Tracking wildlife diseases using community science: an example through toad myiasis

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Abstract
Parasite and pathogen surveillance is crucial for understanding trends in their distributions and host spectra, as well as to document changes in their population dynamics. Nevertheless, continuous surveillance is time-consuming, underfunded due to the non-charismatic nature of parasites/pathogens, and research infrastructure is usually limited to short-term surveillance efforts. Species observation data provided by the public can contribute to long-term surveillance of parasites using photographic evidence of infections shared on community science platforms. Here, we used public photo repositories to document the occurrence across space and time of Lucilia spp. (Diptera: Calliphoridae), a parasite inducing nasal toad myiasis in the European toad Bufo bufo (Anura: Bufonidae). We found a total of 262 toad myiasis observations on iNaturalist (n = 132), on GBIF (n = 86), on Flickr (n = 41), and on observation.org (n = 3). Our results indicate that the distribution of toad myiasis is regionally limited, despite its host being widely distributed and abundant across a wide region in Europe. Observations were found in 12 countries with relatively low prevalence, including Belgium (3.90%, CI 2.44–6.18), Denmark (1.26%, CI 0.89–1.80), France (0.45%, CI 0.14–1.38), Germany (1.27%, CI 0.92–1.75), Lithuania (0.50%, CI 0.13–1.98), Luxembourg (1.30%, CI 0.42–3.95), the Netherlands (2.71%, CI 1.61–4.52), Poland (0.89%, CI 0.34–2.35), Russia (Kaliningrad Oblast) (4.76%, CI 0.67–27.14), Switzerland (NA), Ukraine (0.87%, CI 0.12–5.91), and in the UK (0.45%, CI 0.28–0.72). Nevertheless, the number of uploaded observations of both parasite infection and host presence indicates a stable increase likely due to the growing popularity of community science websites. Overall, community science is a useful tool to detect and monitor certain wildlife diseases and to recognize potential changes in disease dynamics through time and space.

Keywords Amphibian · Community science · Diptera · Lucilia

Introduction
Amphibians are among the most threatened vertebrates globally. Approximately 39% of described amphibian species are currently classified as near threatened (NT), vulnerable (VU), endangered (EN), or critically endangered (CR) by the International Union for Conservation of Nature (IUCN; IUCN 2022). Recent declines in amphibian populations have been observed globally and are often attributed to various anthropogenic or environmental pressures, including commercial trade of amphibians, climate change, habitat loss, and emerging infectious diseases (Sodhi et al. 2008; Collins 2010). For instance, amphibian-associated diseases (e.g., chytrid fungi Batrachochytrium spp.) are well documented to cause severe population declines and are of critical global conservation concern (Fisher and Garner 2020). Batrachochytrium dendrobatidis was found on ~42% of tested amphibian species, globally (Olson et al. 2013), and their presence is occasionally associated with 100% mortality in some populations (Berger et al. 2005). Additionally, amphibians are important “habitats” of a wide variety of obligate parasites, including nematodes, mites, ticks, and dipterans (Campião et al. 2015; Legett et al. 2018; Santos et al. 2018; Mendoza-Roldan et al. 2020). Several dipteran species have been reported to cause myiasis in amphibians globally (Hagman et al. 2005; Kraus 2007;
Eaton et al. 2008; Eizemberg et al. 2008; De Mello-Patiu and De Luna-Dias 2010; Glaw et al. 2014; de Souza-Pinto et al. 2015. In Europe, two dipterans are believed to induce myiasis in toads. One of these is the toad fly Lucilia bufonivora, a highly host-specific dipteran parasite, which causes nasal myiasis in European toads (Bufo bufo), but has been occasionally reported to also infect co-occurring frog species (Brumpt 1934a, b; Lada 2009). The presence of L. bufonivora in North America has recently been confirmed with both morphological and molecular methods. However, contrary to observations across the Palearctic, here it causes non-nasal myiasis in local amphibians (Tantawi and Whitworth 2014; Arias-Robledo et al. 2019b; Whitworth et al. 2021). Furthermore, the molecular analysis of infected individuals demonstrated a relatively large genetic distance between the European and North American L. bufonivora populations, suggesting that the presence of this species across the Nearctic region is unlikely to be the result of a recent introduction (Arias-Robledo et al. 2019b). Infections by L. bufonivora are relatively rarely observed throughout its distribution range (with some local exceptions), showing prevalence that ranges from 0 to 12%, depending also on host age and sex (Strijbosch 1980). Infection by L. bufonivora is generally biased toward female toads, and hosts with larger body sizes or older ages, and is usually fatal to hosts (Strijbosch 1980).

