Title: Citizen science and wildlife disease surveillance

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Abstract

Achieving effective wildlife disease surveillance is challenging. The incorporation of citizen science (CS) in wildlife health surveillance can be beneficial, particularly where resources are limited and cost-effectiveness is paramount. Reports of wildlife morbidity and mortality from the public facilitate large-scale surveillance, both in time and space, which would otherwise be financially infeasible, and raise awareness of incidents occurring on privately-owned land. CS wildlife disease surveillance schemes benefit scientists, the participating public and wildlife alike. CS has been employed for targeted, scanning and syndromic surveillance of wildlife disease. Whilst opportunistic surveillance is most common, systematic observations enable the standardization of observer effort and, combined with wildlife population monitoring schemes, can allow evaluation of disease impacts at the population level. Near-universal access to digital media has revolutionized reporting modalities and facilitated rapid and economical means of sharing feedback with participants. Here we review CS schemes for wildlife disease surveillance and highlight their scope, benefits, logistical considerations, financial implications and potential limitations. The need to adopt a collaborative and multidisciplinary approach to wildlife health surveillance is increasingly recognized and the general public can make a significant contribution through CS.

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Introduction

For centuries, amateur naturalists have augmented our scientific understanding of the natural world through biological recording (Pocock et al., 2015). Recently, this contribution has been formalized with the advent of the term 'citizen science', defined as a partnership between amateur (typically unpaid) volunteers and scientists to answer real-world questions by contributing data and/or assisting with its analysis (Miller-Rushing et al., 2012; Citizen Science Central, 2014). Currently, there is a growing interest in CS approaches for large-scale ecological research, facilitated by technological advances including web and mobile-platform reporting with built-in sensors (e.g. GPS for location and camera for data capture) combined with additional functionality to improve data quality (e.g. automated validation tools) (Dickinson et al., 2010; Newman et al., 2012; August et al., 2015). CS has been applied across a wide variety of biological disciplines although, arguably, ornithologists have championed this opportunity, with long-standing schemes across continents generating relative measures of species distributions and abundance (Greenwood, 2007; Wood et al., 2011; Tulloch et al., 2013).

In recent decades, CS has increasingly been employed for wildlife disease surveillance. The objective of this study is to review such schemes and highlight their scope, benefits, logistical considerations, financial implications and potential limitations in order to improve our understanding of how CS can best be utilized in this field in the future.

Citizen Science schemes for wildlife disease surveillance

Wildlife disease surveillance schemes ideally are multidisciplinary, involving close collaboration of professionals in animal health, natural history, field ecology and wildlife management (Ryser-Degiorigis, 2013). They may also include medical and public health authorities, especially if zoonotic pathogens are detected. Such partnerships exemplify the "One health" concept where findings are used to help optimise the health of humans, captive and wild animals, plants and the environment (One Health Commission, 2015).

(i)   **Targeted syndromic and scanning surveillance**

Targeted (or active) surveillance schemes for wildlife disease focus on the detection of infection with, or exposure to, a particular pathogen. Pathogens that cause characteristic external signs are best suited to a CS approach, such as *Mycoplasma gallisepticum* which causes house finch conjunctivitis in the USA. This disease emerged in the mid-1990s and its geographical and temporal spread was largely monitored using a CS approach (Hochachka and Dhondt, 2000). The emergence and spread of paridae pox, a severe form of avian pox affecting tit species, was detected and monitored in Great Britain through CS (Lawson et al., 2012a). Public sightings of Tasmanian devils with facial tumour disease were used, in combination with observations from annual spotlighting, trapping and road-kill surveys, to evaluate the spatial and temporal spread of this novel disease (Hawkins et al., 2006).

CS can facilitate the detection and recovery of carcasses of target species used as sentinels of infection, including for pathogens of significance to public or livestock health. Examples include mute swan (*Cygnus olor*) mortality for the detection of H5N1 highly pathogenic avian influenza (Hars et al., 2008), corvid mortality for the detection of West Nile virus (Eidson et al., 2001; Ward et al., 2006) and blackbird (*Turdus merula*) mortality for Usutu virus surveillance (Weissenböck et al., 2003).

