Home security cameras as a tool for behavior observations and science affordability

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Abstract:

Reliably capturing transient animal behavior in the field and laboratory remains a logistical and financial challenge, especially for small ectotherms. Here, we present a camera system that is affordable, accessible, and suitable to monitor small, cold-blooded animals historically overlooked by commercial camera traps, such as small amphibians. The system is weather-resistant, can operate offline or online, and allows collection of time-sensitive behavioral data in laboratory and field conditions with continuous data storage for up to four weeks. The lightweight camera can also utilize phone notifications over Wi-Fi so that observers can be alerted when animals enter a space of interest, enabling sample collection at proper time periods. We present our findings, both technological and scientific, in an effort to elevate tools that enable researchers to maximize use of their research budgets. We discuss the relative affordability of our system for researchers in South America, home to the largest ectotherm diversity.

Introduction:

Accurately quantifying animal behavior is important for understanding how behavioral adaptations evolve and influence the fitness and survival of a species. However, human presence can obscure natural behaviors (Sorge et al., 2014; Puścian & Knapska, 2022) and remote cameras bypass the need for physical presence of the researcher. Remote camera approaches are used to study behavior at the population (Tape & Gustine, 2014; Jachowski et al., 2015; Buchholz et al,. 2021; Cserkész et al., 2023) and individual levels (Caravaggi et al., 2020). Mammals and birds are the most common fauna monitored with cameras in the wild and only a small range of studies (<2%) have focused on ectotherms, specifically amphibians and reptiles (Burton et al., 2015; Hobbs and Brehme, 2017; Welbourne et al., 2017; Barata et al., 2018; Amber et al., 2021). This gap between ectotherms and endotherms can be explained by both technical and logistical difficulties, as many camera traps rely on body heat signatures (infrared, IR) and can be difficult to use in remote areas. An ideal camera system should be capable of detecting small ectotherm movement, weather-resistant, and operational in the absence of electricity and phone connectivity.

Differences in science productivity play against a backdrop of resource disparity. Economically exploited countries in the Global South hold much of the world's ectotherm biodiversity, and yet accessibility and affordability of camera traps for local researchers can be prohibitive. For example, increasing camera weather resistance correlates with higher prices and many camera traps rely on Global North cellular networks. We here describe an affordable camera system (Wyze), that uses pixel change, rather than IR detection, to trigger recording. We benchmark the system against three commonly used camera traps and discuss their suitability to monitor cold-blooded animals. We present a case study on how this camera system can be used to quantify social behavior in a small, diurnal poison frog (*Ranitomeya variabilis*) both in captivity and in the wild. Finally, we suggest efforts to make the system more available for colleagues in the Global South as an example of how privileged institutions can actively contribute to making science more accessible.

Results & Discussion:

Benchmarking remote monitoring systems for small ectotherms

We compared specifications, performance and availability of two monitoring systems (Reconyx [Holmen, WI, USA] and Bushnell [Overland Park, KS, USA], used in Hobbs and Brehme, 2017), two home security cameras (Wyze, used herein; Google Nest [Mountain View, CA, USA], used in Refinetti, 2020 and Hussey and LaPlante, 2024), and a manual camera system (Sony [Tokyo, Japan], used in Shen et al., 2023) used across mammals, fish, and amphibians to evaluate the suitability for lab and field studies of amphibian behavior (Table 1). We found that the home security camera Wyze v3 is on par or superior to other professional systems regarding image and video quality, detection methods, field of view and motion detection video length while being 3-18 times less expensive.

The main challenge in remotely recording ectotherms is that many camera traps rely on passive infrared sensors (PIR) to detect thermal emissions (heat) of endotherms (mainly mammals and birds) (Savidge & Seibert, 1988; Karanth, 1995; Hobbs & Brehme, 2017). Wyze v3 is the most affordable indoor and outdoor camera that uses pixel change, rather than IR detection, to trigger recording, which enables detection of ectotherms. In contrast to other systems we evaluated, Wyze v3 has multiple degrees of night vision capabilities, including color night vision for dawn and dusk hours and for fully dark environments both near-infrared for close distance (940 nm) and far-infrared light range for far distance (850 nm).

