kleiman and Rylands, 2002; Price, 1989).

Reintroduction programs have been increasingly incorporating evidence from research to enhance captive breeding outcomes, ultimately optimizing release techniques to maximize survival (Attard *et al.*, 2016). Captive rearing of species is an important management technique used in an attempt to save species from extinction (Martin, 1975; Temple, 1978; Carpenter and Derrickson, 1981; Carpenter, 1983; Wakchaure and Ganguly, 2016). Different types of breeding programs can influence the success of further release for example, the individuals can be captive- or wild-born, may be reared by parents, surrogate parents, or a puppet, and they may be released into the wild as juveniles or adults, with a hard or soft release (Scott and Carpenter, 1987).

Parasitism

Parasitic infections are of great concern, listed among the most common problems affecting birds in captivity (Ombugadu *et al.*, 2018). Parasites are organisms that live internally (endo) or externally (ecto) to their hosts (e.g., birds) and are responsible for imposing a cost on their host, often with diversion of resources from the host to the parasite (Combes, 2005). Such trade-offs in allocating the finite energy reserves of an individual among survival, growth, and reproduction is explained by life-history theory (Stearns, 1976; Roff, 2002; Christie *et al.*, 2006; Schwanz, 2008). The increased energy expenditure from the host is caused by the parasite's consumption of their energy and nutrients, and increased energy invested in maintaining homeostasis, immune response, or repairing damaged tissue in the face of parasitism (Bush and Clayton, 2018; Khokhlova *et al.*, 2002; Martin *et al.*, 2003). This high energy demand influences the life-history

dynamics of their hosts and can lead to a reduction of components of the host fitness, such as reproductive success and survival (Forbes and Baker, 1991; Fitze *et al.*, 2004). Evolutionarily speaking, parasitic infections are also a strong selection pressure on the hosts driving the coevolutionary dynamics of host defensive mechanisms and parasite counter-adaptations (Dieckmann, 2002). Parasitic infections are also considered a major cause of wildlife health complications and death (Ombugadu *et al.*, 2018), particularly for rare and endangered species, whose survival is essential in conservation programs (Pucek *et al.*, 2004; Viggers *et al.*, 1993). The importance of parasites and their impact on reintroduced animals should be taken into account in conservation and reintroduction programs (Kołodziej-Sobocińska *et al.*, 2018) as a better understanding of the various factors that can cause the failure of a species reintroduction program can improve such programs in designing the most optimal approaches (Kołodziej-Sobocińska *et al.*, 2018).

Studies on birds' host sex-biased parasitism are not as abundant as the well-established mammalian literature (Moore and Wilson, 2002) where a tendency for greater parasitism rates among males has been shown (Poulin, 1996; Schalk and Forbes, 1997). Nonetheless, the literature frequently reports the lack of sex-biased parasitism among avian hosts (Cozzarolo *et al.*, 2019; Valdebenito *et al.*, 2020). The association between individuals' size and parasitism has been reported among many mammal species (Moore and Wilson, 2002) where males would be a larger and more energetically favourable target for parasitic infections (Moore and Wilson, 2002; Christie *et al.* 2003; Hawlena *et al.* 2005). However, the same would not apply to birds because the magnitude of sexual dimorphism among birds may not be comparable to that among mammalian males and females (Nunn *et al.*, 2009). Additionally, male mammals tend to disperse more frequently and further away, increasing their likelihood of contact with parasites in comparison to females, while the opposite usually occurs among birds (Greenwood,

1980; Mabry *et al.*, 2013; Trochet *et al.*, 2016) thus male-biased dispersal occurrence is uncommon (Li and Kokko, 2019). Existent differences in the immune system and mechanisms could also explain the lack of sexual-biased parasitism in birds (Peters *et al.*, 2019).

Age is another phenotypic aspect with contrasting variation within a population (Benton, 2012). It is expected that older birds shall experience decline in body functions and immune response with increasing adult age (Simon *et al.*, 2015). Aging affects not only the susceptibility to hosts and the outcome of diseases but may also influence the within-host competition and diseases prevalence (Ben-Ami, 2019). Although the immune response is expected to decline over time, juvenile individuals have yet to achieve their prime immune response are also considered more susceptible to infections (Ashby and Bruns, 2018).

Study Species

One species that has experienced cases of parasitism in its captive-breeding program is the eastern loggerhead shrike (*Lanius ludovicianus spp.*; ELOSH). Recovery strategies have been drafted for ELOSH, as a part of a Canadian recovery program, because this species is greatly affected by habitat loss (COSEWIC, 2014). The eastern loggerhead shrike is considered a bio-indicator species for its habitat, bringing attention not only to the decline of the species itself but its surrounding ecosystem – prairies, open areas dominated by grasses and/or forbs, interspersed with scattered shrubs or trees, and bare ground (COSEWIC, 2014). The large-scale population decline and range contractions of ELOSH have been observed since the 1970s (Miller, 1931), as well as a reduction in the extent of occurrences, index of the area of occupancy, number of

locations, and in extent and/or quality of habitat (COSEWIC, 2014). The eastern loggerhead shrike has been extirpated in New Brunswick since the 1970s, and currently is only reliably found in two areas in southern Ontario (< 100 individuals) and sporadically in southwestern Québec (< 10 individuals; COSEWIC, 2014). A long-term study in Ontario, with targeted surveys from 1992 - 2013, revealed a 26% reduction in the number of mature individuals over the last 10 years (Imlay and Lapierre 2012, Cadman *et al.*, 2007), leading to its designation as an endangered species (COSEWIC, 2014, Sibley, 2016), being protected in Canada, Mexico, and the USA by the Migratory Birds Convention Act (MBCA). Under Canada's Species at Risk Act (SARA), the eastern subspecies (formerly called *L. l. migrans*) is listed as Endangered.

The causes of the decline in loggerhead shrikes are not yet fully understood or reversible, nor have they ceased (COSEWIC, 2014). These declines are, however, correlated with habitat loss and degradation (Kridelbaugh, 1982; Luukkonen, 1987; Woods, 1994; Yosef, 1996). This is typically caused by farmland abandonment, development, widespread changes in farming practices, reforestation and succession (Novak, 1989; Cadman, 1985; Cadman, 1990; Cuddy, 1995; Jobin *et al.*, 1996; Jobin *et al.*, 2010), loss and degradation of wintering habitat (Lymn and Temple, 1991; Brooks, 1988), mortality from vehicle collisions on roads (Miller, 1931; Campbell, 1975; Luukkonen, 1987; Novak, 1989; Flickinger, 1995), presence of pesticides (Anderson and Duzan, 1978; Rudd *et al.*, 1981; Fraser and Luukkonen, 1986), competition with species more tolerant of human-induced changes (Yosef, 1996), changes on weather conditions (Collister and Wilson, 2007b), and presence of infectious diseases, such as West Nile virus (WNV; Bertelsen *et al.*, 2004). These factors can lead to reduced food supplies (Cadman, 1985; Yosef, 1994; Yosef, 1996), egg and nestling predation (Bent, 1950;

Collister, 1994; DeGeus, 1990; Gawlik and Bildstein, 1990; Scott and Morrison, 1990; Collister and Wilson, 2007), and poor egg quality (Hands *et al.*, 1989).

The recovery efforts include habitat stewardship projects and a captive-breeding and release program in Ontario and Québec (COSEWIC, 2014). In 1997, the captive-breeding program was initiated, with the goal to recover the ELOSH population and preserve their genetic diversity. The program is currently managed by Wildlife Preservation Canada (WPC) in partnership with Environment Canada and the Canadian Wildlife Service (CWS) – Ontario (Imlay *et al.*, 2010). Parasites are considered a medium priority in the ELOSH recovery plan, and the approach chosen is applied research to understand their importance and impacts on the ELOSH population (OMNRF, 2016). The presence of parasites has been recurrently observed in the WPC captive population reports of ELOSH (OMNRF, 2016). Juvenile mortality following fledging has been observed, with studies indicating 33 to 53% mortality occurring within 10 days after fledging (Burton, 1990; Yosef, 1996; Chabot *et al.*, 2001). In 2001, several captive ELOSH died at the Toronto Zoo, and nematodes (e.g., *Capillaria* sp.) detected during necropsy were suspected to be a contributing factor to the deaths.

Capillaria is a thin and small nematode (roundworm), from the Order Trichinellida, found in different species of mammals (Wright, 1961), reptiles (Rataj *et al.*, 2011), and birds (Yabsley, 2008). *Eucoleus contortus* (Gagarin, 1951, syn. *Capillaria contorta* Creplin, 1839) affects the digestive tract of birds and is found in the mucosa and submucosa of the oral cavity, esophagus, and crop. The infection can occur with the ingestion of eggs or intermediate hosts containing infective larvae (McDougald *et al.*, 2008). According to OMNRF (2016), *Capillaria spp.* is the only consistent endoparasite known to persist in the captive populations of ELOSH, to varying degrees, and increasing in the past years, despite repeated treatments. Although a minimal number of deaths have

been directly attributable to *Capillaria* infection in the program, it has been identified during several subsequent necropsies of captive birds at this location, suggesting its persistence (OMNRF, 2016). Capillariasis can be diagnosed through findings of their distinctive eggs – bipolar, small, long-oval shape, and striated shells – in feces or certain organs according to the species, e.g. *Capillaria hepatica* in the liver and *C. philippinensis* in the small intestine (Mehlhorn, 2016). A commonly used approach for detecting the presence of *Capillaria* sp. is the flotation method, which is used to obtain parasites of lower density (lighter) from fecal samples. According to the specific genus, the characteristics of the parasite may change, such as that the life cycle that can be direct (e.g., *C. aerophila*) or indirect (e.g., *C. annulata* uses earthworms as intermediate hosts), host species, and organ affected, with accordingly clinical signs, and severity of the infection. For example, while *C. hepatica* may be mostly asymptomatic, *C. philippinensis* can cause malabsorption with diarrhea, followed by emaciation, and hypoproteinemic edema, which often precedes a fatal outcome after an illness in up to 2 months (Mehlhorn, 2016). In avian species, *Capillaria obsignata* (*Baruscapillaria*) infects chicken and turkeys (Mehlhorn, 2016), but the species responsible for infection in ELOSH is still to be described. The proper identification by morphology of the *Capillaria* species is difficult and the clinical diagnosis of capillariasis vague and often associated with nonspecific signs such as apathy, ruffled feathers, emaciation, wasting, and death (McDougald *et al.*, 2008).

Typically, captive-born ELOSH receive standardized antiparasitic treatment from the early stages of their life (OMNRF, 2016), which could result in lowered parasitic prevalence later in life. Additionally, wild individuals may present elevated stress levels in captivity, which could lead to reduced immunity and greater parasitic prevalence (Christe *et al.*, 2006; Bais *et al.*, 2017). Therefore, higher parasitic measures, both

prevalence, and intensity should be found in wild-born individuals, in comparison to the ones from the captive origin.

The objective of this study was to describe and quantify the endoparasites present in the captive population of the ELOSH CBP. Additionally, I examined the potential effects of the detected parasites, especially of *Capillaria* sp., on the captive population, and the reproductive output of ELOSH dams, by collecting and examining historical data of the individuals, and their parasitic parameters (prevalence and abundance). Such data provide insight into how endoparasites can affect hosts, focusing on an endangered species' captive breeding, and if certain groups (e.g., age class) would be more prone to parasitism.

Literature Cited

- Anderson, W. L. and R. E. Duzan. (1978). DDE residues and eggshell thinning in Loggerhead Shrikes. *Wilson Bulletin*, 90, 215-220
- Ashby, B. and Bruns, E. 2018. The evolution of juvenile susceptibility to infectious disease. *Proceedings of the Royal Society B: Biological Sciences*, 285, 2018084
- Attard, C. R. M., Möller, L. M., Sasaki, M., Hammer, M. P., Bice, C. M., Brauer, C. J., Carvalho, D. C., Harris, J. O., Beheregaray, L. B. (2016). A novel holistic framework for genetic-based captive-breeding and reintroduction programs. *Conservation Biology*, 30(5), 1060–1069
- Bais, B., Tak, L., Mahla, S. (2017). Study of Preventive Health Measures for Wildlife in Captivity: A Review of Management Approaches. *International International Journal of Avian and Wildlife Biology*, 2(3), 73–75.
<https://doi.org/10.15406/ijawb.2017.02.00020>
- Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 15(4), 365–377.
<https://doi.org/10.1111/j.1461-0248.2011.01736.x>
- Ben-Ami, F. (2019). Host Age Effects in Invertebrates: Epidemiological, Ecological, and Evolutionary Implications. *Trends in Parasitology*, 35(6), 466–480.
<https://doi.org/10.1016/j.pt.2019.03.008>
- Bent, A. C. (1950). Life histories of North American Wagtails, Shrikes, Vireos and Their Allies. *U. S. National Museum Bulletin*, 197
- Benton, T. G. (2012). Individual variation and population dynamics: lessons from a simple system. *Philosophical Transactions of the Royal Society B*, 367, 200–210

- Bertelsen, M. F., Olberg, R. A., Crawshaw, G. J., Dibernardo, A., Lindsay, L. R., Drebot, M., Barker, I. K. (2004). West Nile virus infection in the eastern Loggerhead Shrike (*Lanius ludovicianus migrans*): Pathology, epidemiology and immunization. *Journal of Wildlife Diseases*, 40, 538-542
- Brooks, B. L. (1988). The breeding distribution, population dynamics, and habitat availability and suitability of an upper Midwest Loggerhead Shrike population. M.Sc. thesis, University of Wisconsin, Madison, Wisconsin
- Burton, K. M. (1990). Loggerhead shrike update. *Indiana Audubon Quarterly*, 68, 57–58.
- Bush, S. E., Clayton, D. H. (2018). ‘Anti-parasite behaviour of birds’, *Philosophical Transactions of the Royal Society B*, 373(1751), 0–13. doi: 10.1098/rstb.2017.0196
- Cade, T. J., Burnham, W. (2003). Return of the Peregrine. The Peregrine Fund, Boise, Idaho
- Cadman, M. D. (1985). Status report on the Loggerhead Shrike (*Lanius ludovicianus*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario
- Cadman, M. D. (1990). Update status report on the Loggerhead Shrike (*Lanius ludovicianus*) in Canada. COSEWIC, Ottawa
- Cadman, M. D., Sutherland, D. A., Beck, G. G., Lepage, D., Couturier, A.R. (2007). Atlas of the Breeding Birds of Ontario, 2001-2005. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources and Ontario Nature, Toronto
- Campbell, C. (1975). Distribution and breeding success of the Loggerhead Shrike in southern Ontario. Canadian Wildlife Service, Report Number 6065