Targeted surveillance for wildlife pathogens in the absence of obvious clinical effects, including serosurveillance studies, can also benefit from the employment of CS. In these cases, invested volunteer groups, rather than the general public, are generally used since specialized sample collection and submission is required. Examples include the submission of fox carcasses by hunters in Sweden for *Echinococcus multilocularis* surveillance (Osterman et al., 2011), the collection of lymphoid tissue from hunter-killed deer in England for *Mycobacterium bovis* surveillance (Paterson, 2008), and amphibian skin swabs for *Batrachochytridium dendrobatidis* detection by amateur herpetologists in the UK (Smith, 2014).

Similar approaches (termed syndromic surveillance) can be used to appeal for reports of disease syndromes of known or unresolved aetiology with visibly characteristic signs. Public sightings of birds with beak deformities have been used to investigate the prevalence of, and species affected by, keratin beak disorder in Alaska (Handel et al., 2010).

Scanning (also called general or passive) surveillance identifies the pathogens and diseases that occur in a population, usually including both infectious and non-infectious diseases, through pathological investigations (Ryser-Degiorgis, 2013). Such investigations identify the cause of death,

differentiate significant from incidental disease and enable the collation of sample archives which can be used for retrospective studies (e.g. Horton et al., 2013; Beckmann et al., 2014).

(ii)   Choice of species and habitat

While CS schemes have been employed for the detection of emergent plant diseases (Ashtag, 2014; Oakmapper, 2014; Pocock and Evans, 2014), the majority target diseases of vertebrates. Such schemes are well suited for species that are accessible, visible and frequently observed. CS projects, however, can be valuable for detecting incidents involving rare species, for which reporters understand the value of any sightings. Appeals for reports from the general public are likely to have more success when targeting native, endangered or charismatic species (Tweddle et al., 2012).

Supplementary feeding of wild birds has become increasingly popular in recent decades and the majority (64%) of garden owners across England now feed wild birds (Davies et al., 2012). This close human-wildlife interface offers research opportunities, including the ability to investigate disease occurrence in garden wildlife and the influence of supplementary feeding on disease epidemiology (Jones and Reynolds, 2008; Sorensen et al., 2014). Similarly, garden ponds are common and widespread in GB, creating important amphibian habitat (Carrier and Beebee, 2003) and presenting opportunities for disease surveillance (e.g. Cunningham et al., 1996).

(iii)   Anthropogenic causality

The human-wildlife interface has frequently been targeted by schemes soliciting reports of wildlife mortality incidents with anthropogenic causation. This includes reporting road kill to improve understanding of species distribution and relative abundance (Froglife Toads on Roads Survey, 2014; Mammals on Roads Survey, 2014), investigating the frequency of window collision (Dunn 1993) or the impact of domestic cat predation (Dunn and Tessaglia, 1994). Even in these cases, pathological examinations can be rewarding to obtain base-line data on, for example, body condition, parasite occurrence or contaminant levels, and to determine if disease is an underlying factor to the proximate cause of death (Lawson et al., 2006).

(iv) Opportunistic and systematic surveillance

Most CS schemes to date have solicited opportunistic reports of wildlife morbidity or mortality and *ad hoc* sample submission. Opportunistic reporting from any member of the public offers the greatest potential network of reporters, in time and space, and increases the likelihood of obtaining reports of

unusual, novel and infrequent incidents. However, the need for CS schemes with known observer effort, such as standardized weekly observations at identified locations, has been recognized. This has been implemented by a small number of CS schemes, such as the Garden Bird Health *initiative* (GBH*i*) (Robinson et al., 2010) and its successor, Garden Wildlife Health (GWH) (www.gardenwildlifehealth.org). While these systematic schemes are more resource-intensive, they have two major advantages: First, reporting bias over time and space can be identified, quantified and accounted for. Second, it enables the co-collection of baseline information on species relative abundance and disease occurrence, including disease absence, which can be used over time to identify possible associations between demographic and epidemiologic trends. A combination of opportunistic and systematic surveillance may be optimal for wildlife disease surveillance.