An additional feature that is advantageous in the laboratory is the ability to signal to cellular devices to notify the user of a trigger. Many home security devices use the same technical infrastructure for monitoring filmed areas, such as a baby's nursery or the front door to a home. Wyze v3 connects to local networks rather than having 3G or 4G coverage, which is better for accessibility in countries in the Global South. Other considerations for remote recording of ectotherms are the humid wet environments, device weight, and connectivity. Most cameras we evaluated are water resistant and suitable for outdoor placement. Wyze cameras are also relatively lightweight, which is critical for field applications where cameras are carried long distances to record for long periods of time.

Wyze cameras have been used to record behavior in frogs (Gupta et al., 2016), fish (McGaugh et al., 2020), pigs (Netzley et al., 2021), and chimpanzees (Havercamp et al., 2022). Recently, Wyze cameras have also been paired with robotics to quickly and efficiently manipulate behavioral interactions when the camera was triggered (Chen et al., 2023). The diversity of animals and environments studied with these cameras illustrate their adaptability for many research projects.

Table 1. Wyze v3 performance for studying ectotherm behavior in comparison to four leading surveillance devices. We benchmark features and accessibility of Wyze v3 against four hypothetical camera traps for animal behavior currently on the United States commercial market (Google Nest, Sony, Reconyx Hyperfire 2, Bushnell Nature View HD). If cameras are no longer commercially available by the original vendor, we provide the most similar commercially available camera from the same vendor. We discuss each feature in the context of studies on amphibian behavior. Abbreviations: LTE: long term evolution (a standard for wireless data transmission), HD: high definition, PIR: passive infrared sensor, IR: infrared, CMOS: Active pixel sensor; IP65 and IP66: indices for ingress protection (weather resistance, the higher the better), AA: single cell dry battery. Prices retrieved April 2024.

System Specifications	Consequence on Amphibian Studies	Wyze Camera v3	Google Nest Camera, Indoor & Wired	Sony Camera HDR-CX405	Reconyx Hyperfire 2 Cellular Professional Covert IR Camera	Bushnell Nature View HD
Ability to notify phone with local network	Quickly alerts researchers to behavior	Yes	Yes	No	Yes	No
Ability to notify phone without local network	Quickly alerts researchers to behavior	No	No	No	No	No
Cellular Source	Alerts rely on either local networks or cellular ones	2.4 GHz local Wifi	2.4GHz/5GHz) Wi-Fi	None	3-4G LTE (ATT & Verizon, some international plans)	None
Price (USD)	Cost influences number of cameras purchasable	$25.98	$99.99	$229.99	$459.99	$299.99
Image Resolution	Equivalent across most cameras	HD 1920 x 1080p	HD (1920 x 1080)	2.1 Megapixels (1920 x 1080)	1080P HD Widescreen	HD 1080P
Video Quality and sound	Equivalent across most cameras	HD 1920 x 1080p	HD (1920 x 1080)	1920 x 1080/60p	720P HD Video with Audio (cellular enabled cameras do not transmit video)	HD 1920x1080p
Detection Method (Day)	Risk of not detecting amphibians with PIR	Pixel change	Pixel change	Exmor R CMOS Sensor	PIR	PIR
Motion Detection Video length	Variable, depends on research goal	Up to 5 minutes per notification	Up to 3 hours of event history totally	None, manual	Up to 90 seconds per notification	up to 60s
Continuous Video length	Remote monitoring of behaviors that may last	24/7 for up to 4 weeks	24/7 for up to 10 days with subscription	Approximately 2 hrs 35	No continuous recording abilities	No continuous recording abilities

	longer than several minutes.	with SD card		minutes of battery life		
Detection Method (Night and wavelength in nm)	IR wavelength that can detect amphibians	Near-IR (940) and Far-IR (850)	Far-IR (850)	None explicitly stated	No-Glow™ High Output Covert IR	PIR
Camera weight (g)	Lower weights are more carryable for fieldwork	98.8	393	190-215	~750	246.6
IP Score	IP66 best for heavy pressurized water exposure, IP65 handles rain	IP65	None provided.	None provided.	IP66	IP66
Operating Temperatures (°C)	Most cameras tolerate most biome temperature ranges	-20 - +40	0-+40	None provided.	-40 - +60	-4 - +140
Night vision distance (m)	Depends on animal of interest	None provided	15	None provided.	45	18.3
Cloud saving abilities	Depends on researcher needs	Yes, with extra fees	Yes, with extra fees	No	No	No
Highest amount of internal memory allowed on camera via SD card (Gb)	Higher Gb allows for cameras being left alone longer	256	Up to 1 hr of internal storage (no Gb amount provided).	No limit for SD card	512	32
Power source (years last)	USB requires continuous power source, which needs to be resolved before field work	USB	USB	Battery or USB	12 AA (2 yrs)	AA (4-12) Up to one year
Field of View	Depends on camera's ability to orient and point towards area of interest	130°	135°	90-270°	None provided	50°