- Carpenter, J. W. (1983). Species decline: a perspective on extinction, recovery and propagation. *Zoo Biology*, 2, 165-178
- Carpenter, J. W., Derrickson, S. R. (1981). The role of captive propagation in preserving endangered species. Pp. 109-113 in Nongame and endangered wildlife symposium (R. R. Odum, Ed.). Georgia Department of Natural Resources and Georgia Chapter of the Wildlife Society. Tech. Bull. WL5
- Chabot, A. A., Titman, R. D., Bird, D. M. (2001). Habitat use by Loggerhead Shrikes in Ontario and Québec. *Canadian Journal of Zoology*, 79, 916-925
- Christe, P., Giorgi, M. S., Vogel, P., Arlettaz, R. (2003). Differential species-specific ectoparasitic mite intensities in two intimately coexisting sibling bat species: Resource-mediated host attractiveness or parasite specialization? *Journal of Animal Ecology*, 72(5), 866–872. <https://doi.org/10.1046/j.1365-2656.2003.00759.x>
- Christe, P., Morand, S., Michaux, J. (2006). Biological conservation and parasitism. In: Morand S., Krasnov B.R., Poulin R. (eds) *Micromammals and Macroparasites*. Springer, Tokyo. https://doi.org/10.1007/978-4-431-36025-4_27
- Collen, B., Strien, A. Van, Nat, C., Bruno, J., Chanson, J., Galloway, J. N., Genovesi, P. (2010). Global Biodiversity: Indicators of. *Science*, 328(May), 1164–1168
- Collister, D. M. (1994). Breeding ecology and habitat preservation of the loggerhead shrike in southeastern Alberta. M.S. thesis, University of Calgary, Calgary, Alberta. 161 pp
- Collister, D. M., Wilson, S. (2007). Territory size and foraging habitat of Loggerhead Shrikes (*Lanius ludovicianus*) in Southeastern Alberta. *Journal of Raptor Research*, 41(2), 130–138. [https://doi.org/10.3356/0892-1016\(2007\)41\[130:TSAFHO\]2.0.CO;2](https://doi.org/10.3356/0892-1016(2007)41[130:TSAFHO]2.0.CO;2)

- Collister, D. M., Wilson, S. (2007b). Contributions of Weather and Predation to Reduced Breeding Success in a Threatened Northern Loggerhead Shrike Population. *Avian Conservation and Ecology*, 2(2). <https://doi.org/10.5751/ace-00193-020211>
- Combes, C. (2005). *The Art of Being a Parasite* (trans. by D Simberloff). University of Chicago Press, Chicago
- Conde, D. A., Flesness, N., Colchero, F., Jones, O. R., Scheuerlein, A. (2011). ‘An Emerging Role of Zoos to Conserve Biodiversity’, *Science*, 331, 1390–1391. doi: 10.1002/zoo.20369/abstract
- Conde, D. A., Colchero, F., Gusset, M., Pearce-Kelly, P., Byers, O., Flesness, N., Browne, R. K., Jones, O. R. (2013). Zoos through the lens of the IUCN red list: A global metapopulation approach to support conservation breeding programs. *PLoS ONE*, 8(12). <https://doi.org/10.1371/journal.pone.0080311>
- Cook, R. A., Karesh, W. B. (1995). Applications of Veterinary Medicine to in Situ Conservation Efforts. *Oryx*, 29(4), 244–252. <https://doi.org/10.1017/S0030605300021232>
- COSEWIC (2014) Assessment and Status Report Loggerhead Shrike *Lanius ludovicianus*
- Cozzarolo, C. S., Sironi, N., Glaizot, O., Pigeault, R., Christe, P. (2019). Sex-biased parasitism in vector-borne disease: Vector preference? *PLoS ONE*, 14(5), 1–11. <https://doi.org/10.1371/journal.pone.0216360>
- Cuddy, D. (1995). Protection and restoration of breeding habitat for the Loggerhead Shrike (*Lanius ludovicianus*) in Ontario, Canada. In: Yosef, R. and Lohrer, F. E. eds. *Shrikes (Laniidae) of the World: Biology and Conservation*. Proceedings of the Western Foundation of Vertebrate Zoology, 6, 67-69

- DeGeus, D. W. (1990). Productivity and habitat preferences of Loggerhead Shrikes inhabiting roadsides in a midwestern agro-environment. Master's thesis, Iowa State University, Ames, Iowa
- Dieckmann, U. (2002). Adaptive dynamics of pathogen–host interactions. In: Dieckmann, U., Metz, J.A.J. , Sabelis, M. W., Sigmund, K. Adaptive Dynamics of Infectious Diseases. 39–59. Cambridge University Press, Cambridge, UK.
- Environment Canada. (1995). Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity. Environment Canada: Hull, Québec
- Fitze, P. S., Tschirren, B., Richner, H. (2004). Life history and fitness consequences of ectoparasites. *Journal of Animal Ecology*, 73, 216– 226. doi:10.1111/j.0021-8790.2004.00799.x
- Flickinger, E. L. (1995). Loggerhead fatalities on a highway in Texas. In: Yosef, R. and Lohrer, F. E. eds. Shrikes (Laniidae) of the World: Biology and Conservation. *Proceedings of the Western Foundation of Vertebrate Zoology*, 6, 67-69
- Forbes, M. R., Baker, R. L. (1991). Condition and fecundity of the damselfly, *Enallagma eribium* (Hagen): the importance of ectoparasites. *Oecologia (Berl.)*, 86, 335–341. doi:10.1007/ BF00317598
- Fraser, J. D., Luukkonen, D. R. (1986). The Loggerhead Shrike. Pages 933-941 in DeSilvestro, R. L. ed. *Audubon Wildlife Report – 1986*. National Audubon Society, New York, New York
- Gawlik, D. E., Bildstein, K. L. (1990). Reproductive success and nesting habitat of Loggerhead Shrikes in north-central South Carolina. *Wilson Bulletin* 102:37-48
- Gherman, C. M. (2013). Trichinelloidea. In: *Textbook of Veterinary Parasitology*. AcademicPres, Cluj-Napoca. 244-267

- Greenwood, P. J. (1980). Mating systems, philopatry and dispersal in birds and mammals. *Animal Behaviour*, 28(4), 1140–1162. [https://doi.org/10.1016/S0003-3472\(80\)80103-5](https://doi.org/10.1016/S0003-3472(80)80103-5)
- Hands, H. M., Drobney, R. D, Ryan, M. R. (1989). Status of the loggerhead shrike in the northcentral United States. Missouri Coop. Fish and Wildlife Research Unit, University of Missouri. 15.
- Hawlena, H., Abramsky, Z., Krasnov, B. R. (2005). Age-biased parasitism and density-dependant distribution of fleas (Siphonaptera) on a desert rodent. *Oecologia (Berl.)*, 146, 200–208. doi:10.1007/s00442-005-0187-0
- Imlay, T. I., Crowley, J. F., Argue, A. M., Steiner, J. C., Norris, D. R., Stutchbury, B. J. M. (2010). Survival, dispersal and early migration movements of captive-bred juvenile eastern loggerhead shrikes (*Lanius ludovicianus migrans*). *Biological Conservation*, 143(11), 2578–2582. <https://doi.org/10.1016/j.biocon.2010.06.027>
- Imlay, T. I., Lapierre, J. (2012). Population monitoring and field propagation and release programs. Unpublished. report for the Ontario Ministry of Natural Resources and Canadian Wildlife Service.
- IUCN (World Conservation Union). 1998. Guidelines for re-introductions. IUCN/SSC Re-introduction Specialist Group, IUCN, Gland, Switzerland, and Cambridge, United Kingdom
- Jobin, B., DesGranges, J.-L. , Boutin, C. (1996). Population trends in selected species of farmland birds in relation to recent developments in agriculture in the St. Lawrence Valley. *Agriculture, Ecosystems and Environment*, 57, 103-116
- Jobin, B., Latendresse, C., Grenier, M., Maisonneuve, C., Sebbane, A. (2010). Recent landscape change at the ecoregion scale in Southern Québec (Canada), 1993-2011. *Environmental Monitoring and Assessment*, 164, 631-647

- Karesh, W. B., Cook, R. A. (1995). Applications of Veterinary Medicine to in Situ Conservation Efforts. *Oryx*, 29(4), 244–252. <https://doi.org/10.1017/S0030605300021232>
- Khokhlova, I. S., Krasnov, B. R., Kam, M., Burdelova, N. I., Degen, A. A. (2002). Energy cost of ectoparasitism: The flea *Xenopsylla ramesis* on the desert gerbil *Gerbillus dasyurus*. *Journal of Zoology*, 258, 349–354
- Kleiman, D. G., Rylands, A. B. editors. (2002). *Lion tamarins: biology and conservation*. Smithsonian Institution Press, Washington, D.C
- Kołodziej-Sobocińska, M., Demiaszkiewicz, A. W., Pyziel, A. M., Kowalczyk, R. (2018). Increased Parasitic Load in Captive-Released European Bison (*Bison bonasus*) has Important Implications for Reintroduction Programs. *EcoHealth*, 15(2), 467–471. <https://doi.org/10.1007/s10393-018-1327-4>
- Kridelbaugh, A. L. (1982). An ecological study of Loggerhead Shrikes in central Missouri. M.Sc. thesis, University of Missouri, Columbia
- Li, X. Y., Kokko, H. (2019). Sex-biased dispersal: a review of the theory. *Biological Reviews*, 94(2), 721–736. <https://doi.org/10.1111/brv.12475>
- Lina, H., Welden, Å., Stelvig, M., Nielsen, C. K., Purcell, C., Eckley, L., Bertelsen, M. F., Hvilson, C. (2020). The contributions of EAZA zoos and aquaria to peer-reviewed scientific research. *Journal of Zoo and Aquarium Research*, 8(2), 133–138
- Loh, T. L., Larson, E. R., David, S. R., de Souza, L. S., Gericke, R., Gryzbek, M., Kough, A. S., Willink, P. W., Knapp, C. R. (2018). Quantifying the contribution of zoos and aquariums to peer-reviewed scientific research. *Facets*, 3(1), 287–299. <https://doi.org/10.1139/facets-2017-0083>

- Luukkonen, D. R. (1987). Status and breeding ecology of the Loggerhead Shrike in Virginia. Master's thesis, Virginia Polytechnique Institute and State University, Blacksburg, Virginia
- Lymn, N. and S.A. Temple. (1991). Land-use changes in the Gulf Coast region: links to declines in Midwestern loggerhead shrike populations. *Passenger Pigeon*, 53, 315-325
- Mabry, K. E., Shelley, E. L., Davis, K. E., Blumstein, D. T., van Vuren, D. H. (2013). Social Mating System and Sex-Biased Dispersal in Mammals and Birds: A Phylogenetic Analysis. *PLoS ONE*, 8(3), 1-9. <https://doi.org/10.1371/journal.pone.0057980>
- Martin, L. B., Scheuerlein, A., Wikelski, M. (2003). Immune activity elevates energy expenditure of house sparrows: a link between direct and indirect costs? *Proceedings of the Royal Society of London B: Biological Sciences*, 270, 153-158. doi:10.1098/rspb.2002.2185
- Martin, R.D. (1975) Breeding endangered species in captivity. London: Academic Press
- McDougald, L. R., Yazwinski, T. A., Tucker, C. A. (2008). Internal Parasites. In Saif, M. Y. (Ed.) *Diseases of poultry*. Iowa, Blackwell Publishing. 1028-1029
- Mehlhorn, H. (2016). Encyclopedia of Parasitology. *In Encyclopedia of Parasitology* (3rd ed.). Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-662-43978-4>
- Miller, A. H. (1931). Systematic revision and natural history of the American shrikes (*Lanius*). *University of California Publications in Zoology*, 38, 11-242
- Moore, S. L., Wilson, K. (2002). Parasites as a viability cost of sexual selection in natural populations of mammals. *Science*, 297, 2015-2018. doi:10.1126/science.1074196. PMID:12242433

- Nunn, C. L., Lindenfors, P., Pursall, E. R., Rolff, J. (2009). On sexual dimorphism in immune function. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1513), 61–69. <https://doi.org/10.1098/rstb.2008.0148>
- Ombugadu, A., Echor, B., Jibril, A. B., Angbalaga, G. A., Lapang, M. P., Micah, E. M., Njila, H .L., Isah, L., Nkup, C. D., Dogo, K. S., Anzaku, A. A. (2018). ‘Impact of Parasites in Captive Birds: A Review’. *Journal of Neurology, Psychiatry and Brain Research*, 04, 1–12
- OMNRF (Ontario Ministry of Natural Resources and Forestry). (2016). Recovery Strategy for the Loggerhead Shrike (*Lanius ludovicianus*) in Ontario. Ontario Recovery Strategy Series. Prepared by the Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario. v + 9 pp. + Appendix vii + 35 pp. Adoption of Recovery Strategy for the Loggerhead Shrike, migrans subspecies (*Lanius ludovicianus migrans*), in Canada (Environment Canada 2015)
- Peters, A., Delhey, K., Nakagawa, S., Aulsebrook, A., Verhulst, S. (2019). Immunosenescence in wild animals: meta-analysis and outlook. *Ecology Letters*, 22, 1709–1722. <https://doi.org/10.1111/ele.13343>
- Philippart, J. C. (1995). Is captive breeding an effective solution for the preservation of endemic species? *Biological Conservation*, 72(2), 281–295. doi:10.1016/0006-3207(94)00090-d
- Poulin, R. (1996). Sexual inequalities in helminth infections: a cost of being male? *The American Naturalist*, 147,287-295
- Price, S. M. R. (1989). *Animal re-introductions: the Arabian oryx in Oman*. Cambridge University Press, Cambridge, United Kingdom

- Pucek, Z., Belousova, I. P., Krasin' ska, M., Krasin' ski, Z. A., Olech, W. (2004). European bison. Status Survey and Conservation Action Plan. IUCN/SSB Bison Specialist Group IUCN, ix + 54., Gland, Switzerland: Cambridge
- Pyott, B., Schulte-Hostedde, A. (2020). Peer-reviewed scientific contributions from Canadian zoos and aquariums. *FACETS*, 5, 381–392. doi:10.1139/facets- 2019-0052
- Rataj, A. V., Lindtner-Knific, R., Vlahović, K., Mavri, U., and Dovč, A. (2011). Parasites in pet reptiles. *Acta Veterinaria Scandinavica*, 53(1). <https://doi.org/10.1186/1751-0147-53-33>
- Roff, D. (2002). Life history evolution. Sunderland (MA): Sinauer Associates
- Rudd, P. L., Craig, R .B., Williams, W. S. (1981). Trophic accumulation of DDT in a terrestrial food web. *Environmental Pollution Series A, Ecological and Biological*, 25, 219-228
- Schalk, G., Forbes, M. R. (1997). Male biases in parasitism of mammals: effects of study type, host age and parasite taxon. *Oikos*, 78, 67-74
- Schwanz, L. E. (2008). Chronic parasitic infection alters reproductive out- put in deer mice. *Behavioral Ecology & Sociobiology*, 62, 1351–1358
- Scott, J. M., Carpenter, J. W. (1987). 'Release of Captive-Reared or Translocated Endangered Birds: What Do We Need to Know?', *The Auk*, 104(3), pp. 544–545
- Scott, T. A. and M. L. Morrison. (1990). Natural history and management of the San Clemente Loggerhead Shrike. *Proceedings of the Western Foundation of Vertebrate Zoology*, 4, 23-57
- Sibley, D. A. (2016). *The Sibley field guide to Birds of Eastern North America*. 2nd ed. Edited by A. A. Knopf. New York

- Simon, A. K., Hollander, G. A., McMichael, A., (2015). Evolution of the immune system in humans from infancy to old age. *Proceedings of the Royal Society B: Biological Sciences*, 282, 20143085. [https://doi.org/ 10.1098/rspb.2014.3085](https://doi.org/10.1098/rspb.2014.3085)
- Stearns, S. C. (1976). Life-History Tactics: A Review of the Ideas. *The Quarterly Review of Biology*, 51(1), 3–47. doi:10.1086/409052
- Temple, S. A. (Ed.). (1978). *Endangered birds: management techniques for preserving threatened species*. Madison, Univ. Wisconsin Press
- Toronto Zoo. (2016). TORONTO ZOO IS COMMITTED TO SAVING and PROTECTING ENDANGERED CANADIAN SPECIES THE EASTERN LOGGERHEAD SHRIKE
- Trochet, A., Stevens, V. M., Baguette, M. (2016). Evolution of sex-biased dispersal, 91(3), 297–320
- Valdebenito, J. O., Liker, A., Halimubieke, N., Figuerola, J., Székely, T. (2020). Mortality cost of sex-specific parasitism in wild bird populations. *Scientific Reports*, 10(1), 1–10. <https://doi.org/10.1038/s41598-020-77410-6>
- Viggers, K. L., Lindenmayer, D. B., Spratt, D. M. (1993). The importance of disease in reintroduction programs. *Wildlife Research*, 20(5), 687–698. <https://doi.org/10.1071/wr9930687>
- Wakchaure, R., Ganguly, S. (2016). Captive Breeding in Endangered Wildlife: A Review. *Journal of Biological Scientific Opinion*, 4(5), 186–187. <https://doi.org/10.7897/2321-6328.04544>
- Woods, C. P. (1994). *The Loggerhead Shrike in southwest Idaho*. Master's thesis, Boise State University, Boise, Idaho