The second fly species documented to cause myiasis in amphibians is the common toad fly L. silvarum. This species mostly induces non-nasal myiasis in amphibians across North America. However, no evidence has presented its involvement of toad myiasis in Europe (Arias-Robledo et al. 2019a). The saporphagous behavior of L. silvarum has been documented in the Palearctic region (Zumpt 1956). In addition, a recent study on a broad European scale concluded that L. silvarum is not involved in toad myiasis in the Netherlands, Switzerland, and the UK; instead, L. bufonivora was responsible for all documented infections in these countries (Arias-Robledo et al. 2019b). Overall, there is no current evidence that L. silvarum causes nasal myiasis in European amphibians, including in Bufo bufo; therefore, European dipteran-induced toad nasal myiasis cases are currently assumed to be induced by L. bufonivora, exclusively. Nevertheless, L. silvarum occurs through the Palearctic (Williams et al. 2016), and its involvement in toad myiasis cannot be excluded in this region. Across Europe, both toad-associated fly species, L. bufonivora and L. silvarum, and/or toad myiasis have been observed in multiple countries (Richards 1926; Brumpt 1934a; Rognes 1980; Huijbregts 2002; Kaczorowska 2006; Karpa 2008; Fremdt et al. 2012; Sulakova et al. 2013; Gil Arriortua et al. 2014; Pohjoismäki and Kahanpää 2014; Feddern et al. 2018; Arias-Robledo et al. 2019b). Infection patterns of L. silvarum are largely unknown as infection of toads by this species is rarely observed.

European toads have suffered a population decline in the last two decades (Carrier and Beebee 2003; Bosch and Martínez-Solano 2006; Petrovan and Schmidt 2016). Consequently, it is crucial that conservation efforts also recognize the potential threats their host-specific pathogens and parasites might face (Rózsa and Vas 2015; Carlson et al. 2020). While presence/absence as well as density data are often collected for vertebrate species, these are virtually non-existent for most of their metazoan parasites. Such data are however essential to establish population sizes and distribution ranges, as well as to identify potential population declines. Occurrence data of parasite-induced host myiasis can provide a good approximation of distribution, occurrence, and density of amphibian-associated myiasis-inducing parasites (Lucilia spp.) throughout their range. Due to the advances in and the growing accessibility of photographic technology and to the increasing popularity of community science websites, the observations recorded on these sites have become increasingly important and recognized in parasite and disease monitoring/data collection during the past decade (Crowl et al. 2008; Dickinson et al. 2010; Bartel et al. 2011; Lawson et al. 2015).

In this study, we explore the highly specialized dipteran parasites, Lucilia spp. (Diptera: Calliphoridae), that induce nasal myiasis (i.e., infestation by dipterous larvae of live hosts’ tissues) in amphibian hosts. We aimed to document the distribution, host spectra, as well as population trends of these parasites, due to the highly limited knowledge on these. We rely on public photo repositories and emphasize the growing importance of community-based projects in assessing trends in parasitic geographic ranges and densities. Additionally, observations of dipteran-induced nasal myiasis of toads were analyzed to determine how effectively community science can be applied to access the current distribution and infection rate of these amphibian-specific parasites and associated diseases.

