Citizen Science in Schools: Students Collect Valuable Mammal Data for Science, Conservation, and Community Engagement

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Citizen science has been touted as an effective means to collect large-scale data while engaging the public. We demonstrate that children as young as 9 years old can collect valuable mammal monitoring data using camera traps while connecting with nature and learning through their own scientific discoveries. Indian, Kenyan, Mexican, and American students used camera traps near their schools and detected 13–37 species, all of which were verified by professionals. These data describe rich mammal faunas near schools, sometimes surpassing nearby protected areas, and included five endangered species. Ninety-four percent of the camera traps were set in accordance with scientific protocols, and the teachers reported the experience as highly engaging for their students. Furthermore, the generated photos and results had community-wide impacts involving local politicians, community members, and the media. We show that children can run sensors to contribute valid scientific data important for conservation and research.

Keywords: citizen science, camera traps, mammals, education, community conservation

Massive declines in biodiversity make the monitoring of species ever more important (Butchart et al. 2010, Ahumada et al. 2013, Dirzo et al. 2014), as does an understanding of changes in species composition. Studying populations across the large scales necessary for trends to be detected can be difficult, and such difficulties are particularly great in many regions in which biodiversity is highest. Paralleling declines in biodiversity is a global widening disconnect between people and nature; most people now live in urbanized areas with modern lifestyles, have less access to, and spend less time in nature (Turner et al. 2004). This *extinction of experience* has been identified as a major threat to the conservation of biodiversity because people typically care about what they know, and such experiences in nature have been linked to future pro-conservation attitudes and behaviors (Pyle 1978, Chawla 1999). The decline of biodiversity combined with people's inability to recognize it sets the stage for a dangerous, negative feedback cycle in which the loss of biodiversity occurs without people noticing or caring (Schuttler et al. 2018).

To break this cycle, emphasis needs to be placed on initiating new connections between people and nature and on strengthening connections where they are weak. New research suggests that citizen science, an approach in which nonprofessionals participate in scientific research, can foster connections between people and nature where they live (Cosquer et al. 2012, Toomey and Domroese 2013, Schuttler et al. 2018) while providing a means for the long-term and large-scale data collection necessary for biodiversity monitoring (Cooper et al. 2007, Bonney et al. 2009). Across countries and projects, engagement of the public in nature-based citizen science has been shown to increase participants' awareness of the biodiversity where they live and to lead to proenvironmental behavior and attitude changes through their careful observations and purposeful data collection (Cosquer et al. 2012, Toomey and Domroese 2013, Forrester et al. 2016, Johnson et al. 2014, Schuttler et al. 2018). With increased knowledge and awareness of local biodiversity, participants notice changes and patterns in nature where they live (Cosquer et al. 2012), breaking the cycle of indifference.

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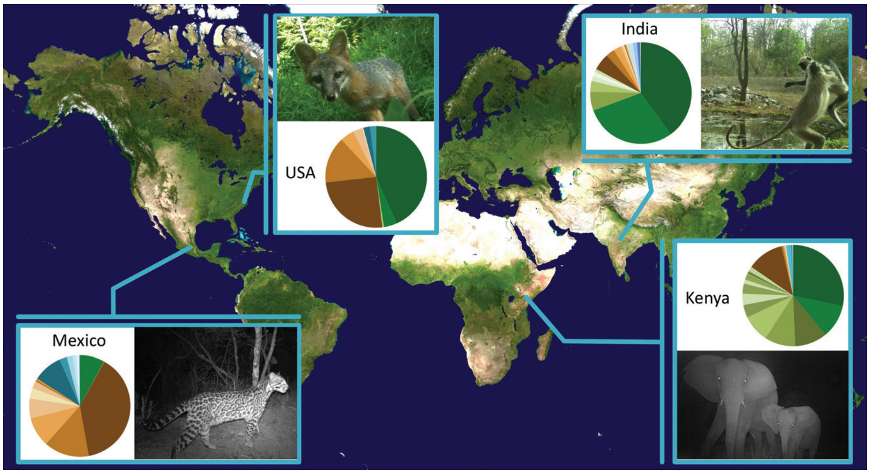

Figure 1. Locations of eMammal K–12 schools around the world with representative camera trap photos: United States, gray fox; India, Northern langur monkey; Mexico, ocelot; Kenya, African savanna elephant. The pie graphs show the total number of species and detections of species photographed in each country and color coded according to their trophic level. The species were categorized into carnivores (blue), omnivores (brown), and herbivores (green).

the Czech Republic (Zárybnická et al. 2017), the United States, and Italy (Lucky et al. 2014). For programs to be successful, activities need to align to education standards for teachers (Lucky et al. 2014), and there are also challenges for scientists; the protocols need to be feasible for the children to do in a reasonable time frame but remain robust and scientifically sound to ensure the data are reliable (Dunn et al. 2016).

In the present article, we describe a scalable model of citizen science research implemented in classrooms across four countries on three continents (figure 1). The central premise is that through engaging students and their teachers in learning about science by doing research, we can improve the public's understanding of scientific knowledge, make new discoveries, and foster a culture of excitement about science (Dunn et al. 2016). This project used the eMammal (emammal.org) camera trap data management system, allowing the students to study the mammal biodiversity that lives in their community, with quality control steps built into the workflow that ensure that the data are research grade. To evaluate the ability of children to collect useful camera trap data in schoolyards, we compared student-collected data with those of adult citizen scientists and professional biologists from protected areas of similar habitat and geographic range. Specifically, we compared the acceptance rates of camera trap deployments set up according to scientific protocols, detection rates, and species richness. Beyond scientific discovery, we also highlight eMammal's impacts on the students' engagement and the far-reaching messages of wildlife conservation to the community.