Although there are multiple examples of CS wildlife disease surveillance schemes, these are most successful when they capitalise on existing ecological CS networks. Volunteers are less likely to be recruited to solely report sick or dead wild animals on a systematic basis as this may not be perceived as an enjoyable activity and because the low frequency of events may lead to low compliance when repeatedly logging negative observations. Minimal additional effort is required to report observations of dead or visibly-diseased wildlife if the animals are already being observed for a pre-existing scheme, and participants are likely to be highly motivated to report such incidents. This is particularly helpful when a rapid response is required: for example, following the emergence of house finch conjunctivitis in North America in 1994, CS surveillance was rapidly established using Project FeederWatch, a continent-wide network of volunteers already observing the species of interest (Hochachka and Dhondt, 2000). This approach was also used for the GBH*i*, where participants were recruited from Garden BirdWatch, an established volunteer network recording the numbers and species of birds visiting their gardens on a weekly basis (Robinson et al., 2010).

Transect surveys conducted at regular intervals offer an alternative means of providing uniform, systematic surveillance with known observer effort. Such transects were used for the detection of seal carcasses during a 2002 phocine distemper epizootic in the UK (Lawson and Jepson, 2004) and coastal surveys were implemented for reporting seabird carcasses in the USA (SEANET, 2014) and UK (Schmitt, 2014). Similar approaches have been used for detecting lakeshore avian mortality during botulism events (Lake Michigan Volunteer AMBLE, 2014).

(v)   Wildlife rescue centers

Wildlife rehabilitators can form a valuable part of a wildlife disease surveillance network, particularly for detection of conditions that typically cause morbidity, rather than mortality. Whilst admissions are *ad hoc,* the use of standardised reporting methods can provide valuable information. For example, quarterly assessments of reasons for presentation by species, summarised by aetiology where available, or on a syndromic basis and by "diagnosis not reached" category, facilitates monitoring of disease trends and early detection of novel conditions,. The opportunity to capitalise on this resource to conduct pathological examinations on animals that die, or are euthanased, should be taken (Gourlay et al., 2014).

(vi) Assessing the population impact of disease

If the population impact or conservation context of a detected disease is to be understood, surveillance outputs need to be analyzed along with population data. Thus, longitudinal population monitoring and disease surveillance are required for the targeted species across the same time and space.

Ideally, the same scheme will collect longitudinal data on species population and disease trends, but usually these are collected through independent CS schemes. In North America, for example, the impacts of West Nile virus and *Mycoplasma gallisepticum* were identified by combining analyses of a disease reporting scheme with population data from the Breeding Bird Survey (LaDeau et al., 2007) and the Christmas Bird Count (Hochachka and Dhondt, 2000). In GB, epidemic greenfinch (*Chloris chloris*) and chaffinch (*Fringilla coelebs*) mortality were tracked through the GBH*i* and population declines were quantified using Breeding Bird Survey data (Robinson et al., 2010; Lawson et al., 2012b). An alternative approach was used by Teacher et al. (2010) to demonstrate the adverse impact of ranavirus infection on common frog (*Rana temporaria*) populations. Amphibian mortality reports solicited from members of the public in the 1990s identified ranavirus-positive sites. Estimates of common frog abundances were made at affected and unaffected sites and this was repeated at the same locations over a decade later.

Benefits

CS provides an approach to facilitate wildlife disease surveillance and has benefits for the scientific community, the general public and wildlife.

(i)   scientific community benefits

CS enables surveillance to be undertaken on a temporal and spatial scale that would otherwise be financially infeasible if reliant on salaried personnel (Tulloch et al., 2013). CS schemes are ideally suited to facilitate the detection of rare and unpredictable events (such as disease emergence) over a wide geographical region that can capture public (and often government) interest and concern (Cooper et al., 2012; Pocock et al., 2014). In addition, the general public's involvement provides an opportunity to learn of incidents that occur on privately-owned land that may otherwise be hidden or inaccessible (Dickinson et al., 2010).

(ii)   public benefits

An adverse consequence of the progressive urbanization of the landscape over recent decades is a growing disengagement of the general public with nature (Miller, 2005). The human health benefits of contact with nature, such as improved well-being and stress relief, are increasingly recognized by healthcare professionals (Maller et al., 2005; Dallimer et al., 2012). Participation in CS schemes that encourage close observation of wildlife on a regular basis, therefore, may have a positive benefit to the health of the reporter.