- Wright, K. A. (1961). Observations on the Life Cycle of *Capillaria Hepatica* (Bancroft, 1893) With a Description of the Adult. *Canadian Journal of Zoology*, 38, 167–182. <https://doi.org/10.1139/z61-022>
- Yabsley, M. J. Capillarid Nematodes. In: Atkinson, C. T., Thomas, N. J., and Hunter, D. B. (2008). *Parasitic Diseases of Wild Birds*. Wiley-Blackwell, 463-497. <https://doi.org/10.1002/9780813804620.ch5>
- Yosef, R. (1994). Evaluation of the global decline in the true shrikes (Family Laniidae). *Auk*, 111, 228–233
- Yosef, R. (1996). ‘Loggerhead Shrike (*Lanius ludovicianus*)’, in Poole, A. and Gill, F. (eds) *The Birds of North America*. Philadelphia and Washington: The Academy of Natural Science and The American Ornithological Union

Chapter I:

Parasitofauna of Captive

Populations of

Eastern Loggerhead

Shrike (*Lanius ludovicianus*

***spp.*)**

in Southeastern Canada

Abstract

Wildlife and its biodiversity have suffered many threats in the past centuries. In particular, bird diversity and abundance have decreased and recovery programs around the world are attempting to mitigate that loss. The eastern loggerhead shrike (*Lanius ludovicianus* spp.; ELOSH) is classified as endangered and part of the recovery efforts in place include captive-breeding. Yet, parasitic infections are among the most common issues in captivity and despite the successes of the ELOSH recovery program, it has experienced such challenges. Endoparasitism can directly cause damage and/or may lead to restriction of growth and reproductive functions of their host. The purpose of this study is to draw attention to the importance of host-parasite interactions in a captive-breeding setting. Using a collection of observational data from 1997 to 2019, I investigated the presence and potential effects of endoparasites in the ELOSH captive-breeding program. Among 1499 parasitological exams, the prevalence of all observed endoparasites was 20.2 % representing 181 individuals from all years included. The two most prominent parasites were *Capillaria* sp. and oxyurids, with respective prevalences of 8.2 % and 11.3 %, while the mean intensities of *Capillaria* and oxyurids were respectively 4 ± 7 and 3 ± 4 parasite egg per slide (EPS). Sex-bias parasitism was observed towards males and the younger individuals were the most parasitized by *Capillaria* sp. Further studies are needed to incorporate other potential factors and uncover their effects on the host-parasite relationship in captive and wild populations.

Keywords: eastern loggerhead shrike, *Capillaria*, parasitology, passerines, zoo research

Introduction

The role of zoos in biodiversity conservation has been well documented (Cade and Burnham, 2003; Conde *et al.*, 2011). In 2013, Byers *et al.* described the One Plan approach that considers the importance of different institutions and stakeholders working under a unified management plan to maximise the conservation benefits, highlighting the performance of the zoo and aquarium community.

In captivity, parasitic infections are among the most common problems affecting birds, especially in high-density populations due to an increased risk of transmission (Ombugadu *et al.*, 2018). Endoparasites are organisms that live inside their hosts and by definition impose a cost on their hosts (Combes, 2005), because they can compete with the host for nutrients. In the case of intestinal helminth worms, they can damage the gastrointestinal tract as well as trigger an immune response (Degen, 2006) thus reducing the amount of energy available to the host (Munger and Karasov, 1989; Kristan and Hammond, 2004). The host may also lose body mass (Khokhlova *et al.*, 2002; Meagher and Dudek, 2002), have reduced growth rate, and reproductive functions via direct damage or a decrease in available nutrients (Sheldon and Verhulst, 1996; Norris and Evans, 2000; Zuk and Stoehr, 2002; Schwanz, 2008). Studying the host-parasite interactions is important to better understand the actual impacts of parasites on their host's breeding success and help improve the design of captive breeding programs (CBPs).

The risk that parasitism poses to the longevity of their hosts is becoming increasingly relevant for understanding the causes of decline in wild populations and challenges to the conservation of threatened species in a captive setting (Altizer *et al.*, 2003; Christe *et al.*, 2006). In the present study, I investigated the parasitofauna of eastern loggerhead shrikes (*Lanius ludovicianus* spp; ELOSH) and the interactions between the

hosts and the parasites present in the ELOSH CBP. In addition to identifying the presence of parasites based on the ELOSH veterinary records, I quantified their prevalence, mean abundance and mean intensity (see Bush *et al.*, 1997).

The ELOSH is a medium-sized passerine bird that is endangered in Canada and since 1997 has been the focus of a CBP, in collaboration with zoos. The wild ELOSH population is known to be threatened by large declines in population size, range of occurrence, and extent and/or quality of habitat (COSEWIC, 2014; Sibley, 2016). The ELOSH occupies a unique position in the food chain (Yosef, 1996), being both a songbird and a bird of prey (COSEWIC, 2014; Sibley, 2016). In Canada, two subspecies occur the ‘prairie’ subspecies (*L. l. excubitorides*) found in Manitoba, Saskatchewan, and Alberta, and the ‘eastern’ subspecies (previously known as *L. l. migrans*) found in Ontario and Québec (COSEWIC, 2014). Despite the efforts of the ELOSH CBP, the program has experienced significant mortality, exemplified by a case of high mortality among ELOSH fledglings in 2007 (Parmley *et al.*, 2015).

Captive born individuals receive standardized antiparasitic treatment from early in life (OMNRF, 2016), which should result in lowered parasitic prevalence later in life. Additionally, wild individuals may present elevated stress levels in captivity, which could lead to reduced immunity and greater parasitic prevalence (Christe *et al.*, 2006; Bais *et al.*, 2017). Although both captive- and wild-born individuals are kept under the same conditions in captivity, their place of birth could produce immunological differences between them (Palme *et al.*, 2005; Christe *et al.*, 2006). Therefore, higher parasitic measures should be found in wild-born individuals, in comparison to the ones of captive origin.

Host sex-biased parasitism cases are infrequent among avian hosts (Valdebenito *et al.*, 2020). When present, the sexual dimorphism may not occur with enough magnitude

to promote different levels of parasitism among birds (Lindenfors *et al.*, 2007). Thus, there should not be any difference between males and females with regards to space and nutrient opportunity for parasitic infections (Moore and Wilson, 2002; Christie *et al.* 2003; Hawlena *et al.* 2005). In the wild, female birds tend to disperse more frequently and further away than males, being more likely to have contact with parasites (Greenwood, 1980; Mabry *et al.*, 2013; Trochet *et al.*, 2016; Li and Kokko, 2019) however, this is not applicable to studies conducted in captive settings. Under these assumptions and since captive individuals are usually kept under the same husbandry procedures, I predicted that no differences in parasitism would be found between males and females.

Finally, age can strongly influence disease dynamics (Benton *et al.*, 2006; Ben-Ami, 2019). The variation present across individuals of different ages is considered one of the most acute aspects of phenotypic variation within a population (Benton, 2012). This can be exemplified by the differences in host susceptibility, virulence, and also may influence disease prevalence and within-host competition (Ben-Ami, 2019). The theory of aging describes the decline in body function and immune response, with the increasing adult age (Simon *et al.*, 2015). Although the immune response is expected to decline over time (Lavoie, 2006), juveniles are yet to achieve their prime immune response, therefore may also be more susceptible to parasitic infections (Ashby and Bruns, 2018). Therefore, I predict that both juvenile (< 2 years old) and older individuals (>10 years old) would present greater parasitic prevalence and intensity.

Material and Methods

Pre-study methodology and data collection

This retrospective study was conducted by collection of hardcopy and electronic files from 1997 to 2019 provided by Wildlife Preservation Canada (WPC), the Toronto Zoo (TZ, Toronto, Canada), and the African Lion Safari (ALS, Cambridge, Canada). The ELOSH CBP has been held at these host institutions consistently throughout the existence of the CBP. The available data were used to calculate descriptive statistics (including summary counts, proportions, and mean values) and to characterize the parasitofauna observed within the captive population. All available records of parasitological exams, from 1997 to 2019, were included in the present study, except for 12 individuals with missing information about sex and source type.

The ELOSH captive breeding program has followed standardized treatment protocols across all facilities housing shrikes, with moxidectin used as the sole anthelmintic until 2017. In 2018, a new drug was implemented with alternate treatments: in the even years (beginning 2018), ivermectin (concentration: 0.8 mg/ml and dose: 1 mg/kg) was chosen to be administered orally once per week for four weeks; in the odd years (starting 2019), fenbendazole (concentration: 100 mg/ml and dose: 100 mg/kg) was administered orally bi-weekly for two weeks. All individuals were treated followed by collection of a fecal sample for parasitological evaluation one week after the end of the treatment. These treatments were scheduled twice per year, first in the spring before breeding season and in the fall after arriving at the overwintering facilities. All juvenile birds were also given 1-2 doses of ivermectin prior to release.

The parasitological evaluations were executed following the same protocol, by different qualified examiners approved by the program in place at each holding

institution, including field technicians, veterinary technicians, veterinarians, and supervisors of each facility, overseen by the designated supervisor from WPC. The protocol for examination of parasitic presence in ELOSH was based on microscopic examinations of fecal samples, either fresh or preserved (Ward *et al.*, 1997). The main method of analysis of the fecal samples was the flotation method, also known as the Willis method (Willis, 1921), which uses the faecal material in a flotation fluid – commonly NaCl or sugar. The specific gravity of the solution allows the parasite eggs to be separated from the sediment and accumulate at the top part of the tube (float) where it is collected to produce a smear. (Mesquita *et al.*, 2017). Samples examined by different methods were not included in the analysis. The identification of structures found in the examinations is performed by each facility examiner, based on morphology and dimensions of structures present, following the facility's key of identification and guidelines.

The host's individual information included ID number of host, date of birth of host, host's source of birth (Captive / Wild born), and sex (Female / Male). The parameters collected from the parasitology examinations and records were the date of sample collection, the described species of eggs found in each slide, and the number of eggs of each parasitic species observed per slide (EPS). The quantitative descriptors of the parasite populations were presence (binomial response representing positive (1) and negative (0) results of each parasitology examination), prevalence (percentage of positive results among the total number of examinations), abundance (number of parasites of a particular species in a host), mean abundance (abundance divided by the total number of parasitology examinations), intensity (number of parasites of a particular species in an infected host), and mean intensity (intensity divided by the total number of infected hosts), as defined by Bush *et al.* (1997).

Statistical analysis

Descriptive statistics were used to characterize the endoparasites observed within the captive population. Statistical analyses were conducted in R (R Core Team, 2020 [v 4.0.2]), using base R, and packages ‘lme4’ (Bates *et al.*, 2015 [v 1.1-23]), ‘caret’ (Kuhn, 2020 [v 6.0-86]), ‘MuMIn’ (Bartoń, 2020 [v. 1.43.17]), and ‘ggplot2’ (Wickham, 2016 [v 3.2.1]). Quantitative parasitic measures of prevalence and mean intensity of parasites were performed using QPweb (Reiczigel *et al.*, 2019), and standard deviation values were calculated using R. Statistical models were performed to study how parasitic measures were affected by the independent variables: host age, host sex, population birth source, host ID, year of sampling, and Julian date of sampling. To encompass the age differences in the program, more than one observation was included per individual throughout the years. For all models, the variables host ID and year of sample collection were set as random variables in order to control for the fact that some records of the same individual are included throughout the years of the study.

Three generalized linear mixed-effects models were built to evaluate the effects of host’s sex, age, source of birth, and Julian date of sampling on the presence of any parasite species (**Table 1.3**), the presence of *Capillaria* eggs (**Table 1.4**), and the presence of Oxyurid eggs (**Table 1.5**). The argument “family = binomial” was added to the calculation to account for the binomial nature of the distribution of these 3 parasitic presence models. Using the same predictor variables, another 4 linear mixed effects models were built to determine their effects on the abundance and intensity of *Capillaria* eggs (**Table 1.6** and **Table 1.7**, respectively), and the abundance and intensity of Oxyurid eggs (**Table 1.8** and **Table 1.9**, respectively).

A multi-level approach was selected to account for potential factors present and the model assumptions for each model were tested using a residual vs. fitted values plot, residual QQ plot, and residual histogram. To investigate collinearity of predictors, a VIF (variance inflation factor) test was performed to confirm the absence of collinearity between predictors, as all results were lower than two, all predictors were maintained (see Zuur *et al.*, 2010).

Results

Among all the parasitological exams available, a prevalence of 20.2 % (303 of 1499) was reported across all parasite species. The two most prominent parasites were *Capillaria* sp. and oxyurids, with respective prevalences of 8.2 % and 11.3% (**Table 1.1** and **Table 1.2**), while the remainder (<1%) was comprised of protozoans (e.g., coccidians and flagellates) and occasional ectoparasites (e.g., mites and lice); hence only *Capillaria* sp. and oxyurids were considered in the statistical models. The mean intensities of *Capillaria* sp. and oxyurids were respectively 4 ± 7 and 3 ± 4 parasite eggs per slide (EPS).

The models predicting parasitic presence and abundance (of all samples) totalled 1499 observations from 181 individuals, while the 2 remaining models totalled 123 observations from 53 individuals for intensity (of only infected samples) of *Capillaria* sp., and 169 observations from 56 individuals for intensity of oxyurids. From the 1499 exam records, 58.8% were females and 40.4% males, 66.9% captive and 33.1% wild-born, of varying ages (1 - 14) across years, in the period between 1997 and 2019. A total of 14 individuals (17 observations) did not have identified sex (NA) and 1 individual (2 observations) did not have identified source of birth; these were excluded from the statistical analyses.

Among the fixed effect predictor variables, males were significantly more parasitized than females in the model predicting abundance of *Capillaria* sp. ($p = 0.036$; **Table 1.6**). The same variable was strongly positive, but marginally significant in the model regarding intensity of *Capillaria* sp., ($p = 0.077$; **Table 1.7**). Source of birth had a nearly significant negative and strong effect, in only one of the models, predicting the presence of *Capillaria* sp. ($p = 0.064$; **Table 1.4**). The date of the exam did not have significant effects in any of the models studied and no variables were significant in explaining the 3 models associated with Oxyurid presence, abundance and intensity.

The age distribution of the host at the exam date varied between <1 and 15 years old, with a mean of 4 years old (**Figure 1.1**). Age presented a significant negative, but weak effect on the models predicting presence of any parasite species ($p = 0.0007$; **Table 1.3**), presence of *Capillaria* sp. ($p = 0.0006$; **Table 1.4**), and abundance of *Capillaria* sp. ($p = 0.005$; **Table 1.6**).