Proof of concept in the lab and field

As ectotherms constitute more than 99% of species diversity (Wilson, 1992; Ohlberger, 2013), affordable remote camera systems would substantially improve approaches for studying behavior across a wide range of species. In this case study, we show how Wyze v3 overcomes challenges of monitoring ectotherm behavior under lab and field conditions by monitoring parental behavior of *Ranitomeya variabilis* (Fig 1). In this species, eggs are laid terrestrially and then males transport their offspring to a pool of water, where the tadpole completes development (Brown et al., 2008).

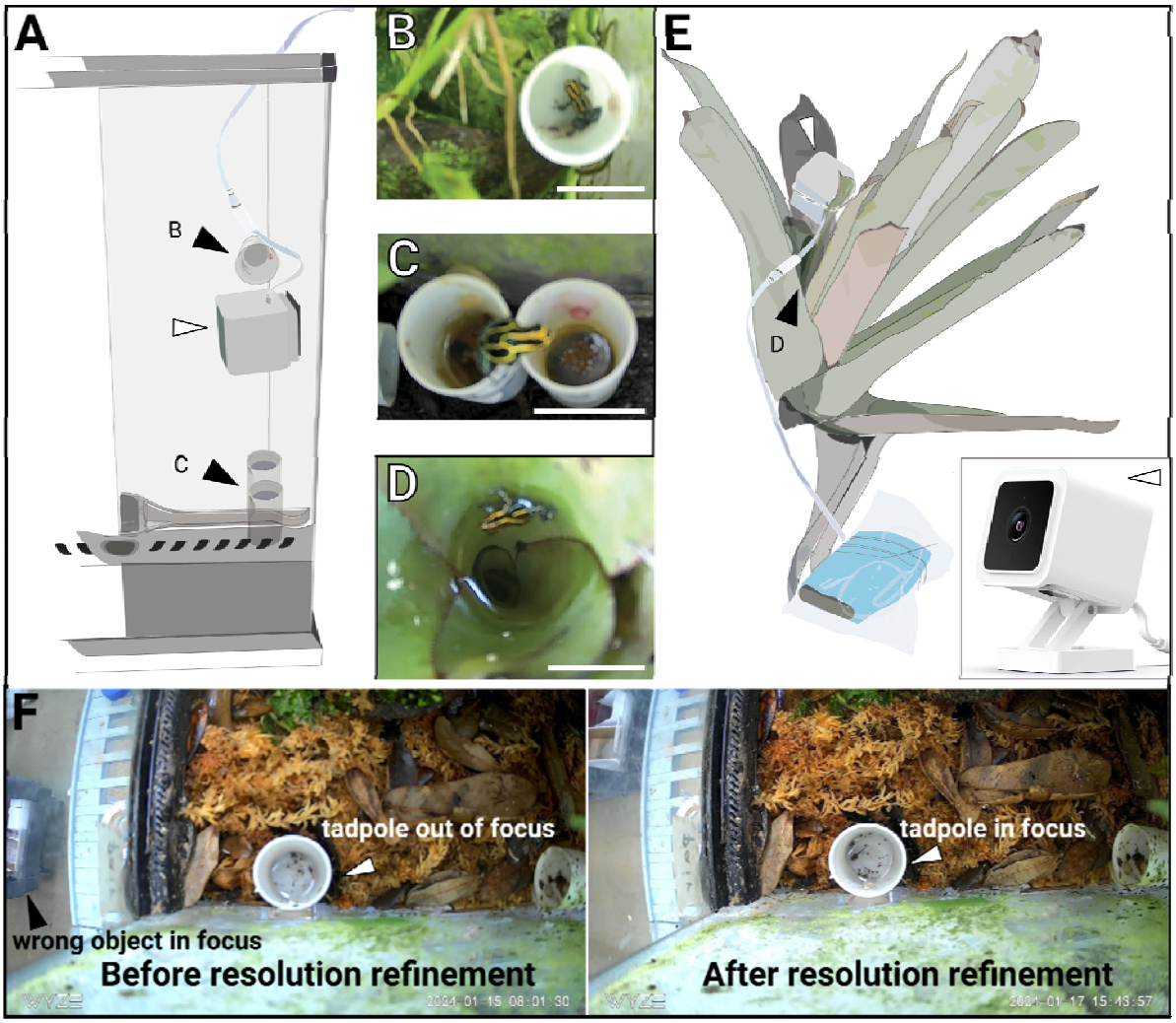

Fig 1. Camera installations in lab vivaria and in the field. **(A)** In lab vivaria, velcro was used to fix cameras above the desired focal subject, allowing for easy removal of the camera to switch SD cards. For monitoring parent-offspring interactions, the camera body (inlay, white arrow) was adjusted to focus on either the canisters containing the eggs that were mounted horizontally (inlay B) or the tadpole nursery (inlay C) (black arrows). The USB cables were connected to an outlet via a USB charging station. Inlay pictures represent screenshots extracted from the recordings obtained from **(B)** egg attendance, **(C)** tadpole attendance in captivity and **(D)** tadpole attendance in the field. White scale bars represent 30 mm. **(E)** In nature, tadpoles grow up in water bodies formed by tightly overlapping leaf bases (black arrow,

inlay (D) of large terrestrial plants called bromeliads. For observations, rubber bands were used to mount the cameras on bromeliad leaves above natural tadpole nurseries. The cameras (white arrows) were connected to the USB port of a power bank protected from the rain by two layers of plastic zip lock bags. Zoomed camera photo courtesy of Wyze Laboratories. **(F)** Cameras can be manually modified to improve resolution of focal sites, such as the tadpole inside of the plastic canister.