CS schemes offer an opportunity for science education. Participants in CS schemes gain first-hand experience of authentic observation and data collection and direct access to outcomes arising from their contributions, which together may promote scientific literacy and improve understanding of the study area (Bonney et al., 2009).

(iii)   wildlife benefits

Developing a connection and appreciation of nature is likely to increase the public's perception of its intrinsic value, thereby promoting societal support for species conservation and environmental issues, both through political lobbying and through direct participatory action such as volunteering. Participation in CS schemes can increase environmental stewardship and prompt changes in land management strategy (Cooper et al., 2007).

CS schemes can improve our understanding of how infectious and non-infectious disease influences wildlife populations, such as contributing to species declines. For wildlife disease surveillance, participation can help inform the implications of anthropogenic activities on wildlife health and welfare

and can facilitate optimization of habitat management for biodiversity (e.g. the promotion of wildlife-friendly gardening practices; GWH, 2014).

Logistical considerations

Guides and toolkits are now available to provide a decision-making framework for creating CS projects that yield both scientific and educational outcomes (Bonney et al., 2009; Citizen Science Central, 2014; Pocock et al., 2014). The suitability, or otherwise, of CS for wildlife disease surveillance will vary with location and with local societal and cultural opinion. The logistics and feasibility of employing CS for a wildlife disease surveillance project should be considered at the planning stage and piloted prior to launching on a large-scale. There are various aspects that should be considered, which include:

(i) Legislation

CS schemes for wildlife disease surveillance must be fully compliant with governing legislation, at national, regional and international levels. CS scheme organisers should consult with relevant authorities to avoid conflict with state-organized schemes or disease control regulations. CS practitioners must be aware of all relevant wildlife laws (e.g. pertaining to wildlife harassment or possession), and species-specific legislation (e.g. for migratory and endangered species). Permits must be obtained from the relevant wildlife authorities if required. In terms of carcass recovery and sample submission, CS schemes must ensure compliance with postage and transport regulations. Also, the storage and use of personal data must be legislation compliant.

(ii) Health and safety

CS schemes must minimise the likelihood of volunteers being harmed by project activities. This can be facilitated by conducting risk assessments (Pocock et al., 2014). Volunteers should be made aware of potential risks at the outset of the project. In addition to physical injuries that might be incurred, consideration should be given to the risks of zoonotic disease (e.g. bat lyssaviruses (Banyard et al., 2011); H5N1 highly pathogenic avian influenza (Hars et al., 2008)).

Guidance or training should be provided for volunteers, even if this informs them to contact the CS scheme coordinator without taking any further action on finding a reportable event. Risk assessments

may dictate that wild animal handling and restraint should only be undertaken by professional staff (e.g. veterinarians, wildlife rehabilitation center staff) or that carcass collection is conducted by staff with appropriate personal protective equipment. Where risks are low, sensible recommendations, such as using gloves or inverted plastic bags to handle sick or dead wildlife and thorough washing of hands afterwards, should be made.

(iii) Reporting modality

With the advent of near universal internet access, most current CS schemes are now reliant on electronic data reporting, through web-based (e.g. GWH, 2014), social media (e.g. Project Splatter, 2014) and mobile phone (e.g. Epicollect, 2014) applications. Options for paper based, e-mail and telephone reporting of data should be considered.

(iv) Participant time investment

The majority of CS schemes require *ad hoc* reporting of observations of sick or dead wildlife and therefore little time investment, provided that efficient, simple and well-publicized reporting mechanisms are in place. When CS schemes rely on a long or repeated time investment it is crucial that the process of data collection is enjoyable and can be made part of the participants' normal routines in order to maintain long-term compliance and volunteer retention. Incentives to promote participation can be used, for example using league tables (e.g. BirdTrack) of reporters or virtual badges (e.g. iSpot) to denote individuals who have accomplished a particular reporting task (August et al., 2015). Understanding the motivation of CS participants is both pre-requisite to successful adoption of such gamification (August et al., 2015) and to improving volunteer retention (Garner and Garner, 2011).

