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Short Communication

Webcams as an untapped opportunity to conduct citizen science: Six years of the American Kestrel Partnership's KestrelCam

Sarah E. Schulwitz*, D. Paul Spurling, Tala S. Davis, Christopher J.W. McClure

The Peregrine Fund, 5668 W. Flying Hawk Lane, Boise, ID, 83709, USA

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ABSTRACT

Hundreds of zoo-based or wildlife webcams have become available during the past twenty years, mostly with the goal of educating the public. However, there has been virtually no peer-reviewed research that evaluates the education, conservation, or scientific impact of webcams. Here, we provide one of the few examples of a webcam used for citizen science, and the only test of efficacy for crowd-sourced data collection using webcams. The Peregrine Fund streamed six seasons of American Kestrel (*Falco sparverius*) nests using the same nest box from 2012 through 2017 and viewers input observations into an online portal. We analyze trends in participant and kestrel behavior and test for sources of bias in this citizen scientist-generated dataset by independently reviewing a subset of recordings to determine accuracy of viewer-logged data. Citizen scientists logged a maximum of approximately 5.25% of all footage, but with an accuracy of 88%. Although number of participants declined yearly, on average, participants became more engaged. Sources of bias were related to people's daily activity periods (i.e., less participation at night) and activity within the nest box (i.e., less participation when there were no birds in the box). This citizen scientist-generated dataset generally corroborated the literature regarding American Kestrel biology. Researchers may be cautiously optimistic that datasets generated by citizen scientists can provide valuable information on a given system or study species. Given the ubiquity of webcams and their potential competition for conservation dollars, more research evaluating any aspect of their impact or application is sorely needed.

1. Introduction

Technological advances have revolutionized mass communication, web-based data collection, and the ability to mobilize and engage large audiences in specific activities. These opportunities enabled a burgeoning of research projects involving citizen scientists (Bonney et al., 2014; Bonney and Dickinson, 2012; Silvertown, 2009) and, simultaneously, online wildlife webcams that aim to engage and educate public audiences in issues related to biology and conservation (Dodson and Murphy, 2012). In response, leaders in citizen science have developed a community, tools, and guides to facilitate practitioners in the development of successful citizen science projects. For example, in the past decade, the Citizen Science Association (citizensci.

* Corresponding author.
E-mail address: Schulwitz.Sarah@peregrinefund.org (S.E. Schulwitz).

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org) and its associated journal, *Citizen Science: Theory and Practice* were launched. Additionally, the publications of books (e.g., Dickinson and Bonney, 2012), user's guides (e.g., Phillips et al., 2014), and dozens of peer-reviewed articles (e.g., Bonney et al., 2009; Freitag et al., 2016; West and Pateman, 2016) help in these endeavors.

Simultaneously, a few organizations have emerged as leaders in providing wildlife webcams on multiple species for viewing by the public, including Explore.org, Cornell Lab of Ornithology's Bird Cams, and Raptor Resource Project, each receiving millions of views per year. Additionally, hundreds of individual wildlife webcams are available to the general public and many are operated by non-profits conservation organizations, zoos, aquariums, or science museums (Dodson and Murphy, 2012). However, surprisingly little research has focused on any aspect of zoo-based or wildlife webcams, be it biological discoveries or the influence of webcams on learning or human behavior. Indeed, a Web of Science search (webofknowledge.com, accessed June 6, 2018) for ‘wildlife AND webcam’ returned only 3 results (Cushing and Washburn, 2014; Dodson and Murphy, 2012; Hayward and Hayward, 2012) and ‘bird AND webcam’ returned seven results, only six of which were generally relevant to birds and webcams (e.g., Peluso et al., 2013; Verstraeten et al., 2010). Of the few studies investigating aspects of webcams, most are focused on data collected on the webcam subject (e.g., Davis et al., 2017; Hayward and Hayward, 2012; McClure et al., 2015; Peluso et al., 2013), rather than practitioner objectives and methods or viewers behaviors (but see Dodson and Murphy, 2012).