Materials and methods

Toad fly–induced myiasis shows a characteristic infection in the nasal cavity of the host; therefore, it is easily recognizable from photos and can be used to detect dipteran parasitism in these hosts. Infection data were collected from three online photo and data repositories (Flickr, GBIF, and iNaturalist). Additionally, the date and locality coordinates of observations were recorded whenever provided by the observer (either on the website or upon request). Uploaded photos of the target host species were screened for signs of nasal myiasis infection to find parasite occurrence data on all three platforms. Additionally, relevant photos were
searched using a combination of different keywords: toad fly AND toad AND parasite OR infection OR disease OR larvae OR Lucilia, to find further occurrence data in secondary host species. Toad fly infections were recorded when the photographed amphibians showed signs of nasal myiasis and the presence of dipteran larvae could be established. Consequently, the infestation rate established here is conservative due to the (presumable) exclusion of hosts with early-stage toad fly infections. Additionally, myiasis presence of only alive toads was considered, excluding visibly deceased individuals. Images duplicated across platforms were considered only once. Given that iNaturalist (unlike Flickr or GBIF) allows the extraction of the total number of observations for specific search criteria, it allows the estimation of prevalence. Therefore, we report all results both specifically to iNaturalist and for combining the three repositories separately. Infection occurrence data was visualized in QGIS (version 3.20.1) (QGIS Development Team 2019) and in R (version 4.0.3) (RTeam 2020), using ggplot2 (Wickham and Chang 2016).

Results

Observations across primary and secondary host species

A total of 129 observations of dipteran-induced myiasis in B. bufo were detected on iNaturalist, and 115 observations on other platforms, including Flickr (n = 30) and GBIF (n = 85). Furthermore, seven individuals of three additional (secondary host) species showed signs of myiasis in their nasal cavities, including B. spinosus (Spain, n = 4), Pelophylax sp. (the Netherlands, n = 1), and Rana temporaria (East European Region of Russia, n = 2) (Fig. 1).

Geographical distribution of dipteran-induced nasal myiasis in toads across Europe

The presence of nasal myiasis in B. bufo was observed in 12 countries, including Belgium, Denmark, France, Germany, Lithuania, Luxembourg, the Netherlands, Poland, Russia (East European Region), Switzerland, Ukraine, and UK (Fig. 1, Table 1). Based on the iNaturalist database, toad myiasis was most frequent in Germany (n = 37), in Denmark (n = 30), and in Belgium (n = 17). However, when data from all three repositories were combined, most observations were reported from the Netherlands (n = 87) (Table 1). The highest prevalence was observed in the East European Region of Russia (Kaliningrad Oblast), with 4.76% (95% CI 0.67–27.14); however, sample size was low in the region (n = 21). High prevalence (with a relatively high observation rate) was observed in Belgium and the Netherlands with 3.90% (95% CI 2.44–6.18) and 2.71% (95% CI 1.61–4.52) of individuals being infected, respectively (Table 1). No infection has been recorded in certain areas, such as Central and Southern Europe, where B. bufo observations are abundant based on community science data.

Fig. 1 Distribution of dipteran-induced nasal myiasis in B. bufo. Green dots indicate iNaturalist; white dots indicate Flickr and GBIF observations. Countries where toad myiasis is confirmed through community science observations are indicated in green, whereas its absence is indicated in dark gray (historically present). Secondary host use (other than B. bufo) observations represented with red stars
Distribution of toad myiasis between 2004 and 2021 on iNaturalist

Both host and infection observations increased between January 2004 and December 2021 (Fig. 2). The highest number of *B. bufo* observations was submitted in 2021 (*n* = 6344), a 30.61% increase from 2020 (*n* = 4857) (Fig. 2). Similarly, the highest number of nasal myiasis presence was observed in 2021 (*n* = 57), an increase of 62.85% compared to 2020 (*n* = 35) (Fig. 2). The highest infection rate (1.01%) was observed in 2016, including all host individuals, and excluding the years with less than 100 host observations (i.e., 2004–2014). The overall mean prevalence of toad myiasis between 2015 and 2021 was 0.83%. Most observations were reported from June to August (Table S1), with the earliest observations in May and the latest in October (Table S1).