We first used Wyze v3 for recording and quantifying parental care behavior in laboratory vivaria. We specially tested whether there were sex differences in parental interactions with egg clutches or tadpoles in two *R. variabilis* families (Fig 2). Only the father showed clutch attendance, where he visited daily, with a maximum of four times in a day, over a period of 10 days. He spent more time with his clutch for the first 3 days after deposition (roughly 10 min) compared to the last 3 days of his clutch's development just before tadpole transport (roughly 5 min). These visits were typically spent touching or sitting on the eggs. In contrast, clutch visits by the female were limited to one brief event without physical contact with the clutch. During tadpole transport, the father transported each tadpole individually (n=3), with tadpole onboarding lasting 36 min on average. We also observed canister site fidelity for raising clutches, where the day after tadpole transport finished, the male resumed courtship and after two days of courting, the next clutch of eggs were laid.

Next, we observed nursery visitations by parents. Nurseries are pools of water where poison frog fathers transport their tadpoles, and tadpoles grow in nurseries until metamorphosis. To distinguish hydration from parenting, we added an empty water pool adjacent to the nursery. We found that both the male and female preferred to visit unoccupied canister pools (Figure 2B; 60% of female visits and 67% of male visits). The number and length of visits to tadpole pools was equivalent in both parents (Fig 2C).