Given that the stated objective of many webcams is to educate the public in issues of wildlife and conservation (Dodson and Murphy, 2012) and that they can potentially compete with conservation dollars, studies focused on the utility, learning outcomes, or conservation impacts of such projects are warranted. Additionally, because many zoo or wildlife webcams are developed for educational outreach (Dodson and Murphy, 2012), there is a fantastic opportunity for webcams to serve as an avenue for conducting citizen science. Webcam practitioners may benefit by adopting strategies for setting goals and conducting evaluations as described by citizen science leaders (Louv et al., 2012; Phillips et al., 2014).

The American Kestrel Partnership (hereafter referred to as the AKP; online at kestrel.peregrinefund.org) is a project of The Peregrine Fund that engages the public in issues of raptor biology and conservation. The mission is to galvanize a continent-wide community of informed citizen and professional scientists that contribute high quality data to help uncover the mystery of the long-term and steady decline of American Kestrels (*Falco sparverius*; McClure et al., 2017; Smallwood et al., 2009). Toward achieving the mission, two components of the program are a box-monitoring program and a wildlife webcam focused on an American Kestrel nest box located in Boise, Idaho (hereafter referred to as the KestrelCam; accessed at kestrel.peregrinefund.org/webcams). The KestrelCam has streamed the contents of a nest box each breeding season from 2012 through 2017. Features aimed to enhance learning and engagement among viewers of the KestrelCam include Activity Logging, a shared Discussion Board, and in 2017, weekly Live Chat sessions with a staff member of AKP. The Activity Logging feature enables the public to act as citizen scientists by logging their observations of the KestrelCam into a shared database.

In this study, we analyze data collected from six years of activity logging of the KestrelCam. Our objectives were to analyze trends in citizen scientists' contributions, report trends in kestrel activities and food deliveries as recorded by citizen scientists, identify biases in a data set generated by citizen scientists, and evaluate the efficacy of harnessing the power of webcams and citizen science as a method of data collection. Our evaluation is intended to improve data quality, viewer participation, and retention for the KestrelCam and to also inform other potential practitioners on the use of webcams for citizen science endeavors.

2. Methods

2.1. Hardware & streaming

The KestrelCam nest box is located at The Peregrine Fund's headquarters at the World Center for Birds of Prey in Boise, Idaho. There are two cameras that together provide a view of the inside of the box and the outside of the box. The inside camera is focused from above looking down onto the floor of an American Kestrel nest box and the outside camera is most often focused on the exterior of the nest box so the entire nest box and some of the surrounding landscape is in view (Fig. 1A). The camera footage from the inside and outside cameras are placed beside each other on the streaming screen so that viewers can observe real-time activity both inside and outside the nest box simultaneously (Fig. 1A; see Supplemental Fig. 1 for nest box, camera, and streaming specifications). Each season, we started streaming the cameras 24 h per day for public viewing around the time that the first egg was laid. We terminated the stream a few days after the nestlings fledged, thus while the camera was streaming, the box was nearly continuously occupied. The inside camera was equipped with infrared so activity inside the box was visible at night.

2.2. Activity logging by citizen scientists

When viewing the KestrelCam on the AKP website, viewers could log what they saw by clicking a button labeled “Activity Log.” They were prompted to input their screen name and select an “actor” and an “action” (Supplemental Tables 1 and 2 list all “actions” and “actors” available for selection). All submitted observations were automatically saved to a database with a time and date stamp recorded in addition to their selected screen name. Importantly, screen names were designated by the user without restrictions on names accepted, and could be different with each entry and be shared by multiple users.