Such changes in participants can occur at any age, but we hypothesize that nature-based citizen science programs will be most effective when applied to youth, especially in school programs. Children are still forming their values and connections with nature during childhood are important and can endure into adulthood (Chawla 1999, Haywood et al. 2016). Therefore, programs targeted at youth may reach more receptive participants with long-lasting impacts. In addition, for the extinction of experience to be truly reversed, it is important to preach beyond the choir of those who care about nature. Many volunteers in citizen science are already interested in nature and highly educated, making before-and-after differences in attitudes and behaviors negligible (Schuttler et al. 2018). Incorporating citizen science in schools removes any participation bias as all children participate as part of their classroom activity.

Real science in schools

The logistics of targeting youth, especially during the school day, is more challenging. Some already question the reliability and quality of data collected by adult citizen scientists, let alone by children (Kremen et al. 2011, Gardiner et al. 2012, Kamp et al. 2016). Most studies demonstrating that children can do real science require heavy, hands-on involvement, which limits scalability and access of programs to classrooms. For instance, scientists in England incorporated 8–10-year-old students in a study on the learning behavior of bumblebees, allowing 25 students to devise and perform experiments, draw figures, and publish findings in a peer-reviewed scientific journal (Blackawton et al. 2011). Other projects, such as BirdsOnline and the School of Ants, have scaled to schools without in-person visits from scientists in

Teacher–scientist collaborations

We designed lesson plans to be mutually beneficial to scientists, teachers, and students. In 2014–2016, teachers engaged in scientific inquiry in a 3-week internship with scientists at the North Carolina Museum of Natural Sciences (NCMNS) and received ongoing support. They collaboratively developed lesson plans (available at https: //emammal.si.edu/content/emammal-academy) that aligned research with state and national science standards (Schuttler et al. 2017). We invited teachers from Mexico and India to participate through a collaboration among the NCMNS, the Museo de Paleontologia de Guadalajara, the Bombay Natural History Society, and in 2015, we expanded to Kenya through the Northern Kenya Conservation Club. Additional teachers joined in subsequent years through word of mouth.

Camera trap methods for classrooms

We trained the teachers in camera trap protocols through in-person workshops or online instructional videos, and

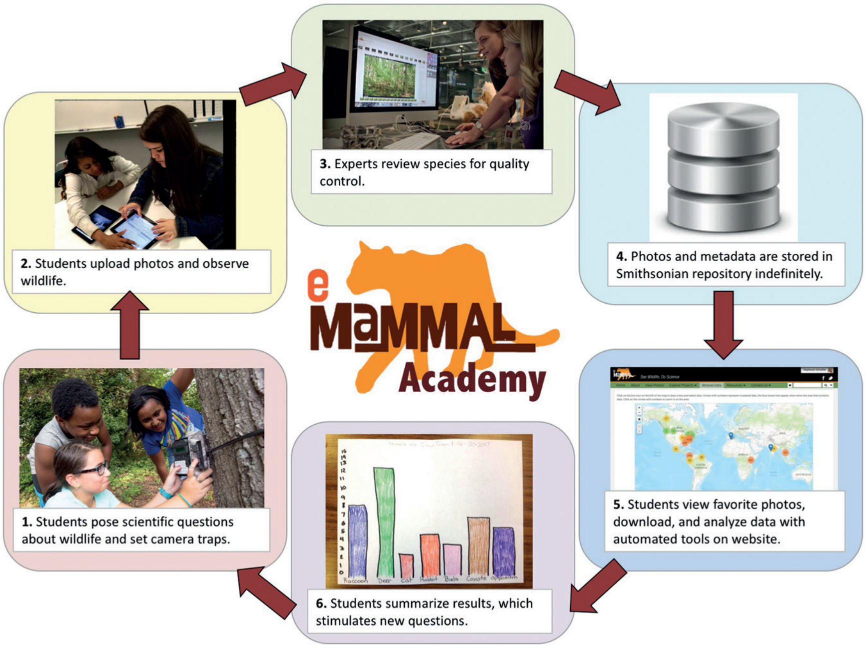

Figure 2. Student workflow of eMammal in the classroom. Data collection, viewing of photos, and the ability for students to download and analyze data through automated tools or by hand leads to future research questions.

the teachers were encouraged to involve their students in all aspects of research. The students and teachers deployed Reconyx RC55, HC500, PC800 (Reconyx, Inc., Holmen, Wisconsin), or Bushnell Trophy Cam HD (Bushnell Outdoor Products, Overland Park, Kansas) cameras on straight trees approximately 40 centimeters from the ground. The teachers were instructed to select sites randomly, independent of animal movement, and without bait, making the detection rate of animal activity comparable across sites (Rowcliffe et al. 2008, Rowcliffe et al. 2013). All locations were on school property or in areas within walking distance.