Discussion

My results suggest the existence of a host sex-biased parasitism towards ELOSH males. Although a large portion of the avian literature demonstrates no difference in parasitism between the two sexes (Valdebenito *et al.*, 2020), my results are not the first to contrast with the literature, as male-biased prevalence and abundance of endoparasites have been described in different bird species (Isomursu *et al.*, 2006; Robinson *et al.*, 2010). Similar to the mammalian literature (Moore and Wilson, 2002), some studies support the immunosuppressive effect of testosterone in males. Despite the potential differential effects of testosterone on immune function in birds as compared to mammals (Mougeot *et al.*, 2004), it is suggested that testosterone can suppress the immune function in birds through indirect pathways, as energy reallocation and elevated levels of

corticosterone (Owen-Ashley *et al.* 2004). Although it is argued that birds usually present an insufficient magnitude of sexual dimorphism to promote different levels of parasitism (Lindenfors *et al.*, 2007), it may not be the case for ELOSH, and further studies should investigate these differences. Additionally, it is important to note that these results may be relevant only to ELOSH in captivity and other *in situ* studies should be carried out as it has been suggested that female-biased dispersal can occur among wild birds (Greenwood, 1980) thus leading to greater parasitism among wild females (Trochet *et al.*, 2016; Li and Kokko, 2019).

The younger birds presented the highest prevalence for any parasite species and for *Capillaria* sp. Studies have reported the presence of juvenile-host biased parasitism (Potti and Merino, 1995; Hamstra and Badyaev, 2009) and that the younger individuals tend to be the most negatively affected by parasitic infections (Bais *et al.*, 2017), which can be explained by the naïve condition of the juveniles' immune system (Tolf *et al.* 2013). Moreover, the effects of ageing (senescence) are also deeply rooted in evolutionary research and outcomes such as a decline in immune response have been well-documented (Lavoie, 2006; Maklakov *et al.*, 2015; Flatt and Partridge, 2018). Although the oldest birds were not significantly more affected, to avoid type II errors the present results must be treated cautiously as it may be the result of not having records of older birds in the same abundance as the juveniles thus inflating the number of parasitological exams and the likelihood of positive results in younger birds.

Although no differences were found regarding parasitic intensity, a significantly higher prevalence of *Capillaria* sp. was observed among captive-born ELOSH, in comparison to wild-born ones. Contrary to my prediction, the captive-born birds were the most affected by parasitism. While wild-born individuals could present higher stress levels due to the changes in their environment (Christe *et al.*, 2006), the captive-born

ELOSH have more contact with humans (e.g., zookeepers) since their birth, which could also cause higher levels of stress and lower immune response to parasitic infections (Bais *et al.*, 2017). The encounter-dilution effect (Côté and Poulin, 1995) often explains a greater parasitism found in captive populations in comparison to wild ones (Haweley *et al.*, 2020) however, this is not applicable to the present study because only captive populations – of different sources of birth – were studied. Furthermore, in some *Capillaria* species, autoinfection with larvae appears to explain the constant infection (Mehlhorn, 2016) which is relevant to findings regarding captive populations.

Moreover, in the present study, it was not possible to evaluate the effects of the different parasiticide treatments due to a lack of available data. It would be of great interest to study the effects of the different parasiticide treatments and how the captive population has responded to them throughout the program. Nevertheless, this can be an important factor to be further explored in the ELOSH CBP because of the high financial cost of parasiticide treatments (Cruz *et al.*, 2016). Another point to consider is the extermination of parasites prior to releasing birds into the wild and if this practice would be harmful to the individuals once they are challenged by parasites in the natural environment, potentially causing deadly infections (Kołodziej-Sobocińska *et al.*, 2018). Additionally, it was challenging to determine the precision of parasite identification, which could be a venue for further studies, including identification through molecular techniques, along with the current microscopic identification of parasite eggs. The present study only examined records only from individuals kept in the CBP however, more research should be carried out to detect and describe the parasitofauna of free-ranging ELOSH.

Small sample sizes and difficulty in collecting data are some of the challenges that may arise when working with endangered species, particularly when collecting

experimental data from species with low numbers of existing individuals or those with high sensitivity to stress. An important approach for data acquisition is the use of observational retrospective studies but an unfortunate characteristic is the limited amount of information available and the impossibility of additional data collection, such that inferences from these data are also limited (Miller *et al.*, 2015; Globokar *et al.*, 2017). Nonetheless, retrospective studies must continue to be performed not only to improve the methodology of such approaches but also of the CBPs data collection and storage.

Parasitism in CBPs is not only a challenge but also may be one of the causes of failure in reintroduction programs of threatened or endangered species (Price and Soorae, 2003; Kock *et al.*, 2010; Mañas *et al.*, 2019). The common presence of parasites in *ex situ* institutions (e.g., zoos) highlights the need for more focused studies on the relationships between hosts and parasites in captive settings. Being aware that certain groups of a population (e.g., males) are more susceptible to parasitism can assist in the development of targeted treatment protocols, with the purpose of reducing costs and increasing the success of CBPs and zoos in conservation.

Chapter I - Tables and Figures

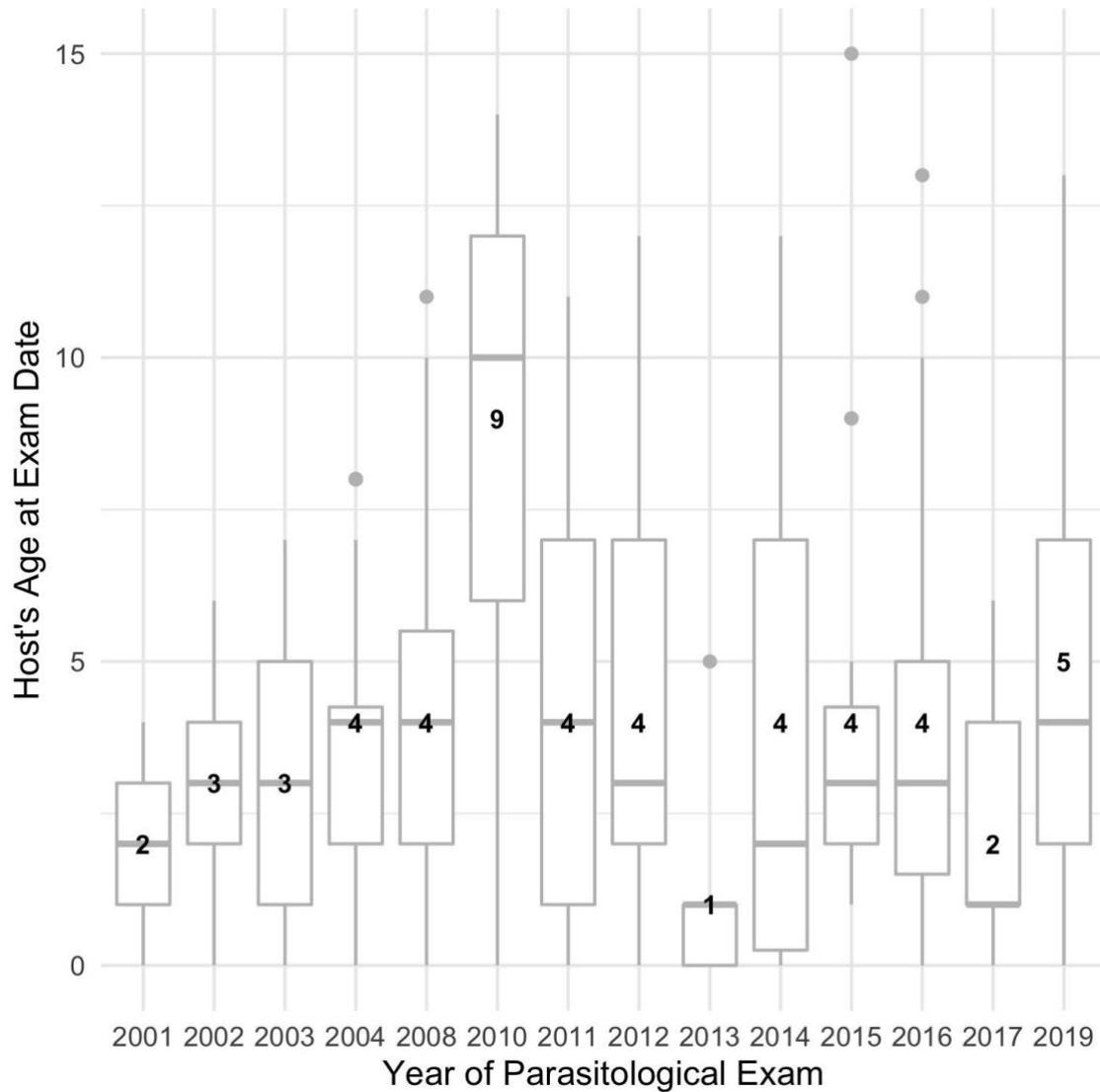


Figure 1.1. Age distribution of eastern-loggerhead shrikes (*Lanius ludovicianus* spp.) from the 1499 recorded observations (181 individuals), across each year included. Means of host's age at the exam date are highlighted per year.

Table 1.1. Parasitic measures of *Capillaria* sp. observed in eastern loggerhead shrike (*Lanius ludovicianus* spp.). All 1499 samples from 181 individuals were included, from the period of 1997 to 2019, across the analyzed groups: sex, source, and age class. Bold values indicate significant effects.

	Group	Samples	Infected samples	Prevalence (%)	Mean Intensity
Sex	female	882	55	6.2	3 ± 3
	male	606	68	11.2	5 ± 8
Source	captive	1002	138	12.3	5 ± 7
	wild	496	14	2.6	2 ± 2
Age Class	≤ 1 y.o.	360	69	19.2	5
	> 1 ≤ 4 y.o.	782	45	5.8	3.64
	> 4 y.o.	357	9	2.5	3.22

(y.o.) = years old.

Table 1.2. Parasitic measures of oxyurids observed in eastern loggerhead shrike (*Lanius ludovicianus* spp.). All 1499 samples from 181 individuals were included, from the period of 1997 to 2019, across the analyzed groups: sex, source, and age class.

Group	Samples	Infected samples	Prevalence (%)	Mean Intensity	
Sex	female	882	104	11.8	3 ± 4
	male	606	65	10.7	3 ± 3
Source	captive	1002	114	11.4	3 ± 4
	wild	496	55	11.1	3 ± 3
Age Class	≤ 1 y.o.	360	40	11.1	4
	> 1 ≤ 4 y.o.	782	93	11.9	3
	> 4 y.o.	357	36	10.1	4

(y.o.) = years old.

Table 1.3. Generalized linear mixed effect model results of each independent variable effect on the binomial presence of any parasite species in samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (1499 samples from 181 individuals). This interaction had marginal R^2 values of 0.05 (theoretical) and 0.03 (delta), conditional R^2 values of 0.17 (theoretical) and 0.09 (delta), and AIC 1474.26. Bold values indicate where p-values ≤ 0.05 .

Independent Variable	Estimate	Standard Error	z value	Pr (> z)
Intercept	-1.105	0.287	-3.854	<0.001
Host's sex (Male)	0.206	0.166	1.240	0.215
Host's Age	-0.184	0.054	-3.379	<0.001
Source of Birth of Host (Wild)	-0.107	0.233	-0.460	0.646
Julian Date of Exam	< -0.001	<0.001	-0.107	0.915
Year of Exam	-	-	-	-
Host's ID	-	-	-	-

Table 1.4. Generalized linear mixed effect model results of each independent variable effect on the binomial presence of *Capillaria* sp. in samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (1499 samples from 181 individuals). This interaction had marginal R² values of 0.17 (theoretical) and 0.07 (delta), conditional R² values of 0.47 (theoretical) and 0.19 (delta), and AIC 763.14. Bold values indicate where p-values ≤ 0.05 .

Independent Variable	Estimate	Standard Error	z value	Pr (> z)
Intercept	-2.254	0.501	-4.502	<0.001
Host's sex (Male)	0.380	0.310	1.227	0.220
Host's Age	-0.329	0.096	-3.428	<0.001
Source of Birth of Host (Wild)	-0.926	0.500	-1.854	0.064
Julian Date of Exam	0.001	0.001	0.789	0.430
Year of Exam	-	-	-	-
Host's ID	-	-	-	-

Table 1.5. Generalized linear mixed effect model results of each independent variable effect on the binomial presence of oxyurids in samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (1499 samples from 181 individuals). This interaction had marginal R^2 values of 0.010 (theoretical) and 0.003 (delta), conditional R^2 values of 0.397 (theoretical) and 0.137 (delta), and AIC value of 1040.51.

Independent Variable	Estimate	Standard Error	z value	Pr(> z)
Intercept	-2.658	0.644	-4.127	<0.001
Host's sex (Male)	-0.071	0.188	-0.380	0.704
Host's Age	-0.081	0.072	-1.126	0.260
Source of Birth of Host (Wild)	0.055	0.286	0.192	0.848
Julian Date of Exam	-0.001	0.001	-1.156	0.248
Year of Exam	-	-	-	-
Host's ID	-	-	-	-

Table 1.6. Linear mixed effect model results of each independent variable effect on the abundance of *Capillaria* sp. in samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (1499 samples from 181 individuals). This interaction had a marginal R^2 of 0.02, conditional R^2 of 0.11, and AIC value of 6564.09. Bold values indicate where p-values ≤ 0.05 .

Independent Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr(> t)
Intercept	0.635	0.227	0.286	2.795	0.009
Host's sex (Male)	0.346	0.161	0.509	2.152	0.036
Host's Age	-0.103	0.036	0.031	-2.842	0.005
Source of Birth of Host (Wild)	-0.120	0.201	0.615	-0.576	0.567
Julian Date of Exam	<0.001	<0.001	0.001	0.494	0.621
Year of Exam	-	-	-	-	-
Host's ID	-	-	-	-	-

Table 1.7. Linear mixed effect model results of each independent variable effect on the intensity of *Capillaria* sp. in infected samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (123 samples from 53 individuals). This interaction had a marginal R² of 0.06, conditional R² of 0.22, and AIC value of 815.73. Bold values indicate where p-values ≤ 0.05.

Independent Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr(> t)
Intercept	4.755	1.812	15.455	2.624	0.019
Host's sex (Male)	2.417	1.345	58.707	1.798	0.077
Host's Age	-0.173	0.356	109.279	-0.484	0.629
Source of Birth of Host (Wild)	-1.657	2.114	62.969	-0.784	0.436
Julian Date of Exam	-0.003	0.006	46.551	-0.502	0.618
Year of Exam	-	-	-	-	-
Host's ID	-	-	-	-	-

Table 1.8. Linear mixed effect model results of each independent variable effect on the abundance of oxyurids in samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (1499 samples from 181 individuals). This interaction had a marginal R^2 of 0.002, conditional R^2 of 0.017, and AIC value of 5636.54.

Independent Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr(> t)
Intercept	0.440	0.126	23.8	3.481	0.002
Host's sex (Male)	-0.026	0.086	72.1	-0.303	0.763
Host's Age	-0.019	0.024	319	-0.801	0.424
Source of Birth of Host (Wild)	0.016	0.111	120	0.141	0.888
Julian Date of Exam	<0.001	<0.001	1050	-0.895	0.371
Year of Exam	-	-	-	-	-
Host's ID	-	-	-	-	-

Table 1.9. Linear mixed effect model results of each independent variable effect on the intensity of oxyurids in infected samples of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH) from the captive breeding program from 1997 to 2019. The random effect variables were year of exam and host ID (169 samples from 56 individuals). This interaction had a marginal R^2 of 0.002, conditional R^2 of 0.071, and AIC value of 930.29.