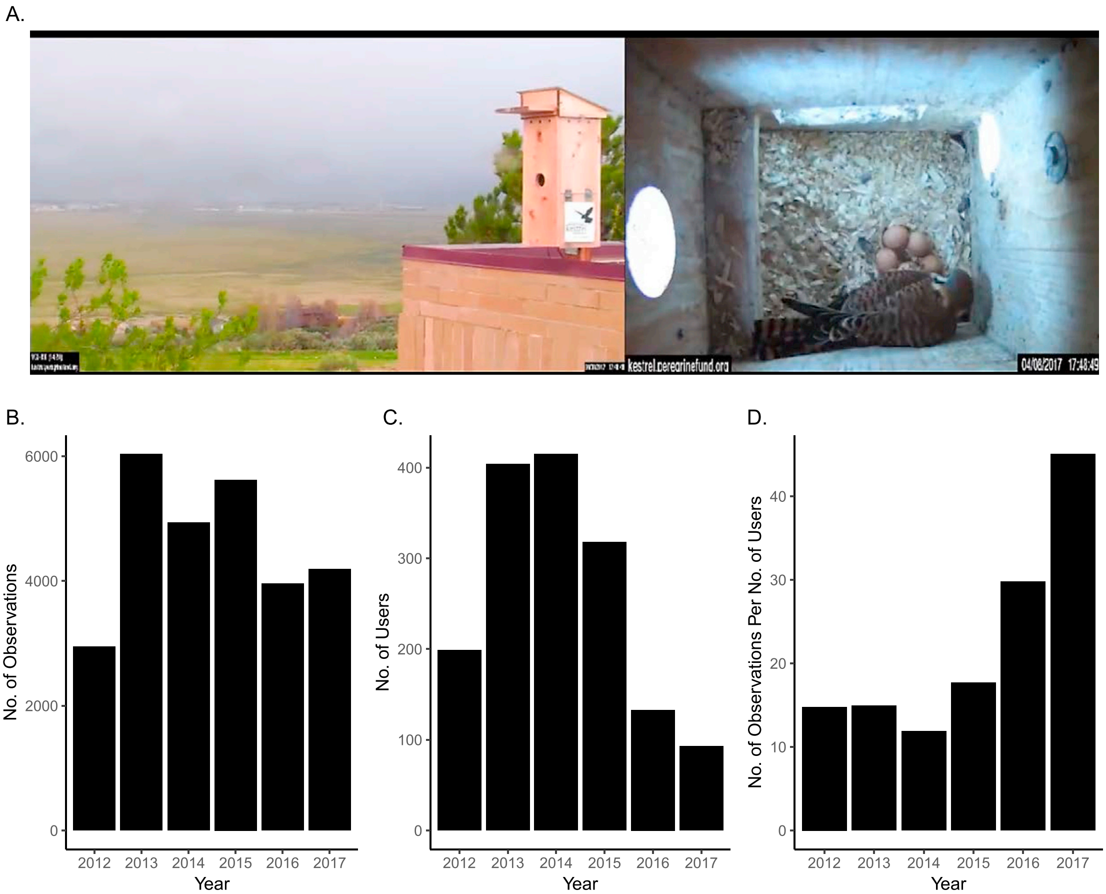

Fig. 1. (A) Outside (left) and inside (right) views of the KestrelCam nest box. The KestrelCam (online at kestrel.peregrinefund.org) is managed and operated as part of The Peregrine Fund's American Kestrel Partnership. (B) Number of observations, (C) number of users that logged observations, and (D) number of observations per number of users that logged observations per year based on the American Kestrel Partnership's KestrelCam activity logging by citizen scientists from 2012 to 2017. There were significant declines in observations and users per year after the first year, but significant increase in the number of observations per number of users per year.

2.3. Statistical analysis

In November 2017, all data from the 2012 through 2017 breeding seasons were downloaded for analysis. Screen names were manually cleaned in Microsoft Excel by removing commenting after screen names and ensuring continuity in capitalization and spelling between obviously matching screen names (e.g., McCoy5668, mccoy5668, and Mcoy5668 all revised to McCoy5668).

To determine trends in viewing behavior, we quantified the number of users (i.e., distinct screen names) and observations logged per year. Observations and users rose after the first year, then appeared to decline. We therefore performed linear regressions to determine if there were significant trends in either observations or users over time from 2013 through 2017. We also calculated observations per users for each year and performed a linear regression to determine if the resulting increasing trend over time was statistically significant. We further determined whether most observations were submitted by a few avid viewers, or if viewers were somewhat equal in number of observations submitted. We thus examined approximately how many observations were collectively logged by the most active 10% and 20% of users as a percentage of all observations logged by year. To discuss patterns in viewer behavior, we define breadth of engagement as the number of users that logged at least one observation, and depth of engagement as the average number of observations logged per user.