All of the cameras used an infrared flash and were secured by a lock. The cameras recorded 3, 5, or 10 photographs per trigger at a rate of 1 frame per second, retriggering immediately if the animal was still in view. We grouped consecutive photos into sequences less than 60 seconds apart, which were used as independent detection records for analysis (Kays et al. 2016). The teachers ran camera traps for at least one deployment, during which the cameras were left in one place for approximately 2–4 weeks; afterward, their memory cards were collected. The teachers were encouraged to continuously run camera traps throughout the school year at the same or different sites.

The teachers and students uploaded photos and identified species using customized eMammal software. The students identified species in small groups on individual computers or as a class with photos projected and the class reaching a consensus on species identifications. They chose the species they believed were in each sequence from a list of species that could be found in their geographic area.

All of the photos were reviewed by experts to ensure correct species identifications and were stored in a Smithsonian Data Repository (figure 2). The photos that did not meet eMammal protocols (e.g., cameras set too low or too high) were rejected and not included in further analyses. To assess the quality of the data collected by the students, we compared the acceptance rate of camera trap deployments set by the students with those deployed by adult citizen scientists from a previous study with the same protocols. After expert review, the species were classified as herbivores, omnivores, or carnivores according to the criteria in Jones and colleagues (2009) or Kingdon (2015). We calculated the detection rate for each species by dividing the number of detections by camera nights to compare the relative activity levels.

Worldwide school locations and comparison sites

We compared the student-collected data to previously collected data from adult citizen scientists in William B. Umstead State Park (hereafter, *Umstead*) from Kays and colleagues (2016). The teachers in North Carolina were in five counties across the state; however, most of the schools were in Wake county, in the central zone of North Carolina, and we therefore chose Umstead, a state park also located in Wake county (figure 3a). The data in Umstead were collected according to the same methods as those of eMammal citizen science, except in Kays and colleagues (2016), volunteers were directed to a GPS coordinate and instructed to deploy a set of three cameras—one on the hiking trail, and the others 50 meters (m) and 250 m from the trail (measured perpendicular to the trail).

The final locations in Kenya included six schools across northern central Laikipia county (figure 3b). The schools were located in similar habitats, but the densities of domestic species varied greatly among them. We compared the school data from a previous study using cameras set on conservancies managed for livestock and wildlife, tourism, or research also in the northern central region of Laikipia county (Kinnaird and O'Brien 2012). In this this study, film and digital camera traps were placed within 50 m of a centroid created from 1- or 2-square-kilometer sampling units and typically on game trails. The cameras were run for 19–23 days, and consecutive photos of animals of the same species were grouped into sequences as independent detection records if they were less than 30 minutes apart (O'Brien et al. 2003).

We included six schools outside of Central Guadalajara, in Jalisco, Mexico, in almost all directions (northern, southeastern, southwest, and eastern, figure 3c). We did not have access to comparable camera trap data from a similar