(v) Motivation and engagement

Maintaining participant motivation is fundamental to the success of CS projects (Tweddle et al., 2012). Various intrinsic and extrinsic factors may be important for participant motivation, including personal enjoyment, education, skills development, social contact and societal contribution (Raddick et al., 2010). For wildlife disease surveillance, the drivers to participate may also include concern for wild animal health and welfare; concern for public or domestic animal health; custodial responsibility for wildlife; access to veterinary diagnostics, and/or advice on mitigation. Obtaining a sound

understanding of the reasons for public participation is recommended; these may differ from the primary motivation of the scientists without conflict, provided that the needs of both parties are met.

Every CS scheme should have a communications strategy, including frequent dialogue with participants. Previously, this was done using relatively costly paper-based magazines or newsletters, but with current mass electronic communication, the feasibility of such dissemination has increased while costs have decreased. The use of social media and online forums to deliver immediacy and interactivity with project staff should be considered (Tweddle et al., 2012).

Feedback on individual reports and of overall project results is critical to maintain volunteer engagement and also enables participants to better-understand the value of their contribution and possibly undertake timely mitigation measures. Sharing non-sensitive information and data visualization, such as real-time mapping of report submissions or occurrence of specific disease events, can improve volunteer engagement (Bonney et al., 2009; Tweddle et al., 2012).

Efforts should be made to ensure that peer-reviewed publication outputs are widely disseminated, e.g. through open access publishing and press releases, and that key findings are translated into a publicly-accessible format and distributed to CS participants (Cooper et al., 2007; Bonney et al., 2009). The contribution of citizen scientists should be fully acknowledged in these materials, promoting the importance of the public's assistance within the scientific literature and demonstrating the quality of science that can be derived from CS schemes (Dickinson et al., 2012).

(vi)   Training

Baseline skills for volunteer participation must be pragmatically considered before proceeding with recruitment. Complicated surveys that require particular skills are likely to recruit a smaller number of participants than simple formats (Bonney et al., 2009; Pocock et al., 2014). Online training tools (e.g. species or "symptom" identifiers) may be helpful. Classroom training sessions may be beneficial in some cases and 'train the trainer' sessions may help improve efficiency by enabling cascade training of additional volunteers (Cooper et al., 2007; Tweddle et al., 2012). Where appropriate, biosecurity guidelines (e.g. footwear and equipment disinfection) should be provided to minimize pathogen spread as a consequence of participation.

(vii) Appraisal of success

In order to advance our understanding of how CS can be used to achieve wildlife disease surveillance, there is a need to regularly appraise the success of schemes and to describe failures in the peer-reviewed literature. Projects should have clearly defined aims against which to evaluate success. Development of integrated indicators, considering both the efficacy of research achievements and the educational outreach of schemes, has been recommended (Haywood and Besley, 2014). For wildlife disease surveillance, objectives will vary: e.g. early detection of novel threats; collection of sufficient samples to document pathogen absence/presence in a population; and solicitation of mortality reports from a wide geographical and temporal distribution. Beyond data acquisition, CS schemes have the potential to utilise the information gained to identify disease mitigation activities, such as changes in peri-domestic habitat management.

Financial implications

(i)   Savings and costs of CS schemes

With increased focus on delivering cost-effective approaches for research, and engaging different stakeholders and communities in the process, various studies have appraised the financial benefits of utilising a CS approach. The value attributed to participant effort in Project FeederWatch, a garden bird survey in the USA, has been estimated at $3 million per annum (Dickinson et al., 2010). Goldstein et al. (2014) found CS reporting of squirrel distributions in Ireland to be more cost-efficient than an indirect field survey technique. Levrel et al. (2010) estimated the contribution of volunteer labour to a scheme monitoring butterfly and bird abundance in France at between €678,523 and €4,415,251 per year. Similar approaches can be used to derive monetary estimates of volunteer value for wildlife disease surveillance schemes. For the GWH project, circa 1500 participants observe wildlife on a weekly basis. If we estimate a £20 per week fee for non-volunteers to contribute this information, the cost of delivering this surveillance effort would be around £1.5 million per year.

Whilst such figures offer a compelling argument for utilising CS, it is important to remember that CS schemes are not free. Project co-ordinators are critical to the long-standing success of CS projects since they supervise data collection, collation, and validation; manage participant feedback; produce explanatory, educational and promotional materials to initiate, encourage and maintain participant motivation and, in many cases, summarise and analyse the information collected (Tulloch et al., 2013;

Pocock et al., 2014). Additional costs relate to technological requirements (e.g. website or software development and maintenance), volunteer training and possibly also supply of equipment. For wildlife disease surveillance schemes, veterinary time and pathological investigations are added costs, which are likely to be substantial.