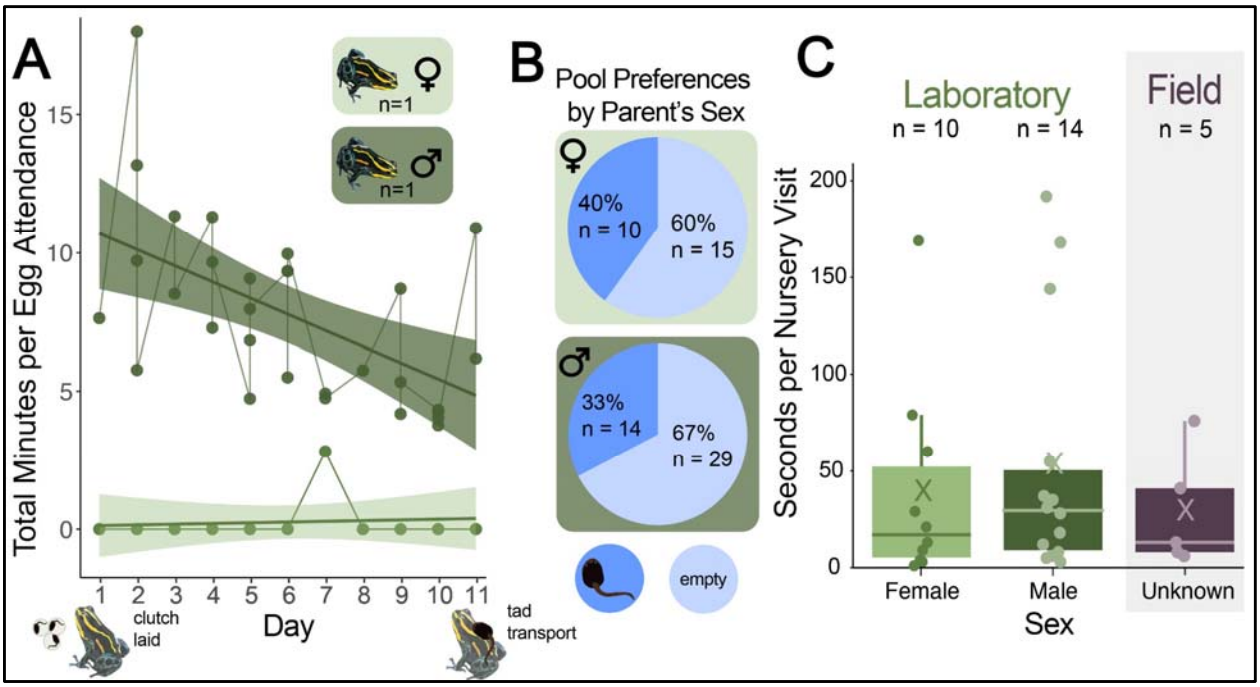

Fig 2. Comparisons of parental investment across offspring stage and in different environments. **(A)** Clutch attendance was a male duty (dark green). Dads displayed high time investments on visiting a freshly laid clutch that steadily decreased as eggs matured. **(B)** Tadpole nursery visits by female (light green) and male (dark green) *R. variabilis* in comparison to visits of an adjacent water canister (blue) not

housing offspring during the same monitoring period. **(C)** Captive frogs (green) visited tadpoles more often and exhibited more variance in durations of the nursery visits than wild frogs (purple), ranging from several seconds to minutes.

Remote observations of poison frogs in their natural humid and rainy climates require cameras with heat and water tolerance. We used the Wyze v3 cameras to record *R. variabilis* parental behavior in the Amazonian rainforest, where daily rainfall at the field site fluctuated between 0 to 30 mm and temperatures ranged from 20.5°C to 50°C. We monitored five tadpoles in bromeliad leaf axil pools for 10 days. Frogs visited tadpoles with less frequency (5 visits) and duration (average of 29 seconds) compared to the lab environment (Fig 1A, E). We also recorded transient behaviors that are rarely documented, like *R. variabilis* adult interactions with heterospecific intruders (Supp Video 1; Fig 3A), predator encounters (Supp Video 2; Fig 3B), and aggressive behavior between tadpoles (Supp Video 3, 0:18). The Wyze v3 camera allowed us to easily compare parental behavior of *R. variabilis*, a very small frog (around 17 to 18 mm, Summers et al., 2008), in lab and field conditions, and capture transient interspecies interactions occurring in nature. We also provide the first evidence that *R. variabilis* surveys water bodies that house tadpoles in lab and field conditions. In the laboratory, we confirmed tadpole transport in *R. variabilis* is performed by male frogs (Summers et al., 2008), and describe how egg attendance behavior is being performed by males.