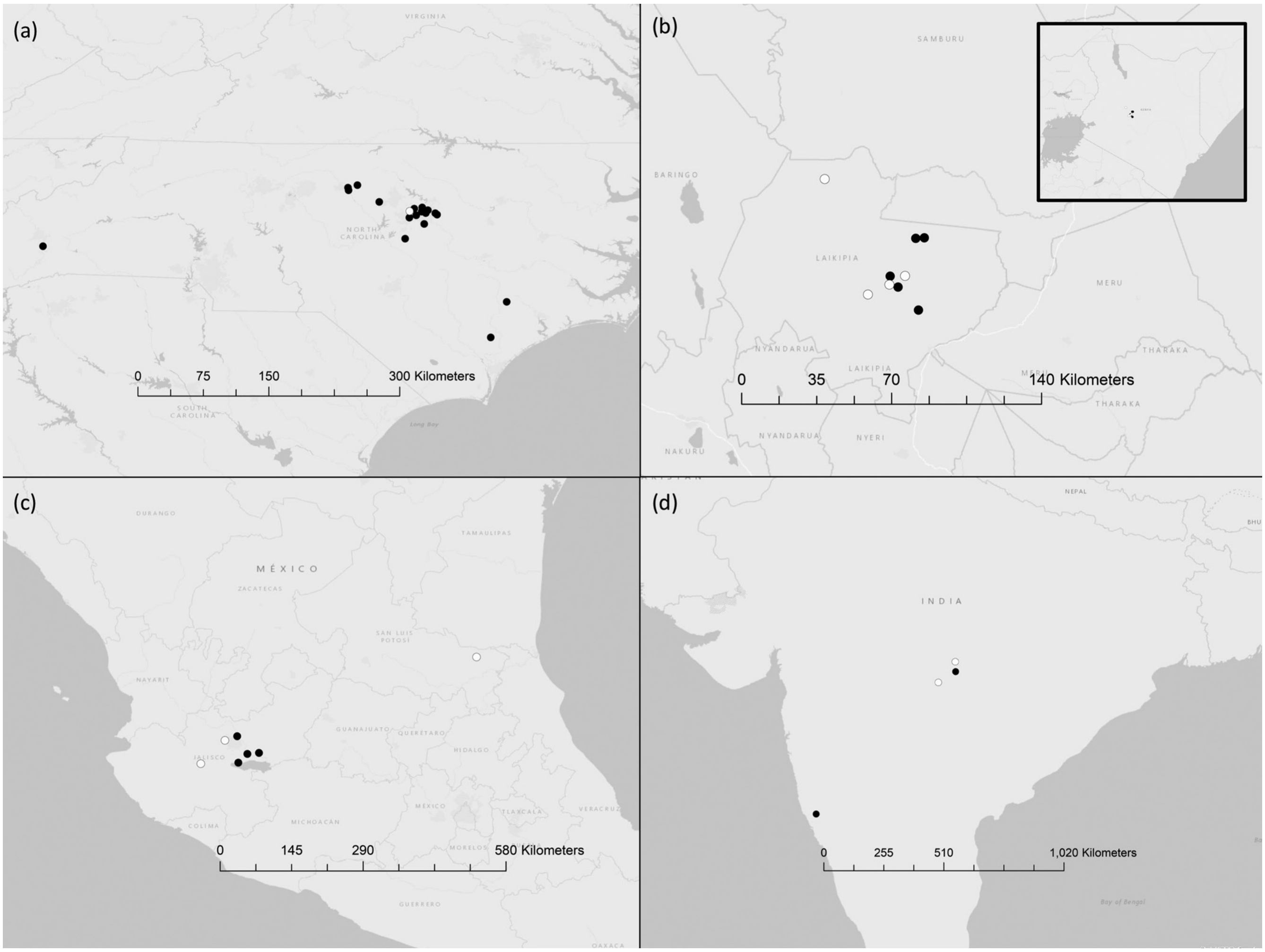

Figure 3. Locations of eMammal schools (the black circles) and nearby protected areas (the white circles) in (a) the United States, (b) Kenya, (c) Mexico, and (d) India.

Table 1. Summary information on camera traps run in each country.

Country	Number of schools	Number of locations	Number of trap nights	Number of wildlife detections	Number of species
United States	15	42	846	6425	13
Mexico	6	12	661	1802	18
India	2	12	155	1364	21
Kenya	5	9	375	4311	37

geographic region. However, the students did set some camera trap deployments in two small wildlife protection areas, La Primavera and Sierra de Quila. We therefore compared the camera trap data from the school grounds with those from these preserves and with the published results of other studies in similar areas within Mexico.

We included two schools in India, both of which were in Maharastra but which were spread across the state (figure 3d). The first school was located in the western Ghats region, near Amboli, whereas the second was located in Central India, north of Nagpur and close to Pench National Park. In India, we also did not have access to comparable data in similar geographic regions and therefore discuss the student results in the context of previously published research.

Results of the student-run camera traps

Students (ages 9–14) from 28 schools around the world deployed camera traps over 2037 trap nights, yielding 13,710 detections of 83 native mammal species, including endangered species. The total wildlife detection rates were highest in Kenya, followed by India, Mexico, and the United States (table 1). The teachers ranged in their frequency of use of eMammal in the classroom, with some using it for only one deployment, whereas others used it for multiple years (up to 37 deployments). Nearly all (94.4%) deployments were set properly and accepted as high-quality data, which was the same percentage observed for the adult

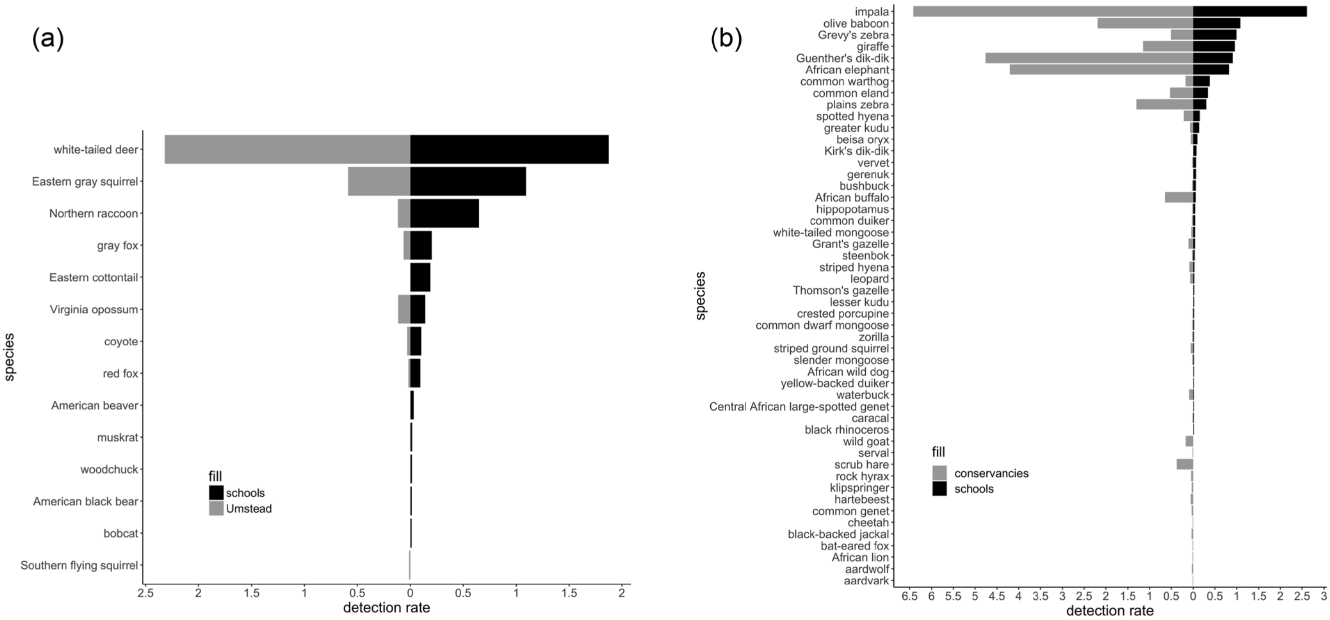

Figure 4. Detection rates of mammal species photographed in (a) the United States and (b) Kenyan schools compared with nearby protected areas. To visualize rarely detected mammals on figures, the value 0.01 was added to all detection rates except for species that were not detected.

volunteers in a previous study using the same protocols (McShea et al. 2016).