Discussion

Community science has already contributed tremendously to the monitoring of numerous parasitic and pathogenic organisms. For instance, information was obtained on the entomopathogenic fungi of the invasive Asian ladybirds (*Harmonia axyridis*) in the USA or on the infectious eye disease (caused by bacteria *Mycoplasma gallisepticum*) in house finches *Carpodacus mexicanus*, producing visible symptoms in their hosts (Altizer et al. 2004). Volunteer observers’ reports on the transmissible facial tumor disease, threatening populations of the endangered Tasmanian devil (*Sarcophilus harrisii*), have proved to be extremely valuable in disease tracking (Hawkins et al. 2006). Moreover, medically important arthropods, such as kissing bugs (Triatominae), the vectors of Chagas disease, which poses a high public health risk, have been tracked using insect...
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Invasive mosquito species, which can carry a wide variety of human pathogens, have also been tracked and monitored based on data provided by volunteers (Palmer et al. 2017; Walther and Kampen 2017; Bartumeus et al. 2018; Pernat et al. 2020). Community science has also been a valuable tool in documenting tick bites and in inferring tick-borne disease distribution and seasonality in several regions (Garcia-Martí et al. 2018; Lernout et al. 2019; Porter et al. 2019; Eisen and Eisen 2020). Additionally, crowd-sourced specimens and occurrence data have significantly contributed to our understanding on the geographic distribution and phylogeny of hairworm (Nematomorpha) species (Hanelt et al. 2015; Doherty et al. 2021). These and similar studies emphasize the importance of community science in the research of non-medical parasites, as well.

Fig. 2 Number of nasal toad myiasis observations (green circles, left \( y \) axis) and \( B. \) bufo (gray barplots, right \( y \) axis) observations found on iNaturalist uploaded between January 1, 2004, and December 31, 2021, in countries where both infection and host occurred (see Table 1).

While reliable species-level identification of parasites requires morphological and/or molecular examination, these observations provide a good indication of the presence and abundance of certain parasite genera in their hosts and at different locations. Using photographs to access the presence, distribution, and seasonality of pathogens is regularly applied, not only in animal-associated pathogens or parasites, but also in research on phytopathogenic species.
For instance, aerial photographs can provide data on widespread infection presence in various plant species (Mohanty et al. 2016; Castelao Teitela et al. 2017; Wiesner-Hanks et al. 2019).

Biodiversity conservation, including the conservation of rare and vulnerable parasites, is increasingly recognized, and needs more research focus both now and in the future (Dougherty et al. 2016; Cizauskas et al. 2017; Carlson et al. 2020; Szentiványi et al. 2020). More studies are needed to better understand which environmental factors drive the distribution of vulnerable parasite species and to better protect their habitats to ensure their future survival. Overall, community science is an increasingly important tool in parasite and disease surveillance, such as in the case of the current study, and may gain further importance in the detection of rarely observed parasite species, contributing to conservation efforts.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s10344-022-01623-5.

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**Author contribution** TS collected and visualized the data and conceptualized the study; both TS and OV analyzed the data and wrote and approved the manuscript.

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**Declarations**

**Competing interests** The authors declare no competing interests.

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**References**

Altizer S, Hochachka WM, Dhondt AA et al (2004) Seasonal dynamics of mycoplasmal conjunctivitis in Eastern North American house finches. J Anim Ecol 73:309–322

Arias-Robledo G, Stark T, Wall RL, Stevens JR (2019a) The toad fly Lucilia bufonivora: its evolutionary status and molecular identification. Med Vet Entomol 33:131–139. https://doi.org/10.1111/mve.12328