To determine trends in observed kestrel behaviors (i.e., parent actions and food deliveries), we reduced observations to one identical action per minute for each actor (e.g., if three users logged that the female kestrel brought a rodent into the nest during the same minute, we retained only a single observation reporting that prey delivery during that minute). To determine actions performed by the adult kestrels, we analyzed only observations that included either the female or the male parent as the actor. We determined the division of observations per parent per year by calculating the proportion of actions per parent out of all actions in a year. We used a binomial test to determine if division of observations between the female and male was statistically equal across years. To determine the actions most commonly recorded for each parent, we combined several related actions so that the final 11 categories included in analysis of actions by parent were “Deliver Food”, “Feed Nestlings,” “Incubate Eggs,” “Exit Box,” “Enter Box,” “Brood Nestlings,” “Sleep,” “Preen,” “Perch On/In Box”, “Rearrange bedding/Eggs”, and “Other” (see Supplemental Tables 1 and 2).

To analyze food deliveries by parent, we reduced this dataset to include only actions related to delivering food and included the final food type categories “Insect,” “Rodent,” “Reptile,” “Bird,” and “Unk/Other” (combined “deliver an unidentifiable chunk” and “deliver some other food”). We quantified the count of each food type across years for each sex. We also calculated food delivery profiles per sex per year as a proportion of the total food deliveries by each parent that year. To compare food delivery profiles between sex and year, we removed food type “Unk/Other” and ranked each year based on the proportion of rodents and insects delivered for each sex then compared the ranks for each sex between the years.

We also tested if biases in logging behavior were detectable in the dataset. In an unbiased dataset, observations would be logged at consistent or random intervals independent of time of day. To test this, we quantified observations logged per hour of day across years. Additionally, in an unbiased dataset “Enter Box” and “Exit Box” would be reported with approximately equal frequency. To assess equality in frequency of these actions, we performed a binomial test for each sex across years. We also performed binomial tests for each year (combining observations for both sexes). All statistical analyses were performed in R (R Core Team, 2017).

Finally, we sought to assess the accuracy of the citizen scientist-generated dataset. We randomly selected ten groups of ten observations made by citizen scientists and checked their accuracy by comparing them to the KestrelCam footage for each observation's date and time. We scored the citizen scientist-generated data as either accurate or inaccurate. We divided the total number of observations that were scored as accurate by the total number of citizen scientist observations that were scored.

During this process, we realized that little of the video footage actually had a corresponding data point (i.e., we noticed long stretches of footage with no observation recorded), so we decided to also measure approximately how many minutes of footage had a corresponding data entry point, which we will term “completeness.” As a rough approximation, we calculated the maximum percentage of total estimated minutes across all years that were recorded by citizen scientists. To do so, we divided the total number of observations (27,710 observations) by the estimated number of minutes of footage (~61 days each for six years had approximately 527,040 min).

3. Results

In total, 27,710 observations were reported from 2012 to 2017 (16 logged observations did not contain a date and time stamp due to technical errors, leaving 27,694 remaining observations). A reduced dataset, retaining only one observation per minute per actor, contained 25,936 observations.

Observations per year ranged from 2946 in 2012 to 6036 in 2013 (4615 ± 1143, mean ± SD; Fig. 1B). Users per year ranged from 93 in 2017 to 415 in 2014 (260 ± 138; Fig. 1C). After the first year, there were significant declines in both observations logged ($\beta = -0.094$, SE = 0.005, $p < 0.001$) and number of users ($\beta = -0.348$, SE = 0.021, $p < 0.001$) over time. However, the decline in observations per year was noticeably shallower than the decline in users, such that there was a significant increase in observations per users over time during the same time frame ($\beta = 7.81$, SE = 2.1, $p = 0.035$; Fig. 1D). In 2016, 2017, there were proportionally less users entering one and two observations and proportionally more users entering many observations (Supplemental Fig. 2). This shift in the behaviors of some of the viewers accounts for the increase in number of observations per number of users over time. There was a noticeable pattern in user contribution, whereby relatively few users contributed the majority of the data (Fig. 2). For example, we found that the most active 10% of users collectively contributed 70–80% of data; the most active 20% of users collectively contributed 80–90% of data (Fig. 2).

Across years, division of observations by parents at the nest was unequal (binomial test, $p < 0.001$). Females performed 69.7% ± 5.8% (mean ± SD; range 64.4%–77.9%) of 17,692 observations involving parents (Fig. 4A). Across years, females were most commonly reported feeding nestlings (14.7% ± 4.3%, mean ± SD across 6 years), delivering food (14.2% ± 5.4%), incubating eggs (13.7% ± 4.8%), exiting the box (13.4% ± 2.9%) and entering the box (10.3% ± 2.9%; Fig. 3B and Supplemental Fig. 3). Males were most commonly reported incubating eggs (22.4% ± 7.3%), delivering food (17.3% ± 9.9%), perched on or in the box (16.1% ± 4.7%), exiting the box (12.9% ± 2.5%), and entering the box (10.4% ± 1.6%; Fig. 3B and Supplemental Fig. 3).