In the United States, the student-run camera traps in schoolyards captured more species (n = 13) with higher detection rates than those in Umstead (figure 4a). The species captured on school cameras but not captured in Umstead included the American beaver (*Castor canadensis*), the American black bear (*Ursus americanus*), the bobcat (*Lynx rufus*), the Eastern cottontail (*Sylvilagus floridanus*), the muskrat (*Ondatra zibethicus*), and the woodchuck (*Marmota monax*). Only one mammal species, the Southern flying squirrel (*Glaucomys Volans*), was photographed in Umstead and not also detected on the student camera traps.

The highest species richness for schools was found in Kenya, with a total of 37 native species detected. The species richness of mammals detected in school habitats in Kenya was lower than the richness of the conservancies, and most species had lower detection rates near schools than in the conservancies (figure 4b). The conservancy camera traps had higher effort, with cameras running approximately four times longer from January to April 2008 and July to September 2009, photographing 34,819 detections of 42 mammal species over 1489 nights. The conservancy camera traps detected 13 species not captured on the students' cameras, whereas the students captured 8 species not captured on conservancy cameras, including the endangered African wild dog (*Lycaon pictus*) and the critically endangered black rhinoceros (*Diceros bicornis*, figure 5).

In Mexico, the mammal community was largely made up of omnivores and carnivores, representing over 75% of the detections (figure 1). The students photographed 18 species and most frequently detected the Virginia opossum (*Didelphis virginiana*, n = 393), followed by gray fox (n = 145), the endemic ring-tailed ground squirrel (*Notocitellus annulatus*, n = 95), the hooded skunk (*Mephitis macroura*, n = 93), the white-tailed deer (n = 79), the ring-tailed cat (*Bassariscus astutus*, n = 64), the Northern raccoon (*Procyon lotor*, n = 34), the coyote (n = 24), the jaguarundi (*Puma yagouaroundi*, n = 23), the bobcat (*Lynx rufus*, n = 19), the American hog-nosed skunk (*Conepatus leuconotus*, n = 12), the puma (*Puma concolor*, n = 9), the white-nosed coati (*Nasua narica*, n = 7), the ocelot (*Leopardus pardalis*, n = 3), the Southern spotted skunk (*Spilogale angustifrons*, n = 2), the Mexican fox squirrel (*Sciurus nayaritensis*, n = 1), the collared peccary (*Pecari tajacu*, n = 1), and the nine-banded armadillo (*Dasypus novemcinctus*, n = 1).

The students also ran camera traps in two protected areas, Sierra de Quills and La Primavera. The camera traps were run there for fewer days (104.2 compared with 501.5 for schoolyards) and at fewer locations (n = 10 compared with n = 29). The cumulative species detections in the schoolyards exceeded those of the protected areas (17 and 9 respectively). The detection rates were also lower overall for the species in the protected areas, except the Mexican fox squirrel (*Sciurus nayaritensis*).

The students in India detected 21 species, which were dominated by herbivores (75% of detections, figure 1) but also included large predators, such as tigers (*Panthera tigris*, n = 16), dholes (*Cuon alpinus*, n = 22), and leopards (n = 11). Other species detected in the schools included the northern plains gray langur (*Semnopithecus entellus*,