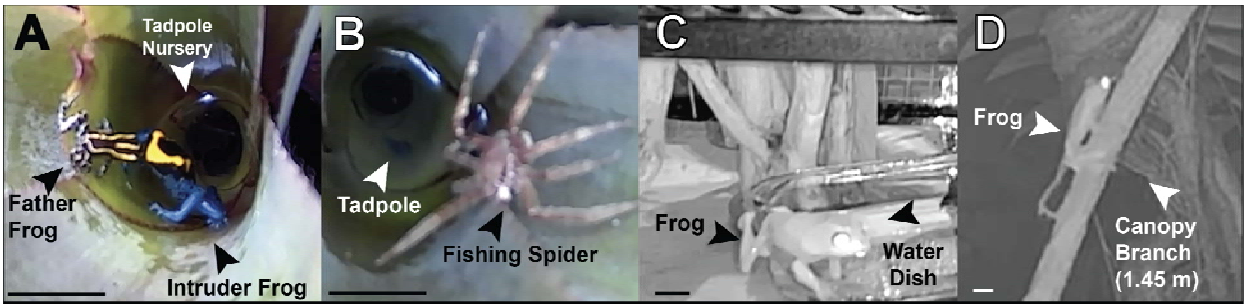

Fig 3. Remote and laboratory observation captures of frog behavioral ecology. (A) An *R. variabilis* male defends his tadpole nursery from a heterospecific intruder frog (*Dendrobates tinctorius*), a species with cannibalistic offspring. **(B)** An *R. variabilis* tadpole encounters a fishing spider (likely *Anclyometes* genus). **(C)** *C. craspedopus* frog visits the water pool at night. **(D)** Field observation of *C. craspedopus* frog climbing a canopy branch, with the frog and camera both at 1.45 m elevation from the ground. White and black scale bars (**A-D**) represent 30 mm.

Finally, we confirmed the camera could be used to record nocturnal ectotherm behavior. We recorded the fringed leaf frog (*Cruziohyla craspedopus*), which successfully triggered our camera (Supp Video 4; Fig 3C) both in captivity and in the field (Supp Video 5; Fig 3D). For example, we can observe a *C. craspedopus* individual climbing a branch during a behavioral experiment where we placed Wyze cameras in the forest to observe the activity and behavior of these frogs in their natural habitat (Fig 3D).

Camera resource affordability and access in scientific research

Much of the world's ectothermic biodiversity is in the Global South, where research takes place within a context of historical and current colonialism and economic exploitation (Green, 2019; Haelewaters et al., 2021; Mahajan et al., 2022). Research is a fundamental activity taking place in almost every higher education institution, but funding inequity between the Global North and South impacts the types of questions that can be asked and how those questions will be answered (Chankseliani, 2023). In contrast to PhD programs in the US and Europe, graduate

students in many South American countries pay for their own tuition and research, usually by incurring debt that takes years to pay off (Britton et al., 2019). We purposely searched for an affordable solution to remote monitoring of ectotherms in field conditions, as field equipment and technology for research are not always available in the Global South and if they are, the prices are very high. We also provide here a Spanish translation of the Wyze v3 app and quick guide to counteract the disadvantage incurred by the dominance of the English language in science (Ramirez-Castaneda, 2020). Researchers in the Global North have an ethical responsibility to lead or participate in efforts that make scientific knowledge and tools more accessible, e.g. by establishing collaborations with less privileged institutions in the Global South and allocating grant resources to collaborators. While our current study focused on one specific type of home security camera, multiple affordable alternatives can be possible, such as Reolink (New Castle, DE, USA) or Tapo/TP-Link (Shenzen, China). Additionally, recent efforts to make Raspberry Pi based-camera set ups allow for further customized camera trap creation (Groffen & Hoskin, 2024). By creating these resources, we hope to make science more easily possible for all researchers.

Methods

Captive bred animals

All *Ranitomeya variabilis* used in the laboratory study were captive bred in our poison frog colony or purchased from Ruffing's Ranitomeya (Tiffon, Ohio, USA). One adult male and one adult female were housed together in a 45.72 x 30.48 x 30.48 cm terraria (Exoterra, Rolf C. Hagen USA, Mansfield, MA) containing sphagnum moss substrate, driftwood, live *Pothos* plants, horizontally mounted film canisters as egg deposition sites, and film canisters filled with water (treated with reverse osmosis R/O Rx, Josh's Frogs, Owosso, MI) for tadpole deposition. Terraria were automatically misted ten times daily for 20 seconds each, and frogs were fed live *Drosophila melanogaster* flies dusted with a vitamin powder and springtails three times per week. The observation housing was set on a 12:12 light cycle from 6:00 to 18:00. The average temperature and humidity of the observation was recorded for each day of observation, usually around 25°C and 95% humidity within the tank. Camera recording of *Ranitomeya* in our captive breeding colony is approved by the Institutional Animal Care and Use Committee at Stanford University (protocol #34242).