Females were observed delivering 69.8% ± 8.5% of 2668 total recorded food deliveries and delivered more of each food type (Fig. 4A). Dependent on year, rodents or insects were the most frequently delivered prey items, but in nearly all years a small fraction of prey deliveries were also reptiles or birds (Fig. 4B). The profile of food deliveries of males and females were more similar to each other within years than among years; for example, there was a striking difference between the female's food delivery profile in 2013 and 2017, but within those years, the delivery profiles between male and female were similar—i.e., in 2013, both sexes delivered a greater proportion of insects than they did in any other year, whereas in 2017 both sexes delivered a greater proportion of rodents than they did in any other year (Fig. 4B). When ranked by the proportion of rodents and insects delivered, each year's rank was identical between the sexes for all but 2012 and 2014 (e.g., 2012 was ranked 3rd for female and 2nd for male for proportion of rodents delivered and vice versa for 2014).

Biases in viewing behavior were apparent based on both tests for bias. For example, the majority of observations were logged between 08:00 and 19:00 MT (80%; Supplemental Fig. 4). Additionally, across years for each sex the number of times a bird was recorded exiting the box exceeded the number of times it was recorded entering the box (binomial tests, $p < 0.001$

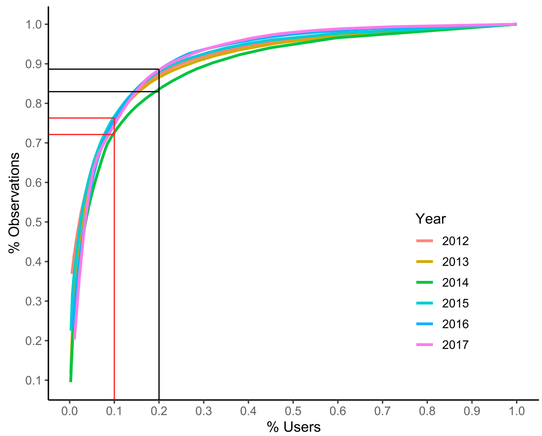

Fig. 2. Percentage of observations by percentage of users contributing data through the American Kestrel Partnership's KestrelCam from 2012 to 2017. For reference, 20% of users contributed 80–90% of data (black lines) and 10% of users contributed 70–80% of data (red lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

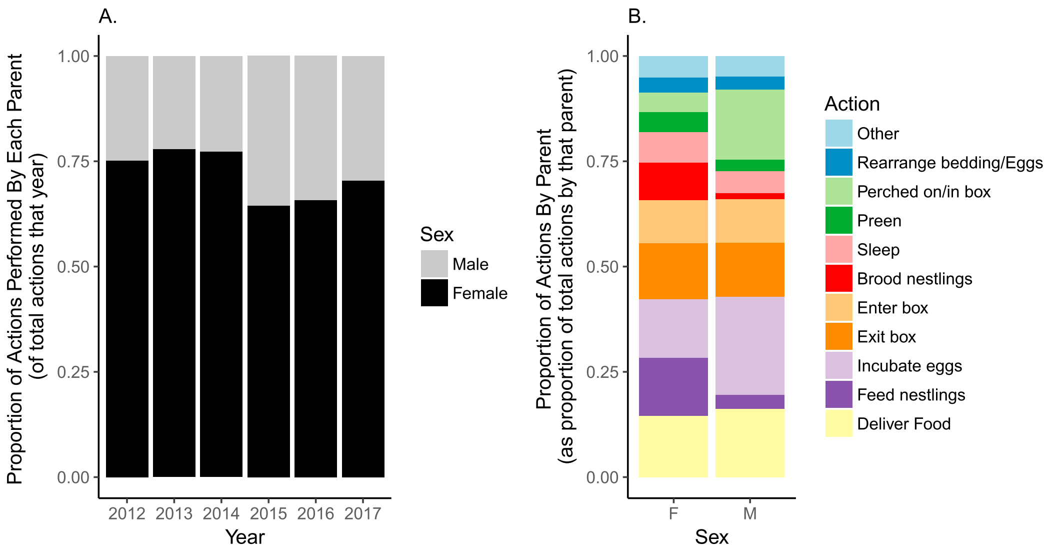

Fig. 3. (A) Proportion of actions performed by the male (grey) or female (black) kestrel and (B) proportion of action by parent (as a proportion of total actions by that parent; based on the American Kestrel Partnership's KestrelCam activity logging by citizen scientists from 2012–2017.