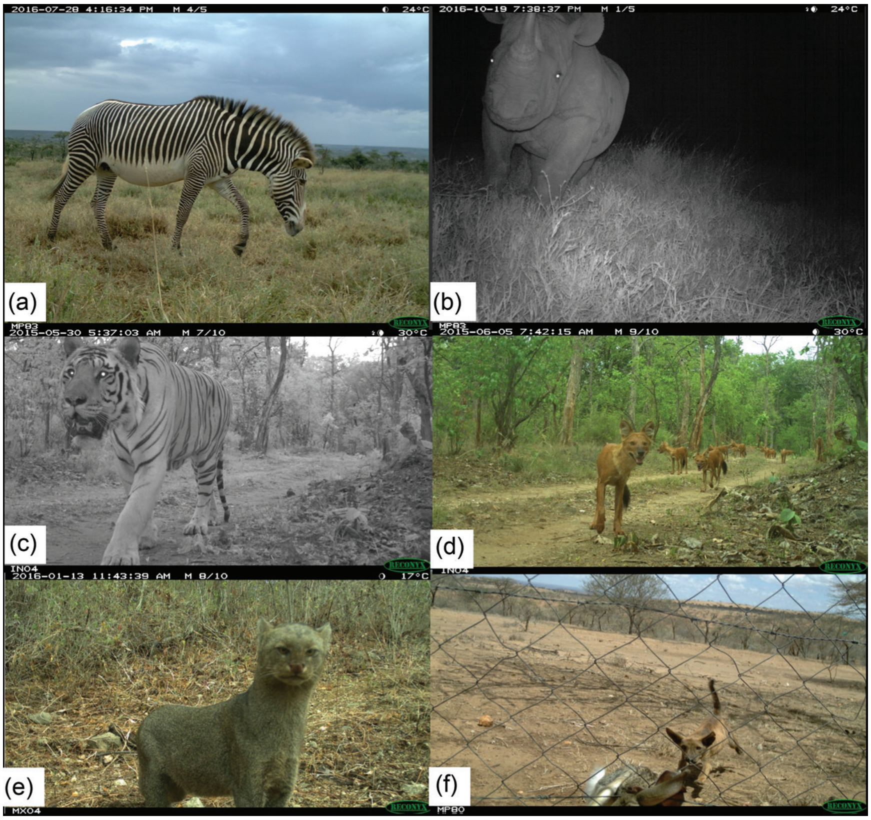

Figure 5. Students ran camera traps that captured species of significant conservation status including (a) the endangered Grevy’s zebra, (b) the critically endangered black rhinoceros, (c) the endangered Bengal tiger, (d) the endangered dhole, and the (e) Mexican listed jaguarundi. The students also captured domestic species, which can negatively influence native species. In Kenya, a dog was observed chasing a native hare (f).

n = 457), the chital (*Axis axis*, *n* = 337), the sambar (*Rusa unicolor*, *n* = 69), the wild boar (*Sus scrofa, n* = 61), the Indian hare (*Lepus nigricollis*, *n* = 40), the Indian crested porcupine (*Hystrix cristata*, *n* = 32), the southern plains gray langur (*Semnopithecus dussumieri*, *n* = 28), the northern red muntjac (*Muntiacus muntjak*, *n* = 18), the gaur (*Bos gaurus*, *n* = 16), the Indian chevrotain (*Moschiola indica*, *n* = 10), the brown palm civet (*Paradoxurus jerdoni*, *n* = 8), the Indian gray mongoose (*Herpestes edwardsii*, *n* = 5), the small Indian civet (*Viverricula indica*, *n* = 5), the honey badger (*Mellivora capensis*, *n* = 3), the jungle cat (*Felis chaus*, *n* = 3), the nilgai (*Boselaphus tragocamelus*, *n* = 1), the common palm civet (*Paradoxurus hermaphroditus, n* = 1), and the ruddy mongoose (*Herpestes smithii*, *n* = 1).

Do children collect data useful for conservation and research?

We have demonstrated that children can collect valuable camera trap data on a variety of species in vastly different settings around the world through sampling habitats on or near their schoolyards. Collectively, the children photographed 13–37 species across four countries with an average of 22.3 species per country, and in most countries, the species diversity was comparable with those of nearby protected areas. The students captured 86% of the mammal diversity of conservancies in Kenya, and in the United States, their count exceeded state park diversity by 62%. The data sets from the students included listed species on the International Union for Conservation of Nature’s (IUCN) red list of threatened species. The students photographed seven vulnerable, four endangered, and one critically endangered species, including high-profile species such as the black rhinoceros, the African elephant (*Loxodonta africana*), and the Bengal tiger (*Panthera tigris*, figure 5).

The student data across countries also provided important information for conservation through detections of invasive species, which negatively affect native species through competition, displacement, or predation (Gurevitch and Padilla 2004). In our study, all invasives were domestic, and of these species, of biggest conservation concern is the domestic cat (*Felis catus*), known for its widespread negative impacts on wildlife—notably, birds (Medina et al. 2011, Loss et al. 2013). Domestic cats were found in each country but were detected at the highest rate in North Carolina (0.15 detections per day) and at the lowest in Kenya (2 detections total).

Dogs (*Canis familiaris*) were widespread on the camera traps and were detected at higher rates than cats in most of the countries we surveyed (0.56 dog detections per day in the United States). Dogs have received less attention in relation to their impacts on wildlife but have contributed to 11 vertebrate extinctions and are a known or potential threat to 188 threatened species worldwide (Doherty et al. 2017). The significance of dogs’ impact on wildlife varies by country. For instance, the detection rates were highest in North Carolina, but previous studies suggest that dogs in the United States have little impact on wildlife, because they are usually accompanied by their owners even when off leash (Parsons et al. 2016). In contrast, the Kenyan students found a similar detection rate (0.58 detections per day), but in Kenya, dogs are frequently unleashed, unattended, free ranging, and less likely to be vaccinated (Knobel et al. 2014). In Kenya, rabies and canine distemper have both previously transmitted to endangered wildlife (Kat et al. 1996, Cleaveland et al. 2000), and estimating the abundance of dogs may provide useful estimates for exposure risk. If they are underfed, individual dogs can prey on small wildlife, and when packs form, larger species are hunted (Silva-RodrÍguez and Sieving 2011, Ritchie et al. 2014). In our study, one photo sequence in Kenya captured a native hare squeezing through a fence to avoid a dog attack (figure 4).

The higher detection rates of carnivores (coyotes, foxes, black bear, bobcat) found in schoolyards are surprising, given that many schools had small patches of forested property suitable to place a camera trap. Historically, carnivores are sensitive to human disturbance and are thought to be the most at risk from urbanization because of the loss of continuous habitat frequently necessary for their larger home ranges (Woodroffe 2000, Crooks 2002). Most schools (66.6%) were located in the suburbs, and these patches, located within a larger, urban matrix, seemed unlikely to support a rich carnivore community.