Arias-Robledo G, Wall R, Szpila K et al (2019b) Ecological and geographical speciation in Lucilia bufonivora: the evolution of amphibian obligate parasitism. Int J Parasitol Parasites Wildl 10:218–230. https://doi.org/10.1016/j.ijppaw.2019.09.005

Bartel RA, Oberhauser KS, De Roode JC, Altizer SM (2011) Monarch butterfly migration and parasite transmission in eastern North America. Ecology 92:342–351. https://doi.org/10.1890/10-0489.1

Bartumeus F, Oltra A, Palmer JRB (2018) Citizen science: a gateway for innovation in disease-carrying mosquito management? Trends Parasitol 34:727–729. https://doi.org/10.1016/j.pt.2018.04.010

Berger L, Marantelli G, Skerratt LF, Speare R (2005) Virulence of the amphibian chytrid fungus Batrachochytrium dendrobatidis varies with the strain. Dis Aquat Organ 68:47–50

Bosch J, Martínez-Solano I (2006) Chytrid fungus infection related to unusual mortalities of Salamandra salamandra and Bufo bufo in the Peñalara Natural Park, Spain. Orx 40:84–89. https://doi.org/10.1017/S0030605306000093

Brumpt E (1934a) Recherches expérimentales sur la biologie de la Lucilia bufonivora. Ann Parasitol Hum Comparée 12:81–97. https://doi.org/10.1051/parasite/1934122081

Brumpt E (1934b) Spécificité parasitaire et déterminisme de la ponte de la mouche Lucilia bufonivora. Comptes Rendus Hebd Des Séances L’académie Des Sci 198:124–126

Campiàno KM, De Aquino Ribas AC, Morais DH et al (2015) How many parasites species a frog might have? Determinants of parasite diversity in South American anurans. PLoS ONE 10:1–12. https://doi.org/10.1371/journal.pone.0140577

Carlson CJ, Hopkins S, Bell KC et al (2020) A global parasite conservation plan. Biol Conserv 250:108596. https://doi.org/10.1016/j.bicon.2020.108596

Carricondo-Sanchez D, Odden M, Linnell JDC, Odden J (2017) The range of the mange: spatiotemporal patterns of sarcoptic mange in red foxes (Vulpes vulpes) as revealed by camera trapping. PLoS ONE 12:1–16. https://doi.org/10.1371/journal.pone.0176200

Carrier JA, Beebee TJC (2003) Recent, substantial, and unexplained declines of the common toad Bufo bufo in lowland England. Biol Conserv 111:395–399. https://doi.org/10.1016/S0006-3207(02)00308-7

Castelao Teitela E, Brandoli Machado B, Belete NADS et al (2017) Identification of soybean foliar diseases using unmanned aerial vehicle images. IEEE Geosci Remote Sens Lett 14:2190–2194. https://doi.org/10.1109/lgrs.2017.2743715

Cizauskas CA, Carlson CJ, Burgio KR et al (2017) Parasite vulnerability to climate change: an evidence-based functional trait approach. R Soc Open Sci. https://doi.org/10.1098/rsos.160535

Collins JP (2010) Amphibian decline and extinction: what we know and what we need to learn. Dis Aquat Organ 92:93–99. https://doi.org/10.1051/da002307

Crowl TA, Crist TO, Parmenter RR et al (2008) The spread of invasive species and infectious disease as drivers of ecosystem change. Front Ecol Environ 6:238–246. https://doi.org/10.1890/070151

Curtis-Robles R, Wozniak EJ, Auckland LD et al (2015) Combining public health education and disease ecology research: using citizen science to assess Chagas disease entomological risk in Texas. PLoS Negl Trop Dis 9:1–12. https://doi.org/10.1371/journal.pntd.0004235

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Porter WT, Motyka PJ, Wachara J et al (2019) Citizen science informs human-tick exposure in the Northeastern United States. Int J Health Geogr 18:1–14. https://doi.org/10.1186/s12942-019-0173-0