for both female and male across years; Fig. 3B). This pattern also held within each individual year (binomial tests for each year, all $p < 0.05$; Supplemental Fig. 3).

In estimating accuracy of our citizen-scientist generated dataset, we found that of the 100 citizen scientist observations scored, 88 (88%) were correct. In estimating completeness, we calculated that a maximum of approximately 5.25% of all footage was recorded by citizen scientists.

4. Discussion

Our study is one of the few to use a webcam for crowd-sourced data collection and the first to examine the accuracy and biases of data collected by citizen scientists via webcam. The trends in user behavior we report should help practitioners further refine the use of webcams in data collection and interpret results from webcam-derived data. Trends in observations logged by citizen scientists showed that although breadth of engagement has declined over time, it is arguable that the depth of engagement of viewers has increased (increase in observations per users over time). Notably, in 2012 and 2013, the Cornell Lab of Ornithology included the KestrelCam on their BirdCams website (cams.allaboutbirds.org), which may have driven users to the AKP site where they could participate in activity logging. Another potential contribution to the decline is the rise in

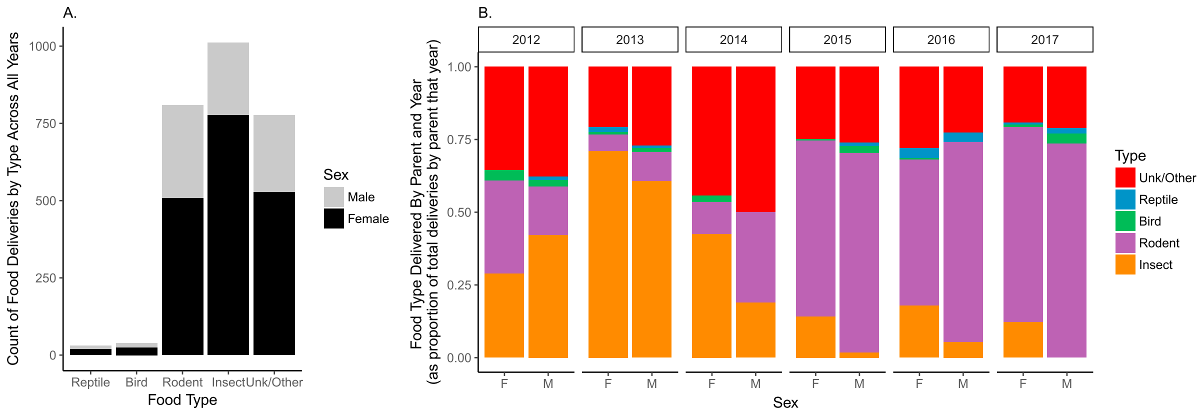

Fig. 4. (A) Count of food deliveries by type across years recorded for the male (grey) and female (black) kestrels and (B) food type delivered by parent and year (as a proportion of total deliveries by that parent that year based on the American Kestrel Partnership's KestrelCam activity logging by citizen scientists from 2012–2017.

popularity of other webcam sites, such as Raptor Resource Project (raptorresource.org), Explore.org, and Cornell's BirdCams, which provide a "one-stop shop" to multiple webcams and have all been successful in attracting large audiences. Although the breadth of engagement may have decreased, depth of engagement may have increased as a result of our continued outreach efforts through social media, newsletters, live chat, and especially our active KestrelCam discussion board, which fosters and supports a tight-knit online community among the viewers of the KestrelCam. For webcam practitioners, as with any citizen science project, it is important to consider methods for evaluating retention over time.