Independent Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr (> t)
Intercept	3.26	0.765	0.118	4.264	0.001
Host's sex (Male)	0.031	0.591	0.330	0.053	0.958
Host's Age	-0.083	0.205	0.688	-0.403	0.688
Source of Birth of Host (Wild)	0.339	0.847	0.581	0.401	0.690
Julian Date of Exam	<0.001	0.003	0.016	0.102	0.919
Year of Exam	-	-	-	-	-
Host's ID	-	-	-	-	-

Literature Cited

- Altizer, S., D. Harvell, E. Friedle. (2003). Rapid evolutionary dynamics and disease threats to biodiversity. *Trends in Ecology and Evolution* 18:589–596
- Ashby, B., Bruns, E. (2018). The evolution of juvenile susceptibility to infectious disease. *Proceedings of the Royal Society B: Biological Sciences* 285, 2018084
- Bais, B., Tak, L., Mahla, S. (2017). Study of Preventive Health Measures for Wildlife in Captivity: A Review of Management Approaches. *International Journal of Avian and Wildlife Biology*, 2(3), 73–75. <https://doi.org/10.15406/ijawb.2017.02.00020>
- Bartoń, K. (2020). MuMIn: Multi-Model Inference. R package version 1.43.17. <https://CRAN.R-project.org/package=MuMIn>
- Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). *Fitting Linear Mixed-Effects*
- Ben-Ami, F. (2019). Host Age Effects in Invertebrates: Epidemiological, Ecological, and Evolutionary Implications. *Trends in Parasitology*, 35(6), 466–480.
- Benton, T. G. (2012). Individual variation and population dynamics: lessons from a simple system. *Philosophical Transactions of the Royal Society B* 367, 200–210
- Benton, T. G., Plaistow, S. J. and Coulson, T. N. (2006) ‘Complex population dynamics and complex causation: Devils, details and demography’, *Proceedings of the Royal Society B: Biological Sciences*, 273(1591), pp. 1173–1181. doi: 10.1098/rspb.2006.3495
- Bush, A. O., Lafferty, K. D., Lotz, J. M., Shostak, A. W. (1997). Parasitology Meets Ecology on Its Own Terms: Margolis *et al.* Revisited. *The Journal of Parasitology*, 83(4), 575–583. <https://doi.org/10.2307/3284227>

- Byers, O., Lees, C., Wilcken, J., Schwitzer, C. (2013) The One Plan approach: the philosophy and implementation of CBSG's approach to integrated species conservation planning. *WAZA Magazine* 14: 2–5
- Cade, T. J., Burnham, W. (2003). *Return of the Peregrine*. The Peregrine Fund, Boise, Idaho
- Christe, P., Giorgi, M. S., Vogel, P., Arlettaz, R. (2003). Differential species-specific ectoparasitic mite intensities in two intimately coexisting sibling bat species: Resource-mediated host attractiveness or parasite specialization? *Journal of Animal Ecology*, 72(5), 866–872. <https://doi.org/10.1046/j.1365-2656.2003.00759.x>
- Christe, P., Morand, S., Michaux, J. (2006). Biological conservation and parasitism. In: Morand S., Krasnov B.R., Poulin R. (eds) *Micromammals and Macroparasites*. Springer, Tokyo. https://doi.org/10.1007/978-4-431-36025-4_27
- Combes, C. (2005). *The Art of Being a Parasite* (trans. by D Simberloff). University of Chicago Press, Chicago
- Conde, D. A., Flesness, N., Colchero, F., Jones, O. R., Scheuerlein, A. (2011). 'An Emerging Role of Zoos to Conserve Biodiversity', *Science*, 331, pp. 1390–1391. doi: 10.1002/zoo.20369/abstract
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada). (2014) *Assessment and Status Report Loggerhead Shrike *Lanius ludovicianus**.
- Côté, I. M., Poulin, R. (1995). Parasitism and group size in social animals: a meta-analysis. *Behavioral Ecology*, 6, 159
- Cruz, C. E. F., Cerva, C., Andretta, I. (2016) Financial Costs of Conserving Captive-bred Wild Birds. *Zoologische Garten*. 85(6), pp. 354–362. doi: 10.1016/j.zoolgart.2016.08.003

- Degen A.A. (2006) Effect of macroparasites on the energy budget of small mammals. In: Morand S., Krasnov B.R., Poulin R. (eds) *Micromammals and Macroparasites*. Springer, Tokyo. https://doi.org/10.1007/978-4-431-36025-4_19
- Flatt, T. and Partridge, L. (2018) Horizons in the evolution of aging. *BMC Biology* 16, 93
- Globokar, M., Fischer, D. and Pantchev, N. (2017) 'Occurrence of endoparasites in captive birds between 2005 to 2011 as determined by faecal flotation and review of literature.', *Berliner Und Munchener Tierarztliche Wochenschrift*, 130(11–12), pp. 461–473. doi: 10.2376/0005-9366-16094
- Greenwood, P. J. (1980). Mating systems, philopatry and dispersal in birds and mammals. *Animal Behaviour* 28:1140–1162
- Hamstra, T. L. and Badyaev, A. V. (2009). Comprehensive Investigation of Ectoparasite Community and Abundance across Life History Stages of Avian Host. *Journal of Zoology*, 3:1-9
- Hawlana, H., Abramsky, Z., Krasnov, B.R. (2005). Age-biased parasitism and density-dependant distribution of fleas (Siphonaptera) on a desert rodent. *Oecologia (Berl.)*, 146: 200–208. doi:10.1007/s00442-005-0187-0
- Hawley, D. M., Gibson, A. K., Townsend, A. K., Craft, M. E., & Stephenson, J. F. (2020). Bidirectional interactions between host social behaviour and parasites arise through ecological and evolutionary processes. *Parasitology, Arrow D*. <https://doi.org/10.1017/S0031182020002048>
- Isomursu, M., Rätti, O., Helle, P., Hollmén, T. (2006). Sex and age influence intestinal parasite burden in three boreal grouse species. *J. Avian Biol.* 37: 516–522. doi:10.1111/j.2006.0908-8857.03838.x. Khokhlova, IUCN (World Conservation

- Union). 1998. Guidelines for re-introductions. IUCN/SSC Re-introduction Specialist Group, IUCN, Gland, Switzerland, and Cambridge, United Kingdom
- Khokhlova, I. S., Krasnov, B. R., Kam, M., Burdelova, N. I., Degen, A. A. (2002). Energy cost of ectoparasitism: The flea *Xenopsylla ramesis* on the desert gerbil *Gerbillus dasyurus*. *Journal of Zoology* 258:349–354
- Kock, R. A., Woodford, M. H., and Rossiter, P. B. (2010). Disease risks associated with the translocation of wildlife. *OIE Revue Scientifique et Technique*, 29(2), 329–350. <https://doi.org/10.20506/rst.29.2.1980>
- Kołodziej-Sobocińska, M., Demiaszkiewicz, A. W., Pyziel, A. M., and Kowalczyk, R. (2018). Increased Parasitic Load in Captive-Released European Bison (*Bison bonasus*) has Important Implications for Reintroduction Programs. *EcoHealth*, 15(2), 467–471. <https://doi.org/10.1007/s10393-018-1327-4>
- Kristan, D. M., and Hammond, K. A. (2004). Morphological plasticity varies with duration of infection: Evidence from lactating and virgin wild-derived house mice (*Mus musculus*) infected with an intestinal parasite (*Heligmosomoides polygyrus*; Nematoda). *Journal of Experimental Biology*, 207(13), 2351–2360. <https://doi.org/10.1242/jeb.01020>
- Kuhn, M. (2020). caret: Classification and Regression Training. R package version 6.0-86. <https://CRAN.R-project.org/package=caret>
- Lavoie, E. T. (2006). Avian immunosenescence. *AGE*, 27, 281–285. <https://doi.org/10.1007/s11357-005-4561-y>
- Li, X. Y., Kokko, H. (2019). Sex-biased dispersal: a review of the theory. *Biological Reviews*, 94(2), 721–736. <https://doi.org/10.1111/brv.12475>
- Lindenfors, P., Nunn, C. L., Jones, K. E., Cunningham, A. A., Sechrest, W., Gittleman, J. L. (2007). Parasite species richness in carnivores: Effects of host body mass,

- latitude, geographical range and population density. *Global Ecology and Biogeography*, 16(4), 496–509. <https://doi.org/10.1111/j.1466-8238.2006.00301.x>
- Mabry, K. E., Shelley, E. L., Davis, K. E., Blumstein, D. T., van Vuren, D. H. (2013). Social Mating System and Sex-Biased Dispersal in Mammals and Birds: A Phylogenetic Analysis. *PLoS ONE*, 8(3), 1–9. <https://doi.org/10.1371/journal.pone.0057980>
- Maklakov, A. A., Rowe, L., Friberg, U. (2015). Why organisms age: Evolution of senescence under positive pleiotropy? *Bioessays*, (37), 7, 802-807. <http://dx.doi.org/10.1002/bies.201500025>
- Meagher, S., Dudek, S. N. (2002). Effects of *Trichinella spiralis* on survival, total mass, and organ mass of old field mice (*Peromyscus polionotus*). *Journal of Parasitology*, 88(5), 833–838. <https://doi.org/10.2307/3285517>
- Mehlhorn, H. (2016). Encyclopedia of Parasitology. In *Encyclopedia of Parasitology* (3rd ed.). Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-662-43978-4>
- Mesquita, J., Esteves, F., Santos, C., Mega, C., Coelho, C., Cruz, R., Vala, H., and Vasconcelos-Nóbrega, C. (2017). ABC series on diagnostic parasitology part 1: the Willis method. *The Veterinary Nurse*, 8(7), 398–402
- Miller, D., Jackson, B., Riddle, H. S., Stremme, C., Schmitt, D., and Miller, T. (2015). Elephant (*Elephas maximus*) health and management in Asia: Variations in veterinary perspectives. *Veterinary Medicine International*, 2015, 19. <https://doi.org/10.1155/2015/614690>
- Moore, S. L., Wilson, K. (2002). Parasites as a viability cost of sexual selection in natural populations of mammals. *Science* (Washington, D.C.), 297: 2015–2018. doi:10.1126/science.1074196. PMID:12242433

- Mañas, E. M., Juan, M. G., Carnero, M. D. R. R. D. Y., Gilbert, T., Ortiz, J., Espeso, G., Benzal, J., Ibáñez, B., & Hernández, F. V. (2019). Survey of husbandry practices for bovidae in zoos: The importance of parasite management for reintroduction programmes. *Veterinary Record*, 184(9), 1–6. <https://doi.org/10.1136/vr.104985>
- Mougeot, F., Bretagnolle, V. (2006). Breeding biology of the Red Kite *Milvus milvus* in Corsica. *Ibis* 148:436–448.
- Novak, P.G. 1989. Breeding ecology and status of the Loggerhead Shrike (*Lanius ludovicianus*) in New York state. M.Sc. thesis, Cornell University, Ithaca, New York
- Munger, J. C., and Karasov, W. H. (1989). Sublethal Parasites and Host Energy Budgets : Tapeworm Infection in White-Footed Mice Author (s): James C . Munger and William H . Karasov Published by: Wiley Stable URL : <http://www.jstor.org/stable/1941358> REFERENCES Linked references are available o. 70(4), 904–921
- Norris, K., Evans MR. (2000). Ecological immunology: life history trade-offs and immune defense in birds. *Behavioural Ecology*. 11:19–26
- Ombugadu, A., Echor, B., Jibril, A. B., Angbalaga, G. A., Lapang, M. P., Micah, E. M., Njila, H .L., Isah, L., Nkup, C. D., Dogo, K. S., Anzaku, A. A. (2018). ‘Impact of Parasites in Captive Birds: A Review’, *Journal of Neurology, Psychiatry and Brain Research*, 2019(04), pp. 1–12
- Owen-Ashley, N. T., Hasselquist, D., Wingfield, J. C. (2004). Androgens and the Immunocompetence Handicap Hypothesis: Unraveling Direct and Indirect Pathways of Immunosuppression in Song Sparrows. *The American Naturalist*, 164(4), 490. <https://doi.org/10.2307/3473398>

- Palme, R., Rettenbacher, S., Touma, C., El-Bahr, S. M., and Möstl, E. (2005). Stress hormones in mammals and birds: Comparative aspects regarding metabolism, excretion, and noninvasive measurement in fecal samples. *Annals of the New York Academy of Sciences*, 1040, 162–171. <https://doi.org/10.1196/annals.1327.021>
- Parmley, E. J., Pearl, D. L., Vogt, N. A., Yates, S., Campbell, G. D., Steiner, J., Imlay, T. L., Hollamby, S., Tuininga, K., and Barker, I. K. (2015). Factors influencing mortality in a captive breeding population of Loggerhead Shrike, Eastern subspecies (*Lanius ludovicianus* ssp.) in Canada. *BMC Veterinary Research*, 11(1), 1–7. <https://doi.org/10.1186/s12917-015-0429-2>
- Potti J, Merino S (1995) Louse loads of pied flycatchers: effects of host's sex, age, condition and relatedness. *Journal of Avian Biology* 26:203–208. <https://doi.org/10.2307/3677320>
- Price, M. R. S., Soorae, P. S. (2003). Reintroductions: Whence and whither? *International Zoo Yearbook*, 38(1), 61–75. <https://doi.org/10.1111/j.1748-1090.2003.tb02065.x>
- R Core Team, (2020) [v 4.0.2] R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>
- Reiczigel, J, Marozzi, M, Fabian, I, Rozsa, L. (2019). Biostatistics for Parasitologists – A Primer to Quantitative Parasitology. *Trends in Parasitology*. 35(4): 277-281
- Robinson, S. A., Forbes, M. R., Hebert, C. E., McLaughlin, J. D. (2010). Male biased parasitism in cormorants and relationships with foraging ecology on Lake Erie, Canada. *Waterbirds*, 33(3), 307–313. <https://doi.org/10.1675/063.033.0306>
- RStudio Team. (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA. <http://www.rstudio.com/>

- Schwanz, L. E. (2008). Chronic parasitic infection alters reproductive output in deer mice. *Behavioural Ecology & Sociobiology*, 62:1351–1358.
- Sheldon B, Verhulst S. (1996). Ecological immunology: costly parasite defences and trade-offs in evolutionary ecology. *Trends in Ecology & Evolution*, 11(8):317–321.
- Sibley, D. A. (2016). *The Sibley field guide to Birds of Eastern North America*. 2nd edn. Edited by A. A. Knopf. New York.
- Simon, A. K., Hollander, G. A., McMichael, A., (2015). Evolution of the immune system in humans from infancy to old age. *Proceedings of the Royal Society B: Biological Sciences*, 282, 20143085. <https://doi.org/10.1098/rspb.2014.3085>.
- Tolf, C., Latorre-Margalef, N., Wille, M., Bengtsson, D., Gunnarsson, G., Grosbois, V., Hasselquist, D., Olsen, B., Elmberg, J., Waldenström, J. (2013). Individual Variation in Influenza A Virus Infection Histories and Long-Term Immune Responses in Mallards. *PLoS ONE*, 8(4). <https://doi.org/10.1371/journal.pone.0061201>
- Trochet, A., Stevens, V. M., & Baguette, M. (2016). Evolution of sex-biased dispersal. *The Quarterly Review of Biology*, 91(3), 297–320
- Valdebenito, J. O., Liker, A., Halimubieke, N., Figuerola, J., Székely, T. (2020). Mortality cost of sex-specific parasitism in wild bird populations. *Scientific Reports*, 10(1), 1–10. <https://doi.org/10.1038/s41598-020-77410-6>
- Ward, A. C. S., Hunter, D. L., Jaworski, M. D., Benolkin, P. J., Dobel, M. P., Jeffress, J. B., and Tanner, G. A. (1997). PASTEURILLA SPP. IN SYMPATRIC BIGHORN AND DOMESTIC SHEEP. *Journal of Wildlife Diseases*, 33(3), 544–557

- Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York
- Willis, H. H. (1921). A Simple Levitation Method for the Detection of Hookworm Ova. *Medical Journal of Australia*, 2(18), 375–376. <https://doi.org/10.5694/j.1326-5377.1921.tb60654.x>
- WPC (Wildlife Preservation Canada). (2015) HUSBANDRY MANUAL FOR THE CARE , BREEDING , AND MAINTENANCE OF CAPTIVE LOGGERHEAD SHRIKES (*Lanius ludovicianus alvarensis*)
- Yosef, R. (1996). ‘Loggerhead Shrike (*Lanius ludovicianus*)’, in Poole, A. and Gill, F. (eds) *The Birds of North America*. Philadelphia and Washington: The Academy of Natural Science and The American Ornithological Union
- Zuk, M., Stoehr, A. M. (2002). Immune defense and host life history. *The American Naturalist*. 160(4):9–S22
- Zuur, A. F., Ieno, E. N., Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* 1(1):3–14 DOI 10.1111/j.2041-210x.2009.00001.x

Chapter II:

Historical Analysis of

Breeding Success of Eastern

Loggerhead Shrikes (*Lanius*

ludovicianus spp.) with

Parasitic Infections in

Captive Populations in

Southeastern Canada

Abstract

Captive breeding programs (CBPs) can be applied in recovery efforts for threatened or endangered species, in face of the current biodiversity crisis faced worldwide. This study presents the case of the CBP of an endangered passerine species in southeastern Canada, the eastern loggerhead shrike (*Lanius ludovicianus* spp.; ELOSH). The objective was to study the effects of the prevalence and intensity of infection of endoparasites, especially *Capillaria* sp., on breeding success by analysing historical data. Among the 50 observations (n = 42 females) from 14 breeding seasons throughout 2001 to 2019, the number of eggs laid by ELOSH varied from 1 to 13 eggs per breeding season, with a mean of 6.3 ± 0.2 eggs, and the parasitic prevalence of *Capillaria* sp. eggs and oxyurids eggs in the parasitological exams were 10% and 6%, respectively. A significant relationship between reproductive output and the abundance of *Capillaria* sp. was observed, while age and source of birth had no significant effect in any of the models proposed here. This negative effect on reproductive output highlights the importance of parasitic management in CBPs, especially in cases of endangered species, where it is essential to prevent any further threats to an already scarce population.

Key Words: bird reproduction, *Capillaria*, parasitology, endangered passerines, zoo research

Introduction

As the threats to biodiversity increase, so does the number of endangered species in need of recovery programs (Collen *et al.*, 2009; Butchart *et al.*, 2010). Captive breeding programs (CBPs) are broadly used as part of recovery efforts for threatened or endangered species to maintain, re-establish or augment wild populations within their historic range (Conde *et al.*, 2011; Pritchard *et al.*, 2011; Ostermann *et al.*, 2001; Wolf *et al.*, 1996). In the IUCN Red List reassessments, 13 of the 68 species listed have shown a status improvement with the implementation of a CBP (Hoffmann *et al.*, 2010; Conde *et al.*, 2011). The CBPs pose a feasible option to avoid the extinction of a species until appropriate habitat can be found or restored (Collen *et al.*, 2009; Butchart *et al.*, 2010; Conway, 2010; Conde *et al.*, 2011; Pritchard *et al.*, 2011). Moreover, it is important to account for diseases and parasites when studying the causes of decline of threatened populations (Christe *et al.*, 2006), particularly for rare and endangered species whose survival is one of the main issues in conservation programs (Viggers *et al.*, 1993; Pucek *et al.*, 2004).

Parasitic infections are amongst the challenges faced by CBPs and their impact must be taken into account in conservation and reintroduction programs (Kołodziej-Sobocińska *et al.*, 2018). Parasites can live in (endo) or on (ecto) their hosts (e.g., birds) and are responsible for negatively affecting their host (Combes, 2005). Parasitism can lead to restriction of growth and reproductive functions, for example by direct damage or a decrease in available nutrients (Sheldon and Verhulst 1996; Norris and Evans 2000; Zuk and Stoehr 2002; Schwanz, 2008). Endoparasites can compete with the host for nutrients and, in the case of intestinal helminth worms, can damage the gastrointestinal tract as well as trigger an immune response (Degen, 2006). Parasites can reduce their host fitness by consumption of the host's rather limited resources that may have been allocated

from other functions, such as the reproductive one (Bonds, 2006; Mageroy et al., 2011). The impacts of parasitism can manifest cumulatively on the host's lifetime reproductive success (Brown et al., 1995; Metcalfe and Monaghan, 2001) or in the short-term with reduced brood sizes and fledgling survival (Marzal et al., 2005; Patterson et al., 2013; Holand et al., 2015).

The present study is based on the eastern loggerhead shrike CPB (*Lanius ludovicianus spp.*; ELOSH), an endangered passerine whose population has suffered a large-scale decline and range contractions since the 1970s (Miller, 1931). In Canada, it is currently only reliably found in southern Ontario (< 100 individuals) and intermittently in southwestern Québec (< 10 individuals, COSEWIC, 2014). According to the ELOSH Husbandry Manual (WPC, 2015), the ELOSH Recovery Program works towards rebuilding the Ontario population where the majority of their wild individuals remain by conducting captive breeding and subsequent releases. In the ELOSH CPB, parasitism cases have often been described, with a noticeably elevated mention of *Capillaria sp.* (WPC, 2015). Nonetheless, the potential negative effects of this parasite on the ELOSH breeding success are yet to be studied.

In a breeding season, ELOSH females generally lay one egg per day until the full clutch is produced (4 to 7 eggs) and the incubation period starts; the female spends at least 75% of her time on the nest (WPC, 2015). A classical and frequent approach to measure breeding success is to estimate the number of offspring produced (Howard, 1978; Holand et al., 2015). In bird studies, a commonly used metric is the number of eggs laid per nest (Masello and Quillfeldt, 2003). My general objective here was to describe and quantify the reproductive output of females in the ELOSH CBP with reference to age and source of birth of dams. Because of the great impact that parasitic infections can have on breeding success, as they are linked with poor health quality and energy redirection

(Kołodziej-Sobocińska *et al.*, 2018), I hypothesized that parasitized ELOSH females would have their reproductive output affected, and thus reduced egg production would be observed.

When studying breeding success, some factors additional to the parasitism effects must be considered (Holand *et al.*, 2015). Captive individuals have been observed to be more likely to be parasitized than their wild counterparts (Ombugadu *et al.*, 2018; Kołodziej-Sobocińska *et al.*, 2018). Although the same protocol is applied to both captive- and wild-born individuals in the ELOSH CBP, the birth source of an individual could be responsible for differences in their immune system throughout life (Palme *et al.*, 2005; Christe *et al.*, 2006). Moreover, as captive-born ELOSH have more contact with humans (e.g., zookeepers) since their birth, they could present lower immune response to infections due to higher levels of stress (Bais *et al.*, 2017); I predicted that captive-born individuals would be more often and heavily parasitized, resulting in lower breeding success.

Age is one of the most acute aspects of phenotypic variation within a population (Benton, 2012). It is an essential component of epidemiological analysis because of its strong influence on disease dynamics (Ben-Ami, 2019; Benton *et al.*, 2006). Many studies report a positive correlation of age and breeding success in birds (Nol and Smith, 1987; Hatch and Westneat, 2007; Bouwhuis *et al.*, 2012). This can be explained by the increased and improved experience of older individuals and because they tend to invest more in a breeding season than younger individuals, because they might not survive to breed again in future years, while it is more probable that the younger counterparts have more breeding opportunities (Forslund and Pärt, 1995). However, with the increasing adult age a decline in body function and immune response can be observed (Simon *et al.*, 2015); older individuals may also become more susceptible to diseases (Ben-Ami, 2019) which

can interfere with their reproductive success. Specifically, Imlay *et al.* (2017) revealed that captive female ELOSH had the highest reproductive success during their mid-life (between 2-10 years of age), while both experienced male and female shrikes had higher fledgling success than individuals that had never bred before. Therefore, I predicted that adult females (2 to 10 years old) would have the highest egg production.

Material and Methods

Pre-study methodology and data collection

The ELOSH CBP has been housed by several institutions throughout the decades of the program. In each facility, every year, key dates are recorded, including date and nature of first courtship behaviour, first nest building, start of incubation, hatching, fledgling, and dates of nest checks (along with the size of clutches). The present study was conducted by collection of hardcopy and electronic files provided by Wildlife Preservation Canada (WPC), and two zoological institutions, the Toronto Zoo (TZ), and African Lion Safari (ALS), from the period of 1997 to 2019. The host's individual information collected were host ID number, host date of birth, host's source of birth (Captive / Wild born), and sex (Female / Male). The measure for reproductive output was the number of eggs laid per individual per breeding season. As for the parasitology evaluations and records, the measures were date of sample collection, method of parasitological exam, described species of eggs found in each slide of the parasitological evaluation, number of eggs of each parasitic species per slide observed, and facility where the individual was housed at the time. The quantitative descriptors of the parasite

populations were presence (binomial response representing positive (1) and negative (0) results of each parasitology examination), prevalence (percentage of positive results among the total number of examinations), abundance (number of parasites of a particular species in a host), mean abundance (abundance divided by the total number of parasitology examinations), intensity (number of parasites of a particular species in an infected host), and mean intensity (intensity divided by the total number of infected hosts), as defined by Bush *et al.* (1997).

Only females were included, as breeding success measurements were related to female reproductive parameters. Only parasitological examinations performed with the floatation method (also known as the Willis method; Willis, 1921) were included for consistency of results. There were no observations from the years 1997 to 2000, 2005 to 2007, and 2018 so this study included 50 observations from 42 females across 14 breeding seasons.

Statistical analysis

Statistical analyses were conducted in R (R Core Team, 2020 [v 4.0.2]), using base R, and packages ‘lme4’ (Bates *et al.*, 2015 [v 1.1-23]), ‘caret’ (Kuhn, 2020 [v 6.0-86]), and ‘ggplot2’ (Wickham, 2016 [v 3.2.1]). Two linear mixed effect models were performed to study the effects of parasitic infections on the breeding success of ELOSH in their CBP. In the first model, the predictor variables included were: host age, host’s source of birth (captive or wild), host ID, year of sampling, presence (binomial) of *Capillaria* sp., and presence of oxyurids. The second model was similar, but with the parasitic measures of abundance (quantitative) of *Capillaria* sp. and of oxyurids, instead of presence. In both models the variables host ID and year of sample collection were

selected as random variables, in order to control for the fact that records of the same host are included from different years.

The response variable was transformed to its square root to meet normality assumptions, with a Shapiro-Wilk normality test result of $p = 0.097$. A multi-level approach was selected to account for potential factors present and the model assumptions for each model were tested using a residual vs. fitted values plot, residual QQ plot, and residual histogram. To investigate collinearity of predictors, a VIF (variance inflation factor) test was performed, in which variables < 2 were kept as the absence of collinearity between predictors was confirmed, as suggested by Zuur *et al.* (2010).

Results

With regards to source of birth, a total of 42 observations (34 individuals) were born in captivity and 8 observations (8 individuals) were wild born. The age of the individuals varied from <1 to 10 years old, with a mean age of 4.3 ± 2.6 years old. The number of eggs laid varied from 1 to 13 eggs per breeding season, with a mean of 6.3 ± 0.2 eggs while the number of hatched eggs had a mean of 4.2 ± 0.2 and the number of fledgelings had a mean of 2.8 ± 2.8 .

The parasitic prevalence of *Capillaria* sp. and oxyurids in the parasitological exams were 10% and 6%, respectively. I only observed a significant effect of the abundance of *Capillaria* sp. on the female reproductive output ($p = 0.049$; **Table 2.1**), with a weak negative effect. The presence of *Capillaria* sp. also presented a negative effect, with moderate effect size, however non-significant ($p = 0.076$; **Table 2.2**). **Error! Reference source not found.** None of the other variables, in either model, showed any significance on yearly egg production of ELOSH in the CBP.

Discussion

From the two statistical models proposed here, abundance of *Capillaria* sp. was the only statistically significant variable associated with the female reproductive output. Yet, the information from each model can complement each other to describe the effects of prevalence and abundance of *Capillaria* sp. in this study. These results corroborate with other studies reporting the effects of parasitism in avian hosts' reproductive output, for example house martins (*Delichon urbica*; Marzal et al., 2005) and the European shag (*Phalacrocorax aristotelis*; Reed et al., 2008).

The negative effects of *Capillaria* sp. can be explained by two main theories. First, during active breeding season, the individuals' resources may be allocated to reproduction functions rather than the immune response (Sheldon and Verhulst, 1996), potentially making the host more susceptible to parasitism. Hanssen *et al.* (2005) describes this as an increased reproductive investment causing reduced fitness. On the other hand, females may present increased food ingestion and a relatively larger size during reproduction, thus increasing their chance of infection via alimentary route and becoming more prone to parasitic infections (Moore and Wilson, 2002; Davies and Deviche, 2014).

The other group of parasites observed in ELOSH reports were from the family Oxyuridae. Their specific identification has proven to be challenging because it is not possible through microscopic examination alone and is often described solely as "mouse pinworm" in parasitic examinations. Also known as spurious parasites, the oxyurid eggs have occasionally been detected in parasitological examinations of carnivorous birds (Globokar et al., 2017). Accordingly, parasitological examinations of such birds should be carried out considering the similarities of avian parasites and the ones of their prey (e.g., rodents; Papini et al., 2012), and when possible, having a repeated sampling

schedule can assist in the diagnosis of parasitology diseases (Globokar et al., 2017). The presence of oxyurids has previously been observed in ELOSH, but anecdotally considered non harmful and suggested to occur primarily due to their presence in the diet (e.g., mice; see WPC, 2015, for detailed nutrition guideline). The lack of significance of oxyurids in the present study corroborates to the previous anecdotal information. However, more research would be required to investigate the potential negative effects on the ELOSH prey, which could impact their nutritional contribution (Pritchett and Johnston, 2002; Bairagi and Adak, 2015) and have further negative effects on reproductive output.

Age did not show any significant relationship with female reproductive output contrary to other bird studies (Nol and Smith 1987; Hatch and Westneat 2007; Reitsma *et al.* 2008; Bouwhuis *et al.* 2012; Imlay *et al.* 2017). In particular, the discrepancy with the results from Imlay *et al.* (2017) on the same population could be caused by the different variables and models studied, but also could indicate that the time frames analyzed present different results. Furthermore, the prediction that captive born individuals would be associated with greater parasitic prevalence and intensity was not held up by the results from either of the proposed models. The lack of difference between these groups may be due to the fact that only breeding females were included in this study, whereas the addition of males could promote different results. It is greatly encouraged that other studies investigate the male interaction in the breeding success, considering the theories of host sex-biased parasitism (Cozzarolo *et al.*, 2019).

Studies conducted in zoos often include small sample sizes, which can lead to extremely low power and often make it impossible to achieve statistically significant results, thus failing to find significant differences when they actually exist (Type II error; Kuhar, 2006). Despite the fact that small sample sizes can be challenging and make it harder to ascertain existing relationships, it does not invalidate differences found, even

when not necessarily significant, if enough care is taken when analyzing results, as also suggested by Kuhar (2006). While at the moment it was not possible to increase the sample size, it was possible to carefully tailor inferences on the results presented here.