However, some species thrive in developed habitats, and even larger carnivores can flourish in some highly urbanized areas. For instance, coyotes have established populations in large metropolitan areas, including Chicago, Los Angeles, and New York City (Bateman and Fleming 2012). However, they still prefer and include nonurban habitat within their home ranges (Gese et al. 2012). Coyotes are more recent arrivals to North Carolina—within the last three decades—and are detected in suburban areas but still tend to be in green spaces rather than people's yards (Kays et al. 2015). An Undeveloped areas within schoolyards may be an important component within suburban coyotes' home ranges.

Also surprising is that the students captured 62% more diversity than was found in the state park, despite running camera traps at fewer locations (42 versus 67). Some of the diversity may be explained by site selection and range. For instance, some schools set up camera traps near ponds, whereas the Umstead sites were chosen on the basis of proximity to trails (Kays et al. 2016). Umstead is also located outside of black bear range, and the camera traps in Umstead were run for 165 fewer days than were those at the schools, collectively. Despite these caveats, the diversity of mammals captured and the overall higher detection rates in schools relative to those in this large state park suggest that school habitat can support mammal diversity similar to protected areas in North Carolina. Furthermore, it shows that the data collected on wildlife around schools are highly relevant in documenting the diversity of species and habitats in the state. These results also echo those of a larger study that vigorously sampled development zones within the urban–wild gradient across Raleigh, North Carolina; Parsons et al. (2018) found that developed areas had the highest detection rates and diversity of species, including of native predators.

The students in Mexico had similar results to those in the United States when comparing school camera trap data with the two protected areas the students ran camera traps in. Almost twice as many species were captured near the schools (9 and 17, respectively), and the detection rates were lower for all species except the Mexican fox squirrel (*Sciurus nayaritensis*) in the protected areas. Overall, no species captured in Mexico were on the IUCN red list, but the jaguarundi (*Puma yagouaroundi*) and the ocelot (*Leopardus pardalis*) are species listed by the Mexican government, and both were detected repeatedly (n = 23 and 3, respectively) around the schools but not in the reserves. Although it is unexpected that cameras in protected areas would have revealed fewer species, this may be explained by the shorter length of time the cameras were deployed for and the lower number of locations they were deployed. For instance, a study in the Sierra del Abra-Tan chipa Biosphere Reserve northeast of Guadalajara in which camera traps were also used had a native species richness almost the same as that of the schools (Hernández-SaintMartín et al. 2013). These camera traps were run much longer than those at the schools, with more than 9000 nights and more than 100 locations. Again, this underscores the importance of schools as habitat for wildlife and the students' ability to contribute important data for conservation. This camera trap study was the only study close enough in geographic proximity to compare the students' data with, which also highlights the need for future studies in this region.

In Kenya, the opposite trends were detected, such that camera traps in the wildlife-protected conservancies had a higher species richness and, for most species, higher detection rates. The conservancy camera traps detected 13 species not photographed on the students' cameras; however, the students did detect 8 species not captured on the conservancy cameras—notably, the endangered African wild dog (*Lycaon pictus*) and the critically endangered black rhinoceros (*Diceros bicornis*). African wild dogs have been documented on conservancies previously, and because of poaching, black rhinoceros are now in fenced sanctuaries, making it impossible for them to be detected elsewhere. Larger cats, such as the African lion (*Panthera leo*) and the cheetah (*Acinonyx jubatus*), were absent around the schools, but leopards (*Panthera pardus*) were detected five times. The abundances of lions and cheetahs have declined following direct persecution in the study region because of livestock losses (Woodroffe and Frank 2005, Durant et al. 2017), whereas leopards are generally better able to survive near settlements (Caro and Riggio 2014).

Species richness varied dramatically among the schools (2–29), and when looking at photos, there were stark differences in the amount of vegetation and land degradation. Two schools with fewer livestock detections had the highest species richness (29 and 15 species), whereas other schools with higher rates of livestock detection and fences had the fewest (2–9 species). Of all the countries, the Kenyan schools had the highest detection rates of livestock, including goats (7.75 detections per day), sheep (6.86 detections per day), and cattle (4.65 detections per day), which likely affected the native wildlife. The native mammal species richness, abundances, and distribution patterns were also related to livestock stocking levels in Kinnaird and O'Brien (2012); in areas in which stocking levels were increased, all metrics of biodiversity declined. Given that the majority of large mammal populations in East Africa occur outside of protected areas (Western 1989, Ottichilo et al. 2000), and in

Figure 6. eMammal had widespread community impacts: (a) Students in Mexico presented their results to the mayor of Guadalajara and the US ambassador to Mexico. (b) A community conservation day in Kenya led to discussions on land use practices in the community. (c) At a capstone event in North Carolina, American, Indian, and Mexican students presented results to an international audience including officials of the US State Department. (d) We had substantial local, regional, or national news coverage.

the Laikipia region almost exclusively, a larger network of properties tolerating wildlife with adequate land use is vital for conservation (Kinnaird and O'Brien 2012).