All *Cruziohyla craspedopus* tree frog juveniles (Fringed leaf frog) used in this study were captive bred in Wikiri (Wikiri Sapoparque, Quito, Ecuador) and purchased from Indoor Ecosystems (Whitehouse, Ohio, USA). Individuals were housed within 45.72 x 30.48 x 30.48 cm terraria (Exoterra, Rolf C. Hagen USA, Mansfield, MA). Terraria were automatically misted ten times daily for 20 seconds each, and frogs were fed live crickets three times per week. As these frogs are nocturnal, the observation housing was set on a 12:12 light cycle from 15:00 to 3:00. The average temperature and humidity of the observation was recorded for each day of observation, usually around 24°C and 98% humidity within the tank. Camera recording of *C. craspedopus* is approved under Stanford University APLAC protocol #34304.

Field study site and wild study population

Cameras were tested for their usability in the field in a tropical primary rainforest in French Guiana. Testing was conducted in a natural study site situated on top of the mountain 'Inselberg' in vicinity to the Centre Nationale de la Recherche Scientifique managed research station (4°5' N, 52°41' W) within the Nature Reserve ´Les Nouragues´. The study site is

characterized by patches of Clusia trees separated by bare granite rocks and exposed to extreme environmental conditions (e.g. temperature oscillations between 18°C - 75°C)(Sarthou et al., 2009). The study site is inhabited by a population of *Ranitomeya variabilis* (CITES Appendix II, IUCN Conservation status: Least Concern). Camera recording of the study population on Inselberg was approved by the scientific committee of the Nouragues Ecological Research Station and under Stanford University APLAC protocol #33691.

Field study species

Ranitomeya variabilis is a small dendrobatid poison frog that uses bromeliads as a resource for egg-laying and tadpole-rearing. Adult frogs are polygamous and typically lay clutches of 3-4 eggs into small arboreal bromeliads (*Catopsis berteroniana*) that are abundant on Clusia trees. Male frogs defend their territory and shuttle hatched tadpoles to individual water bodies that form in the leaf axils of the large terrestrial tank bromeliad (*Aechmea aquilega*). The cannibalistic tadpoles grow up in individual pools of 80 ml (Poelman et al., 2013) where they feed on algae and leaf debris until they complete their development after about 3 months (Poelman and Dicke, 2007). While this species is not considered to engage in further parental care (Brown et al., 2008), frogs of this population have been documented to deposit fertilized eggs into bromeliad pools occupied by tadpoles at the start of the dry season (Poelman and Dicke, 2007). How frogs assess tadpole presence and resource availability to coordinate shuttling of offspring to unoccupied pools under these extreme environmental conditions is not known, presenting an ideal opportunity to test small camera traps in the field.

Camera setup and modifications

Detailed instructions on camera setup and usage can be found in the Supplementary materials on GitHub.

In the laboratory, Wyze v3 cameras were adhered by velcro onto the side of the Exoterra tanks and suspended above the tadpole canister, with the face of the camera approximately 15.5-17.5 cm above the bottom of the canister. For egg care observations, Wyze v3 cameras are oriented horizontally, with the face of the camera facing approximately 10 cm from the canister entry site. Cameras were charged using their prepackaged USB cords and connected via a Nexwell USB charging station (Amazon, Bellevue, WA, USA) to the building outlets. Cameras were given 128 Gb SD cards for continuous recording. 128 Gb SD cards fill after approximately 10 days, and are switched by researchers and replaced with an empty SD card.

In the field, Wyze v3 cameras were equipped with a 128 GB SD card and set to the desired operating mode (motion triggered or continuous) using the WiFi of the field station before being transported to the field. We recommend setting the phone to the time zone in which the camera will be used during setup to avoid incorrect timestamps after changing time zones. Cameras were set to motion detection using the lowest sensibility, sound detection and notifications were switched off. All SD cards were formatted in the camera prior to use. Cameras were disconnected from power sources and WiFi during the transport to the study site. We used Anker PowerCore Fusion 10000 Model A1623 (9700mAh/35.21Wh) power banks for short-term (1 day) monitoring and Anker PowerCore26800 Model A1277 as well as 2nd Gen Astro E7 ModelA1210 (both 26800mAh/96.48Wh) for longer-term (10 days) surveil of tadpoles in their natural habitat. For long-term operation, we replaced the power bank every 2 days and recharged the devices in the camp. Prior to field implementation, we tested the efficiency of

these power banks and found the operating mode of the camera (continuous vs motion-triggered) did not affect the monitoring time.