The activity logging feature of the KestrelCam enabled the public to act as citizen scientists by contributing data on American Kestrels using a wild nest. However, we found evidence for several types of bias based on viewing and participation behavior. For example, there was nearly an order of magnitude difference between the activity logging during the day as opposed to at night, which is understandable given the typical pattern of daily human activity. In an unbiased dataset, the results of the kestrel's 24-h activity would probably include a greater percentage recorded in the "sleeping" category. We also found that people recorded the kestrels exiting the box significantly more often than entering the box. We interpret this imbalance as people being more likely to continue viewing when the box contains an active kestrel as opposed to none, and therefore to be more likely to be watching when a bird leaves the box as opposed to entering it.

Additionally, potential biases in participation data were introduced based on the method in which people recorded their screen name. To log activity, the user manually typed their name with each recording rather than the user name being fixed and identically repeated with each entry. Therefore, variations in screen name could exist both within and between years, which likely introduced bias to our estimate of users over time. For practitioners interested in implementing data logging features with their webcams, we recommend considering the costs and benefits of requiring a one screen name per user system (e.g., a cost may be that requiring user log-in to ensure one screen name per person would present a barrier to participating in data-logging while a benefit may be more accurate data collected on user participation and behavior). Finally, and perhaps most notably, a small percentage of people contributed the vast majority of the data and this pattern was consistent across years. This contribution disparity is the same pattern we see in AKP's nest box monitoring program (unpubl. data) and that Cornell's Lab of Ornithology eBird program has noted among their citizen scientists (Wood et al., 2011). This phenomenon may be widespread among citizen science projects. Our results suggest that additional features associated with the KestrelCam, such as explicit instructions (e.g., record once per minute per actor during a randomly selected 15-min block of time) and automatically recorded usernames, may reduce bias within our dataset. The sources of bias we discovered (decreased viewership at night and of empty screens) may also affect viewership of other webcams and may be considered by practitioners interested in elevating their projects into the realm of citizen science.

Despite patterns in user behavior, this citizen scientist-generated dataset reflects real patterns in the behavior of wild kestrels. First, we found that 88% of the sampled citizen-scientists observations were accurate when we checked the recordings ourselves. Second, several of our results corroborate the literature. For example, past research demonstrated that kestrels prey mostly upon rodents and insects with a small fraction of birds and reptiles, which is what our citizen scientists recorded (Collopy, 1973; Freer, 1973; Heintzelman, 1964; Smith et al., 2017). More specifically, food delivery profiles for the KestrelCam in 2014 were strikingly similar to delivery profiles reported for four of five kestrel nests within the same study site and in the same year (Smith et al., 2017). Additionally, other researchers report that females do most of the work at the nest and this pattern was consistently detected by our citizen scientist-generated dataset (Smallwood and Bird, 2002). Several of our results also corroborate themselves. For example, male and female food delivery profiles are more similar to each other within years than among years, reflecting the variation in prey type available among years. Also, each year shows females doing more work at the nest than males with small deviation among years. This disparity in activity between the sexes is also detectable for each food type (though it is quite possible, probable even, that many prey transfers from male to female occurred out of view of the camera). Our findings suggest that, given biases are considered, researchers may be cautiously optimistic that datasets generated by citizen scientists monitoring webcams can provide valuable information on a given system or study species.

Although the majority of our findings corroborated the literature, the KestrelCam has provided the first footage of some events thought to occur in nature but never directly observed. Though we were not streaming to the public at the time, we collected video documentation for inter and intra-specific competition for nest boxes, both during the breeding (McClure et al., 2015) and winter (Davis et al., 2017) seasons. Further, in 2014 our viewers watched and logged one of the nestlings being cannibalized by its siblings. This behavior has been observed (Bortolotti et al., 1991) in American Kestrels but is not well-studied. They recorded their observations in the open ended screen name field. Especially for species less well-studied than kestrels, the watchful eyes of citizen scientists paired with data-logging features may provide opportunities for documenting yet unknown wildlife behaviors.

From a research perspective, extremely little is known about webcams, how they engage the public, or what kind of educational, scientific, or conservation impact they may have (Dodson and Murphy, 2012). With a few additional features, webcams have the potential to serve as robust citizen science projects. However, given the significant financial and human resources required to provide these services, it is imperative that organizations critically evaluate efforts regarding project goals, to determine breadth and depth of audience engagement, and to inform potential future applications of the project.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.gecco.2018.e00434.

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