The schools in India also proved to be promising habitat for wildlife: The mammal communities detected were comparable to those of previously published camera trap studies in India. Collectively, the schools' species richness values were similar to those of another study conducted in the Bor Tiger Reserve (Bhagat et al. 2016) but were different in composition. Large predators, such as the Indian gray wolf (*Canis lupus pallipes*), the hyena (*Hyaena hyaena*), and the sloth bear (*Melursus ursinus*), were absent from the schools but were detected in Bor. The students did record endangered dholes and tigers—and, for the latter species, more than researchers did in Bor and in another study in Pench National Park (Karanth and Nichols 1998). Sixteen tiger detections representing at least six individuals were photographed on the school camera traps, even though the cameras were not set with protocols to capture and identify individual tigers (Karanth and Nichols 1998). To put this in perspective, four unique individuals were found in Bor, with a much larger camera trapping effort of 49 cameras over 400 square kilometers and 40 days (Bhagat et al. 2016), and 5 cameras in Pench with 16 sampling occasions over 12–15 sites and 788 trap nights (Karanth and Nichols 1998). Tiger populations have increased in India, and camera trap technology has improved since Karanth and Nichols (1998), which likely increased the detection probability of tigers, which may explain why the students detected more individuals. However, these results also support the importance of community-run cameras. India is a stronghold for tigers, and protected areas are not large enough to support growing populations without connectivity for gene flow (Ranganathan et al. 2008, Mondal et al. 2016). For instance, the aforementioned Bor Reserve was created against recommendations set for tiger reserves because it is too small, but it remains an important stepping stone between larger protected areas (Bhagat et al. 2016).

Engaging students in nature through camera traps

The teachers reported that eMammal engaged their students and provoked their curiosity and that the students were more willing to participate in eMammal than in other classroom activities. Some students were so excited to check the camera traps that they counted down the days and "screamed" with excitement when they viewed the images of the animals they had captured. When the students became aware that the photos they collect are stored in a Smithsonian repository, it gave their classroom activities meaning and purpose, resulting in the students' setting cameras more carefully and caring about the data.

The students learned local natural history by identifying diverse species they did not normally see (e.g., nocturnal animals, species that avoid humans), observed that animals navigate and gather information about their environments and are not simply "robots walking through the forest," as they had previously been described by one student. Correct identifications of species (62.6%–76.3%) was lower for the students than for the adult participants from a previously published study (Forrester et al. 2016). eMammal users now receive feedback on their identifications, offering the students the opportunity to improve their knowledge of local mammal biodiversity. Increased knowledge and observations of nature, combined with direct experience in the areas in which they live, are characteristics essential in reversing the extinction of experience (Miller 2005).

Community-wide impacts

The impacts of student research spread beyond the classrooms involved and permeated throughout their communities. The schools organized events in which their photographs were displayed, which led to discussions about the management and conservation of local mammals. On the basis of real data gathered by children, information on wildlife trickled up to adults in these communities and, in Mexico, even to government officials. The students presented their final results to the mayor and the consulado general de los Estados Unidos on a large camera trap they had created using a television screen (figure 6). At the Northern Kenya Conservation Club's annual Community Conservation Day, the students assisted in creating graphs using automated data analysis tools from the eMammal website (figure 2) on the number of detections of each species at the different schools to an audience of hundreds of people from nearby villages. The community members could easily see that the camera traps set in pastoral areas showed many domestic animals, whereas those closer to the Mpala Research Centre and local conservancies showcased more diverse wildlife. In all of the countries, the student research was reported in newspapers and featured on television, reaching regional and even national audiences (figure 6).

Limitations

Despite the success of the program, challenges exist. Research-grade camera traps with short trigger speeds are necessary for quality studies but are expensive ($200–$450) and require school funds if scientists do not provide camera traps for schools to borrow. For international projects, cameras are costlier to ship from US vendors, and developing countries are more likely to be limited by technology to upload photos. These classrooms may require additional funds to purchase hotspots or transportation to bring devices with camera trap data to locations in which the Internet is available.

Camera traps are secured by cables and locks to trees, but thefts and damage to camera traps still occurs. Cameras seem to be more vulnerable internationally, with most damage to cameras from people occurring in Kenya, but theft and damage was also common in one area in North Carolina. Some schools are too urban or not suitable to run camera traps at, either because of a high volume of human triggers or a high risk of theft. In these cases, camera traps can be run in the students' yards or alternative locations.

Finally, the project is currently limited by scientists' time and cloud computing costs. The photos are stored indefinitely in a Smithsonian repository, and the costs are associated with processing and packaging images in the cloud for expert review (figure 2). There is ultimately a limit on how many photographs scientists can review. Crowdsourcing species identifications is an option to reduce the volume of photos for review, and eMammal has collaborated with Zooniverse (zooniverse.org), a crowd-sourcing platform that solicits volunteers from around the world for online classifications. However, there will still be disputed identifications that scientists will have to manually review, and the most promising solution may be automated species identifications through software (He et al. 2016).

Conclusions

Scientists interested in conducting mammal research with K–12 schools are encouraged to use eMammal software and lesson plans to carryout studies. Both are freely available, but funds are needed for camera traps and uploading costs. We found it best to recruit teachers directly, because teachers who are highly interested are motivated to make the program work at their school and to gather the appropriate permissions from their administrators. Scientists and educators interested in participating in the program can visit *https://emammal.si.edu/students-discover* to sign up.

Through camera trapping in eMammal, we show that K–12 students can contribute valuable scientific data with far-reaching impacts in community outreach, classroom engagement, and conservation. A high percentage of the camera trap deployments were accepted, and the students captured thousands of photographs, with overall species richness levels comparable to nearby protected areas, making eMammal an effective tool for monitoring mammal biodiversity. By incorporating citizen science in classrooms, scientists not only have an effective means to monitor biodiversity across a large scale but also a means for youth to experience nature and perhaps to offer them a chance to become stewards for nature.

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