Furthermore, regardless of how successful a CBP may be, if the information is not recorded nor accessible, it is impossible to study the actual benefits of such programs, even less so to make improvements on them. The fragile condition of threatened species makes every step even more critical to a successful program and species conservation. Directions to CBPs include digitizing and centralizing all data pertaining to the program. It would also be beneficial to have more details on the sampling, for example, an individual whose fecal sample was collected during a quarantine period (e.g., after transfers), could inflate the parasitic prevalence or mean intensity of the group. Finally, considering the ongoing presence of *Capillaria* and its negative effects, it is imperative that further research addresses which species of the genus is present in the program, allowing to identify their specific life cycle and transmission. For instance, molecular analyses are able to resolve taxonomic uncertainties and provide valuable information on parasites, such as life cycle and host specificity (Schrenzel *et al.*, 2005; Knight *et al.* 2018), useful information to build a better targeted parasite management protocol.

This research highlights the critical importance of historical analysis in directing future actions, for example in areas regarding parasite management, breeding success, and reintroduction decision making. Such data are vital in monitoring individuals and populations before, during and after reintroductions or translocations (Beck *et al.*, 1993; Gilmartin *et al.*, 1993; Petrzalkova *et al.*, 2006; Spalding and Forrester, 1993). Exploring the effects of parasitism on reproductive success, while considering and/or controlling for biological variables (e.g., age), can provide useful information, as parasitology status alone may not be enough to provoke negative effects on breeding success (Howe, 1992),

thus more knowledge of the individual's condition is required to best assess their likelihood to be more parasitized and how will affect their breeding success. Detecting and better understanding the challenging factors that can lead to the failure of a species recovery program is paramount to improve such programs and advance biodiversity conservation.

Chapter II - Tables and Figures

Table 2.1. Linear mixed effect model results of each independent variable effect on the square root of the egg production of females of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH), from the captive breeding program from 2001 to 2019. The random effect variables were year of exam and host ID (50 samples from 42 individuals). This interaction had a marginal R^2 of 0.07, conditional R^2 of 0.59, and AIC value of 95.63. Bold values indicate where p-values ≤ 0.05 .

Predictor Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr (> t)
Intercept	2.439	0.203	19.090	11.989	<0.001
Host's Age	0.015	0.031	42.248	0.488	0.628
Source of Birth of Host (Wild)	0.048	0.245	44.853	0.195	0.846
Density of <i>Capillaria</i> sp	-0.104	0.051	39.848	-2.031	0.049
Density of oxyurids	0.069	0.108	34.738	0.64	0.526
Year of Sampling	-	-	-	-	-
Host's ID	-	-	-	-	-

Table 2.2. Linear mixed effect model results of each independent variable effect on the square root of the egg production of females of eastern loggerhead shrikes (*Lanius ludovicianus* spp.; ELOSH), from the captive breeding program from 2001 to 2019. The random effect variables were year of exam and host ID (50 samples from 42 individuals). This interaction had a marginal R^2 of 0.06, conditional R^2 of 0.66, and AIC value of 95.63.

Predictor Variable	Estimate	Standard Error	Degrees of Freedom	t value	Pr (> t)
Intercept	2.451	0.220	15.241	11.200	<0.001
Host's Age	0.019	0.031	39.598	0.601	0.551
Source of Birth of Host (Wild)	0.060	0.250	43.436	0.241	0.811
Presence of <i>Capillaria</i> sp	-0.490	0.269	43.403	-1.821	0.076
Presence of oxyurids	0.145	0.271	35.195	0.535	0.596
Year of Sampling	-	-	-	-	-
Host's ID	-	-	-	-	-

Literature Cited

- Bairagi, N. and Adak, D. (2015) 'Complex dynamics of a predator-prey-parasite system: An interplay among infection rate, predator's reproductive gain and preference', *Ecological Complexity*. Elsevier B.V., 22, pp. 1–12. doi: 10.1016/j.ecocom.2015.01.002
- Bartoń, K. (2020). MuMIn: Multi-Model Inference. R package version 1.43.17. <https://CRAN.R-project.org/package=MuMIn>
- Bates, D., Maechler, M., Bolker, M., Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1-48. doi:10.18637/jss.v067.i01
- Beck, B., Cooper, M., Griffith, B. (1993). Working group report: Infectious disease considerations in reintroduction programs for captive wildlife. *Journal of Zoo and Wildlife Medicine*, 24(3), 394–397
- Ben-Ami, F. (2019). Host Age Effects in Invertebrates: Epidemiological, Ecological, and Evolutionary Implications. *Trends in Parasitology*, 35(6), 466–480. <https://doi.org/10.1016/j.pt.2019.03.008>
- Benton, T. G. (2012). Individual variation and population dynamics: lessons from a simple system. *Philosophical Transactions of the Royal Society B*, 367, 200–210
- Benton, T. G., Plaistow, S. J., Coulson, T. N. (2006). Complex population dynamics and complex causation: Devils, details and demography. *Proceedings of the Royal Society B: Biological Sciences*, (1591) 273, 1173–1181. <https://doi.org/10.1098/rspb.2006.3495>

- Bonds, M. H. (2006). Host life-history strategy explains pathogen-induced sterility. *The American Naturalist*, 168(3):281–93. doi: 10.1086/506922 PMID: WOS:000240600200001
- Bouwhuis, S., Choquet, R., Sheldon, B.C., and Verhulst, S. (2012). The forms and fitness cost of senescence: age-specific recapture, survival, reproduction, and reproductive value in a wild bird population. *The American Naturalist*, 179: E15–E27. doi:10.1086/663194. PMID:22173469
- Brown, C. R., Brown, M. B., Rannala, B. (1995). Ectoparasites reduce long-term survival of their avian host. *Proceedings of the Royal Society of London B: Biological Sciences*, 262(1365):313–9. PMID: ISI:A1995TQ73800009
- Bush, A. O., Lafferty, K. D., Lotz, J. M., Shostak, A. W. (1997). Parasitology Meets Ecology on Its Own Terms: Margolis *et al.* Revisited. *The Journal of Parasitology*, 83(4), 575–583. <https://doi.org/10.2307/3284227>
- Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., *et al.* (2010) Global biodiversity: indicators of recent declines. *Science*, 328: 1164–1168
- Christe, P., Morand, S., Michaux, J. (2006). Biological conservation and parasitism. In: Morand S., Krasnov B.R., Poulin R. (eds) *Micromammals and Macroparasites*. Springer, Tokyo. https://doi.org/10.1007/978-4-431-36025-4_27
- Collen, B., Loh, J., Whitmee, S., McRae, L., Amin, R., Baillie, J. E. M. (2009). Monitoring Change in Vertebrate Abundance: The Living Planet Index. *Conservation Biology*, 23(2), 317–327. <https://doi.org/10.1111/j.1523-1739.2008.01117.x>
- Combes, C. (2005). *The Art of Being a Parasite* (trans. by D Simberloff). University of Chicago Press, Chicago

- Conde, D. A., Flesness, N., Colchero, F., Jones, O. R., Scheuerlein, A. (2011). 'An Emerging Role of Zoos to Conserve Biodiversity', *Science*, 331, pp. 1390–1391. doi: 10.1002/zoo.20369/abstract
- Conway, W. G. (2010) Buying time for wild animals with zoos. *Zoo Biology* 30: 1– 8
- COSEWIC (2014) Assessment and Status Report Loggerhead Shrike *Lanius ludovicianus*
- Cozzarolo, C. S., Sironi, N., Glaizot, O., Pigeault, R., Christe, P. (2019). Sex-biased parasitism in vector-borne disease: Vector preference? *PLoS ONE*, 14(5), 1–11. <https://doi.org/10.1371/journal.pone.0216360>
- Davies, S., Deviche, P. (2014). At the crossroads of physiology and ecology: Food supply and the timing of avian reproduction. *Hormones and Behavior*, 66(1), 41–55. <https://doi.org/10.1016/j.yhbeh.2014.04.003>
- Degen, A. A. (2006) Effect of macroparasites on the energy budget of small mammals. In: Morand S., Krasnov B.R., Poulin R. (eds) *Micromammals and Macroparasites*. Springer, Tokyo. https://doi.org/10.1007/978-4-431-36025-4_19
- Forslund, P., and Pärt, T. 1995. Age and reproduction in birds — hypotheses and tests. *Trends Ecol. Evol.* 10: 374–378. doi:10.1016/S0169-5347(00)89141-7. PMID: 21237076
- Gilmartin, W., Jacobson, E., Karesh, W., Woodford, M. (1993). Working group report: monitoring, investigation, and surveillance of disease in free-ranging wildlife. *Journal of Zoo and Wildlife Medicine*, 24:389–393
- Globokar, M., Fischer, D., Pantchev, N. (2017). Occurrence of endoparasites in captive birds between 2005 to 2011 as determined by faecal flotation and review of literature. *Berliner Und Munchener Tierarztliche Wochenschrift*, 130(11–12), 461–473. <https://doi.org/10.2376/0005-9366-16094>

- Hanssen, S. A., Hasselquist, D., Folstad, I., Erikstad, K. E. (2005). Cost of reproduction in a long-lived bird: Incubation effort reduces immune function and future reproduction. *Proceedings of the Royal Society B: Biological Sciences*, 272, 1039–1046. <https://doi.org/10.1098/rspb.2005.3057>
- Hatch, M. I., Westneat, D. F. (2007). Age-related patterns of reproductive success in house sparrows *Passer domesticus*. *Journal of Avian Biology*. 38: 603–611. [doi:10.1111/j.0908-8857.2007.04044.x](https://doi.org/10.1111/j.0908-8857.2007.04044.x)
- Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., Carpenter, K. E., Chanson, J., Collen, B., Cox, N. A., Darwall, W. R. T., Dulvy, N. K., Harrison, L. R., Katariya, V., Pollock, C. M., Quader, S., Richman, N. I., Rodrigues, A. S. L., Tognelli, M. F., Stuart, S. N. (2010). The impact of conservation on the status of the world's vertebrates. *Science*, (6010)330, 1503–1509. <https://doi.org/10.1126/science.1194442>
- Holand, H., Jensen, H., Tufto, J., Pärn, H., Sæther, B. E., Ringsby, T. H. (2015). Endoparasite infection has both short- and long-term negative effects on reproductive success of female house sparrows, as revealed by faecal parasitic egg counts. *PLoS ONE*, 10(5), 1–12. <https://doi.org/10.1371/journal.pone.0125773>
- Howard, R. D. (1978). Estimating Reproductive Success in Natural Populations. *The American Naturalist*, 114(2), 221–231. [doi: 10.1086/283470](https://doi.org/10.1086/283470)
- Howe, F. P. (1992). Effects of *Protocalliphora braueri* (Diptera: Calliphoridae) parasitism and inclement weather on nestling sage thrashers. *Journal of Wildlife Diseases*, 28(1), 141–143. <https://doi.org/10.7589/0090-3558-28.1.141>
- Imlay, T. L., Steiner, J. C., Bird, D. M. (2017). Age and experience affect the reproductive success of captive loggerhead shrike (*Lanius ludovicianus*) subspecies. *Canadian Journal of Zoology*, 95(8), 547–554. <https://doi.org/10.1139/cjz-2015-0169>

- Knight, A. *et al.* (2018) The Evolutionary Biology, Ecology and Epidemiology of Coccidia of Passerine Birds. 1st edn, Advances in Parasitology. 1st edn. Elsevier Ltd. doi: 10.1016/bs.apar.2018.01.001
- Kołodziej-Sobocińska, M., Demiaszkiewicz, A. W., Pyziel, A. M., Kowalczyk, R. (2018). Increased Parasitic Load in Captive-Released European Bison (*Bison bonasus*) has Important Implications for Reintroduction Programs. *EcoHealth*, 15(2), 467–471. <https://doi.org/10.1007/s10393-018-1327-4>
- Kuhar, C. W. (2006). In the deep end: Pooling data and other statistical challenges of zoo and aquarium research. *Zoo Biology*, 25, pp. 339–352. doi: 10.1002/zoo.20089.
- Kuhn, M. (2020). caret: Classification and Regression Training. R package version 6.0-86. <https://CRAN.R-project.org/package=caret>
- Mageroy, J. H., Grepperud, E. J., Jensen, K. H. (2011). Who benefits from reduced reproduction in parasitized hosts? An experimental test using the *Pasteuria ramosa-Daphnia magna* system. *Parasitology*, 138 (14), 1910–5. doi: 10.1017/s0031182011001302 PMID: WOS:000298284500010
- Marzal, A., de Lope, F., Navarro, C., Møller, A. P. (2005). Malarial parasites decrease reproductive success: an experimental study in a passerine bird. *Oecologia*. 142(4):541–5. doi: 10.1007/s00442-004-1757-2 PMID: WOS:000226766400005
- Masello, J. F. and Quillfeldt, P. (2003). Body size, body condition and ornamental feathers of Burrowing Parrots: Variation between years and sexes, assortative mating and influences on breeding success. *Emu*, 103(2), 149–161. doi: 10.1071/MU02036
- Metcalf, N. B., Monaghan, P. (2001) Compensation for a bad start: grow now, pay later? *Trends in Ecology & Evolution*, 16(5), 254–60. doi: 10.1016/s0169-5347(01)02124-3 PMID: WOS:000168454200014

- Miller, A. H. (1931). Systematic revision and natural history of the American shrikes (*Lanius*). University of California Publications in Zoology, 38, 11-242
- Moore, S.L., and Wilson, K. (2002). Parasites as a viability cost of sexual selection in natural populations of mammals. Science (Washington, D.C.), 297, 2015–2018. doi:10.1126/science. 1074196. PMID:12242433
- Nol, E., Smith, J. N. M. (1987). Effects of age and breeding experience on seasonal reproductive success in the Song Sparrow. Journal of Animal Ecology, 56, 301–313. doi:10.2307/4816
- Norris, K., Evans, M. R. (2000). Ecological immunology : life history trade-offs and immune defense in birds. Behavioral Ecology, 11(1), 19–26
- Ombugadu, A., Echor, B., Jibril, A. ., Angbalaga, G., Lapang, M., Micah, E., Njila, H., Isah, L., Nkup, C., Dogo, K., Anzaku, A. (2018). Impact of Parasites in Captive Birds : A Review. Journal of Neurology, Psychiatry and Brain Research, 2019(04), 1–12
- Ostermann, S., Deforge, J., Edge, D., (2001). Captive breeding and reintroduction evaluation criteria: a case study of Peninsular bighorn sheep. Conservation Biology, 15, 749–760
- Palme, R., Rettenbacher, S., Touma, C., El-Bahr, S. M., and Möstl, E. (2005). Stress hormones in mammals and birds: Comparative aspects regarding metabolism, excretion, and noninvasive measurement in fecal samples. Annals of the New York Academy of Sciences, 1040, 162–171. <https://doi.org/10.1196/annals.1327.021>
- Papini, R., Girivetto, M., Marangi, M., Mancianti, F., Giangaspero, A. (2012). Endoparasite infections in pet and zoo birds in Italy. The Scientific World Journal, 2012. <https://doi.org/10.1100/2012/253127>