Puechmaille SJ, Wibbelt G, Korn V et al (2011) Pan-European distribution of white-nose syndrome fungus (Geomyces destructans) not associated with mass mortality. PLoS ONE. https://doi.org/10.1371/journal.pone.0019167

QGIS Development Team (2019) QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Richards OW (1926) Notes on the British species of Lucilia (Diptera). Trans R Entomol Soc London 255–260

Rognes K (1980) The blow-fly genus Lucilia Robineau-Desvoidy (Diptera, Calliphoridae) in Norway. Fauna Nor Nor J Entomol Ser B 39–52

Rózsa L, Vas Z (2015) Co-extinct and critically co-endangered species of parasitic lice, and conservation-induced extinction: should lice be reintroduced to their hosts? Oryx 49:107–110. https://doi.org/10.1017/S0030605313000628

Sántor AD, Mihalca AD, Domşa C et al (2021) Argasid ticks of Palearctic bats: distribution, host selection, and zoonotic importance. Front Vet Sci. https://doi.org/10.3389/fvets.2021.684737

Santos JC, Tarvin RD, O’Connell LA et al (2018) Diversity within diversity: parasite species richness in poison frogs assessed by transcriptomics. Mol Phylogenet Evol 125:40–50. https://doi.org/10.1016/j.ympev.2018.03.015

Sodhi NS, Bickford D, Diesmos AC et al (2008) Measuring the meltdown: drivers of global amphibian extinction and decline. PLoS ONE 3:1–8. https://doi.org/10.1371/journal.pone.0001636

Strijbosch H (1980) Mortality in a population of Bufo bufo resulting from the fly Lucilia bufonivora. Oecologia 45:285–286

Sulakova H, Rognes K, Bartak M, Kubik S (2013) Calliphoridae (Diptera) of Vráž nr. Písek (Czech Republic). Proc Workshop biodiversity, Jevany, 2–3 th July, 2013 381–388. https://doi.org/10.13140/2.1.3268.3203

Szentiványi T, Markotter W, Dietrich M et al (2020) Host conservation through their parasites: molecular surveillance of vector-borne microorganisms in bats using ectoparasitic bat flies. Parasite 27:1–10. https://doi.org/10.1051/parasite/2020069

Tantawi TI, Whitworth T (2014) First record of Lucilia bufonivora Moniez, 1876 (Diptera: Calliphoridae) from North America and key to North American species of the L. bufonivora species group. Zootaxa 3881:101–124. https://doi.org/10.11646/zootaxa.3881.2.1

RStudio Team (2020) RStudio: integrated development for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/

Tompkins DM, Clayton DH (1999) Host resources govern the specificity of swiftlet lice: size matters. J Anim Ecol 68:489–500. https://doi.org/10.1046/j.1365-2656.1999.00297.x

Walther D, Kampen H (2017) The citizen science project “Mueckenatlas” helps monitor the distribution and spread of invasive mosquito species in Germany. J Med Entomol 54:1790–1794. https://doi.org/10.1093/jme/tjx166

Whitworth TL, Bolek MG, Arias-Robledo G (2021) Lucilia bufonivora, not Lucilia silvarum (Diptera: Calliphoridae), causes myiasis in anurans in North America with notes about Lucilia elongata and Lucilia thatuna. J Med Entomol 58:88–92. https://doi.org/10.1093/jme/tjaar143

Wickham H, Chang W (2016) Package “ggplot2.” Cham, Switz

Wiesner-Hanks T, Wu H, Stewart E et al (2019) Millimeter-level plant disease detection from aerial photographs via deep learning and crowdsourced data. Front Plant Sci 10:1–11. https://doi.org/10.3389/fpls.2019.01550

Williams KA, Lamb J, Villet MH (2016) Phylogenetic radiation of the greenbottle flies. Zoolkeys 86:59–86. https://doi.org/10.3897/zoolkeys.568.6969

Zumpt F (1956) Calliphoridae. Die Fliegen der Palaearktischen Region. In: Lindner E (ed) Vol 11. Stuttgart, pp 1–140

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