(ii)   Cost implications of participation

The majority of CS schemes are free to participants with the project covering the costs of any necessary training. There are examples, however, of CS schemes where participants contribute a membership fee which is used to support the administration of the scheme (e.g. British Trust for Ornithology's Garden BirdWatch (BTO 2015; Cannon et al., 2015)). Conversely, for some CS schemes, typically those requiring the participation of specialists or a considerable time investment, participants receive nominal remuneration or expenses reimbursement to encourage participation (e.g. hunters paid for sample collection (Osterman et al., 2011)).

Limitations

The vast majority of CS schemes for wildlife disease surveillance contribute towards our understanding of pathogens where they result in disease rather than infection in the absence of clinical signs. The recruitment of large numbers of citizen scientists usually is required for the detection of wildlife mortality incidents since even large-scale mortality events can lead to comparatively small numbers of detected carcasses and even fewer retrieved in an appropriate condition for useful examination (Balcomb, 1986; Tobin and Dolbeer, 1990; Wobeser and Wobeser 1992; Ward et al., 2006). This is especially relevant for small animals, such as amphibians, which are rapidly removed from the environment by scavengers and decomposition (Santos et al., 2011).

When developing a CS scheme for wildlife disease surveillance, it is important to identify likely sources of data bias or inaccuracy and to determine whether sufficiently high quality data can be collected by non-professionals to achieve the aims of the project. Where CS facilitates the collection of a large volume of data, which would not be possible by other means, a trade-off may need to be made between data quality and quantity (Tulloch et al., 2013). Bias or error in a minority of reports may not unduly influence interpretation of a large dataset. Whilst-specific evaluation is required for

each CS scheme, studies have concluded that contributed CS data are generally reliable and can be used to generate robust findings (Mulder et al., 2010; Szabo et al., 2012).

To minimise the submission of incorrect data by volunteers, expert verification of data has been utilised (Gardiner et al., 2012). Bonter and Cooper (2012) developed a smart filter system that automatically screens data, identifies entries that violate set criteria and forwards them for expert review for clarification before their acceptance into the dataset. Combining automatic validation with manual verification of anomalous reports offers an efficient means to improve the accuracy of data through identification of implausible sightings.

Opportunistic schemes that rely on *ad hoc* reporting of wildlife disease incidents are vulnerable to bias due to uncontrolled observer effort over time and space. For example, raised public awareness following local media attention (Ward et al., 2006) can increase the number of reports in a particular location which could easily be misinterpreted as a peak in disease occurrence.

It might not be possible to overcome some types of data bias in CS projects, but such projects may still be worthwhile provided this is taken into account. Pocock and Evans (2014) conducted statistical modelling to characterise bias in a CS dataset and used this to generate corrected data estimates for analysis.

For wildlife mortality, reporting is likely to be skewed towards incidents involving charismatic or easy-to-detect species, mass mortality incidents and mortalities of unknown cause. For example, Ward et al. (2006) observed that carcasses of large, colourful birds are more likely to be reported by citizen scientists than those of less-visible species. Also, the likelihood of mortality incident detection is greater in urban areas with dense human populations than in rural habitats (Ward et al., 2006). For CS schemes that rely on opportunistic surveillance, it might be possible to estimate variation in surveillance effort per unit area by stratifying disease incident reports by human population density, e.g. Robinson et al. (2010). Systematic surveillance schemes can be used to identify regional differences in disease incidence by comparing the proportion of monitored sites where a specific incident was observed per unit time amongst regions.

Conclusions

The need for a 'Big Science' approach to wildlife health surveillance, employing new methodologies and adopting collaborative and multidisciplinary models following the One Health paradigm has recently been highlighted (Sleeman, 2013). There are several apparently successful examples of CS schemes for wildlife disease surveillance and this review highlights their scope, logistics and limitations. The potential role of CS schemes in optimising cost-effective and novel wildlife health surveillance by harnessing the power of the crowd should be recognized and further developed.

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