- Patterson, J. E. H., Neuhaus, P., Kutz, S. J., Ruckstuhl, K. E. (2013). Parasite removal improves reproductive success of female north american red squirrels (*Tamiasciurus hudsonicus*). Plos One, 8(2). doi: 10.1371/journal.pone.0055779
- Petrzelkova, K. J., Hasegawa, H., Moscovice, L. R., Kaur, T., Issa, M., Huffman, M. A. (2006). Parasitic nematodes in the chimpanzee population on Rubondo Island, Tanzania. International Journal of Primatology, 27(3), 767–777. <https://doi.org/10.1007/s10764-006-9043-2>
- Pritchard, D. J., Fa, J. E., Oldfield, S., Harrop, S. R. (2011). Bring the captive closer to the wild: redefining the role of ex situ conservation. Oryx, 46, 18–23
- Pritchett, K. R. and Johnston, N. A. (2002). A Review of Treatments for the Eradication of Pinworm Infections from Laboratory Rodent Colonies. Contemporary Topics in Laboratory Animal Science, 41(2), 36–46
- Pucek, Z., Belousova, I. P., Krasin' ska, M., Krasin' ski, Z. A., Olech, W. (2004). European bison. Status Survey and Conservation Action Plan. IUCN/SSB Bison Specialist Group IUCN, ix + 54., Gland, Switzerland: Cambridge
- R Core Team (2020) [v 4.0.2] R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>
- Reed, T. E., Daunt, F., Hall, M. E., Phillips, R. A., Wanless, S., Cunningham, E. J. A. (2008). Parasite treatment affects maternal investment in sons. Science, 321(5896):1681–2. doi: 10.1126/science.1159466 PMID: WOS:000259300400037
- Reitsma, L.R., Hallworth, M.T., and Benham, P.M. (2008). Does age influence territory size, habitat selection, and reproductive success of male Canada Warblers in

- central New Hampshire? *Wilson Journal of Ornithology*, 120, 446–454. doi:10.1676/07-109.1
- Schrenzel, M. D., Maalouf, G. A., Gaffney, P. M., Tokarz, D., Keener, L. L., McClure, D., Griffey, S., McAloose, D., Rideout, B. A. (2005). Molecular characterization of isosporoid coccidia (*Isospora* and *Atoxoplasma* spp.) in passerine birds. *Journal of Parasitology*, 91(3), 635–647. <https://doi.org/10.1645/GE-3310>
- Schwanz, L. E. (2008). Chronic parasitic infection alters reproductive output in deer mice. *Behavioral Ecology & Sociobiology*, 62, 1351–1358
- Simon, A. K., Hollander, G. A., McMichael, A., 2015. Evolution of the immune system in humans from infancy to old age. *Proceedings of the Royal Society B: Biological Sciences*, 282. <https://doi.org/10.1098/rspb.2014.3085>
- Spalding, M. G., Forrester, D. J. (1993). Disease Monitoring of Free-Ranging and Released Wildlife. *Journal of Zoo and Wildlife Medicine*, 24(3), 271–280.
- Viggers, K. L., Lindenmayer, D. B., Spratt, D. M. (1993). The importance of disease in reintroduction programs. *Wildlife Research*, 20(5), 687–698. <https://doi.org/10.1071/wr9930687>
- Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. ISBN 978-3-319-24277-4, <https://ggplot2.tidyverse.org>.
- WPC (Wildlife Preservation Canada). (2015) HUSBANDRY MANUAL FOR THE CARE, BREEDING, AND MAINTENANCE OF CAPTIVE LOGGERHEAD SHRIKES (*Lanius ludovicianus alvarensis*)
- Wolf, C. M., Griffith, B., Reed, C., Temple, S. A. (1996). Avian and Mammalian Translocations: Update and Reanalysis of 1987 Survey Data. *Conservation Biology*, 10(4), 1142–1154. <https://doi.org/10.1046/j.1523-1739.1996.10041142.x>

Zuk, M., Stoehr, A. M. (2002). Immune defense and host life history. *The American Naturalist*, 160(4), 9–S22

Zuur, A. F., Ieno, E. N., Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, 1, (1):3–14. doi: 10.1111/j.2041-210x.2009.00001.x

General Discussion

Zoos have gained extensive experience and knowledge of husbandry, behaviour and veterinary procedures of many species, necessary for the establishment of CBPs (Ryder and Feistner, 1995). Research taking place within zoos has grown since the 1990s (Ryder and Feistner, 1995; Pyott and Schulte-Hostedde, 2020), as well as the use of CBPs as a tool to preserve biodiversity (Rahbek, 1993). Despite the fact that the majority of zoo collection plans were not originally focused on endangered species (Cruz *et al.*, 2016), Conde *et al.* (2013) reported that around 25% of zoos collections using the Species 360 (previously ISIS) zoo network, were devoted to endangered species. The zoo community's increased experience with *ex situ* populations has vastly improved our knowledge of husbandry, behaviour and veterinary procedures of diverse species, useful criteria for the development of CBPs (Ryder and Feistner, 1995).

In addition to the One Plan approach highlighting the need for a unified management plan between zoos, aquariums, stakeholders, and other institutions (Byers *et al.*, 2013), it is indispensable to have a multidisciplinary approach (e.g., veterinary medicine and biology) to achieve the most successful results (Cook and Karesh, 1995). In parallel, reintroduction programs have been increasingly incorporating scientific knowledge (Seddon *et al.*, 2007), ultimately optimizing release techniques to maximize the survival and success of individuals (Attard *et al.*, 2016), as demonstrated by the increasing number of peer-reviewed publications by zoological institutions (Pyott and Schulte-Hostedde, 2020).

While wild populations can be challenging to study (Holand *et al.*, 2015), having captive populations allows numerous studies to be performed (Imlay *et al.*, 2017) thus making *ex situ* institutions even more relevant to improve conservation programs,

allowing the development and improvement of non-invasive methods such as historical analysis of medical records from captive animals. However, a cautious approach to interpret results from captive populations is advised, as they may not be a wholesome reflection of what would be observed in wild populations. Moreover, keeping consistent and accessible records of animals in captivity is essential for the understanding of numerous species, both *ex-situ* and *in-situ*, not only from a medical perspective, but on the species biology and their ecological role.

Parasitism has always been listed among the most common medical conditions seen in animals maintained in captivity (Bais *et al.*, 2017; Ombugadu *et al.*, 2018), from small sized fish (Van Oosterhout *et al.*, 2007), to large mammals (*Elephas maximus*; Miller *et al.*, 2015), and birds (Ombugadu *et al.*, 2018). Numerous endoparasitic species are prevalent in faecal samples of different species maintained in captivity; for example, ascarids and strongyles species have been described in birds (Bernardi *et al.*, 2014), *Capillaria* sp. and *Trichuris* sp. in ruminants (Goossens *et al.*, 2005), and strongylids and ascarids in carnivores (Mir *et al.*, 2016). Parasites have been described as important drivers of ecosystem functions, through interactions with their host (Milotic *et al.*, 2020). The impact of parasitism in reintroduction programs of threatened or endangered species is widely described not only as a challenge, but also as one of the causes of failure in those programs (Price and Soorae, 2003; Kock *et al.*, 2010; Mañas *et al.*, 2019). The fact that parasites are commonly observed in *ex situ* institutions (e.g., zoos) thus highlights the need to improve our understanding of the relationships between hosts and parasites in captive settings, to detect challenges and improve conservations applying the best approaches (Kołodziej-Sobocińska *et al.*, 2018).

The incorporation of ecological and life history components (e.g., body condition, sex differences, mating system, parental care, and body mass) is paramount to better

understand parasite-host relationships (Valdebenito et al., 2020; Ellis, 2020). Parasitic prevalence can be affected by environmental factors, as an individual's degree of exposure may vary with changes in the weather (Knowles et al., 2009). For instance, the interaction of parasitism and environmental conditions impacting breeding success has been illustrated in a study where in colder wet weather conditions, the breeding success of parasitized birds was lowered than their non-parasitized counterparts (Howe, 1992). Thus, incorporating environmental conditions throughout the years of the program could be useful to better understand how breeding success is affected in parasitized individuals.

Ultimately, my study highlights the importance of retrospective studies as a non-invasive method that makes possible or increases the quality of analysis regarding species at risk populations, as well as the importance of constant improvement of data collection and storage as it directly relates to the quality and veracity of the results and their potential application in improving CBPs.

Literature Cited

- Attard, C. R. M., Möller, L. M., Sasaki, M., Hammer, M. P., Bice, C. M., Brauer, C. J., Carvalho, D. C., Harris, J. O., and Beheregaray, L. B. (2016). A novel holistic framework for genetic-based captive-breeding and reintroduction programs. *Conservation Biology*, 30(5): 1060–1069.
- Bais, B., Tak, L., Mahla, S. (2017). Study of Preventive Health Measures for Wildlife in Captivity: A Review of Management Approaches. *International Journal of Avian Wildlife Biology*, 2(3), 73–75. <https://doi.org/10.15406/ijawb.2017.02.00020>
- Bernardi, B., Fichi, G., Finotello, R., *et al.* (2014) Internal and external parasitic infections in captive psittacine birds. *Veterinary Record*, 174:69.1–69
- WPC (Wildlife Preservation Canada). (2015) HUSBANDRY MANUAL FOR THE CARE , BREEDING , AND MAINTENANCE OF CAPTIVE LOGGERHEAD SHRIKES (*Lanius ludovicianus alvarensis*)
- Conde, D. A., Colchero, F., Gusset, M., Pearce-Kelly, P., Byers, O., Flesness, N., Browne, R. K., Jones, O. R. (2013). Zoos through the lens of the IUCN red list: A global metapopulation approach to support conservation breeding programs. *PLoS ONE*, 8(12). <https://doi.org/10.1371/journal.pone.0080311>
- Cook, R. A., Karesh, W. B. (1995). Applications of Veterinary Medicine to in Situ Conservation Efforts. *Oryx*, 29(4), 244–252. <https://doi.org/10.1017/S0030605300021232>
- Cruz, C. E. F., Cerva, C., Andretta, I. (2016) Financial Costs of Conserving Captive-bred Wild Birds. *Zoologische Garten*, 85(6), 354–362. doi: 10.1016/j.zoolgart.2016.08.003

- Ellis, V.A., Huang, X., Westerdahl, H., Jönsson, J., Hasselquist, D., Neto, J.M., Nilsson, J.-Å., Nilsson, J., Hegemann, A., Hellgren, O., Bensch, S. (2020). Explaining prevalence, diversity and host specificity in a community of avian haemosporidian parasites. *Oikos*, 129, 1314-1329. <https://doi.org/10.1111/oik.07280>
- Goossens, E., Dorny, P., Boomker, J., *et al.* (2005). A 12-month survey of the gastrointestinal helminths of antelopes, gazelles and giraffids kept at two zoos in Belgium. *Veterinary Parasitology*, 127:303–12
- Holand, H., Jensen, H., Tufto, J., Pärn, H., Sæther, B. E., Ringsby, T. H. (2015). Endoparasite infection has both short- and long-term negative effects on reproductive success of female house sparrows, as revealed by faecal parasitic egg counts. *PLoS ONE*, 10(5), 1–12. <https://doi.org/10.1371/journal.pone.0125773>
- Howe, F. P. (1992). Effects of *Protocalliphora braueri* (Diptera: Calliphoridae) parasitism and inclement weather on nestling sage thrashers. *Journal of Wildlife Diseases*, 28(1), 141–143. <https://doi.org/10.7589/0090-3558-28.1.141>
- Imlay, T. L., Steiner, J. C., Bird, D. M. (2017). Age and experience affect the reproductive success of captive loggerhead shrike (*Lanius ludovicianus*) subspecies. *Canadian Journal of Zoology*, 95(8), 547–554. <https://doi.org/10.1139/cjz-2015-0169>
- Knowles, S. C. L., Nakagawa, S., Sheldon, B. C. (2009). Elevated reproductive effort increases blood parasitaemia and decreases immune function in birds: A meta-regression approach. *Functional Ecology*, 23(2), 405–415. <https://doi.org/10.1111/j.1365-2435.2008.01507.x>
- Kock, R. A., Woodford, M. H., Rossiter, P. B. (2010). Disease risks associated with the translocation of wildlife. *OIE Revue Scientifique et Technique*, 29(2), 329–350. <https://doi.org/10.20506/rst.29.2.1980>

- Kołodziej-Sobocińska, M., Demiaszkiewicz, A. W., Pyziel, A. M., Kowalczyk, R. (2018). Increased Parasitic Load in Captive-Released European Bison (*Bison bonasus*) has Important Implications for Reintroduction Programs. *EcoHealth*, 15(2), 467–471. <https://doi.org/10.1007/s10393-018-1327-4>
- Miller, D., Jackson, B., Riddle, H. S., Stremme, C., Schmitt, D., Miller, T. (2015). Elephant (*Elephas maximus*) health and management in Asia: Variations in veterinary perspectives. *Veterinary Medicine International*, 2015, 19. <https://doi.org/10.1155/2015/614690>
- Milotic, M., Lymbery, A., Thompson, A., Doherty, J. F., Godfrey, S. (2020). Parasites are endangered by the conservation of their hosts: Meta-analyses of the effect of host captivity on the odds of parasite infection. *Biological Conservation*, 248(July), 108702. <https://doi.org/10.1016/j.biocon.2020.108702>
- Mir, A. Q, Dua, K., Singla, L. D, *et al.* (2016). Prevalence of parasitic infection in captive wild animals in Bir Moti Bagh mini zoo (Deer Park), Patiala, Punjab. *Veterinary World*, 9:540–3
- Mañas, E. M., Juan, M. G., Carnero, M. D. R. R. D. Y., Gilbert, T., Ortiz, J., Espeso, G., Benzal, J., Ibáñez, B., & Hernández, F. V. (2019). Survey of husbandry practices for bovidae in zoos: The importance of parasite management for reintroduction programmes. *Veterinary Record*, 184(9), 1–6. <https://doi.org/10.1136/vr.104985>
- Ombugadu, A., Echor, B., Jibril, A. ., Angbalaga, G., Lapang, M., Micah, E., Njila, H., Isah, L., Nkup, C., Dogo, K., Anzaku, A. (2018). Impact of Parasites in Captive Birds: A Review. *Journal of Neurology, Psychiatry and Brain Research*, 2019(04), 1–12

- Price, M. R. S., Soorae, P. S. (2003). Reintroductions: Whence and whither? *International Zoo Yearbook*, 38(1), 61–75. <https://doi.org/10.1111/j.1748-1090.2003.tb02065.x>
- Pyott, B. E., Schulte-Hostedde, A. I. (2020). Peer-reviewed scientific contributions from Canadian zoos and aquariums. *Facets*, 5(1), 381–392. <https://doi.org/10.1139/facets-2019-0052>
- Rahbek, C. (1993) Captive breeding – a useful tool in the preservation of biodiversity? *Biodiversity and Conservation*, 2: 426–437
- Ryder, O. A., Feistner, A. T. C. (1995) ‘Research in zoos: a growth area in conservation’, *Review of Industrial Organization*, 4(6), pp. 671–677. doi: 10.1007/BF00222522
- Seddon, P. J., Armstrong, D. P. and Maloney, R. F. (2007) ‘Developing the Science of Reintroduction Biology’, *Conservation Biology*, 21(2), pp. 303–312. doi: 10.1111/j.1523-1739.2006.00627.x
- Valdebenito, J. O., Liker, A., Halimubieke, N., Figuerola, J., Székely, T. (2020). Mortality cost of sex-specific parasitism in wild bird populations. *Scientific Reports*, 10(1), 1–10. <https://doi.org/10.1038/s41598-020-77410-6>
- Van Oosterhout, C., Smith, A. M., Hänfling, B., Ramnarine, I. W., Mohammed, R. S., Cable, J. (2007). The guppy as a conservation model: Implications of parasitism and inbreeding for reintroduction success. *Conservation Biology*, 21(6), 1573–1583. <https://doi.org/10.1111/j.1523-1739.2007.00809.x>