Cameras were labeled and secured to bromeliad leaves 20-40 cm above the water reservoir housing a tadpole (Fig 1E, black arrow) using commercial rubber bands (Fig 1E, white arrow). Power banks were wrapped with an absorbent diaper and placed in 2 plastic zip lock bags with their opening facing into different directions to minimize the amount of rain water seeping in (Fig 1E). We purposefully chose inexpensive zip lock plastic bags to cover the power supply from rain to test the operation of our system on a budget. Alternatively, plastic bags can be replaced by a variety of outdoor waterproof boxes designed for electrical equipment. We tried to shelter Power banks from the sun and rain by placing them under bromeliad leaves. To assure an accurate timestamp, we recorded the screen of our mobile phone showing the accurate time as a first action with the camera after reconnecting the camera to the power source. We replaced the SD card every 2 days when changing the power source to back up contained footage and moved the camera to a different tadpole nursery after 10 days.

As home security cameras are designed to film focal subjects at a distance (such as a driveway), filming animals within a close range presented a challenge. To improve resolution of objects at a closer distance, we dismantled the camera and shortened the lens distance. The protocol to replicate resolution modifications can be accessed on Protocols.io (dx.doi.org/10.17504/protocols.io.dm6gp3p38vzp/v1).

Data Processing

With continuous recording, every minute of every day is recorded. Videos were first processed and kept only when frogs entered the camera. The scorer marked the times the frog entered the focal canister, defining entrance and exit as when the entire frog's body was within the canister. Data processing was performed in RStudio (version 4.2.3, PBC, Boston, MA). Figures were created using the package '*ggplot2*' (Wickham, 2016) and in Adobe Illustrator (Adobe Illustrator 2023).

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Data Availability

Videos as well as code for running visualizations can be found in supplementary materials. Detailed instructions for setting up cameras can be found on Github.

Conflict of Interest Declaration

The authors declare no conflicts of interest. Specifically, they do not have financial or non-financial competing interests from Wyze Labs, Inc.

Author Contributions

Conceptualization: BG, MTF, TGC
Data Curation: BG, MTF, GR, DPM, MPL
Formal Analysis: BG
Investigation: BG, MTF, GR, AL, DPM, TGC, DAS, MPL
Visualization: BG, MTF, TGC, DAS, DPM
Methodology: BG, MTF, DAS, TGC
Writing - Original Draft: BG, MTF, DPM
Writing - Review and Editing: BG, MTF, DPM, DAS, TGC, MPL, GR, AL, LAO
Project Administration : BG, MTF, LAO
Supervision: BG, MTF
Resources: LAO, MPL
Funding Acquisition: LAO

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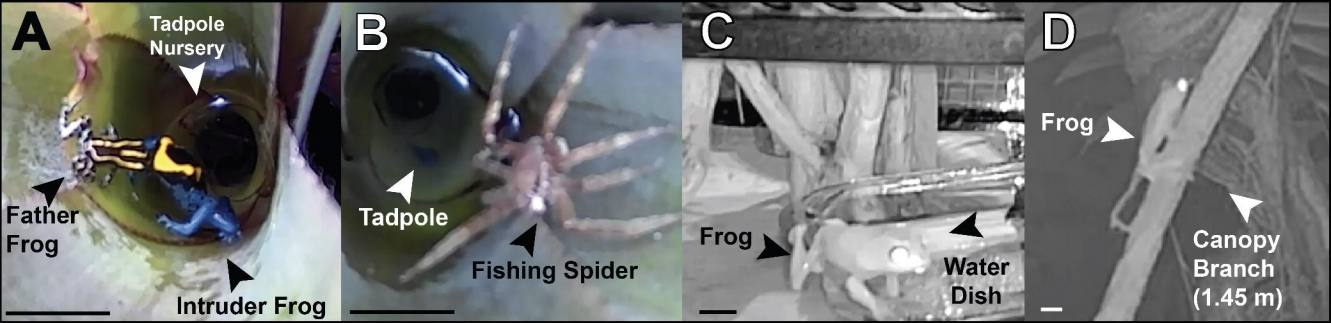
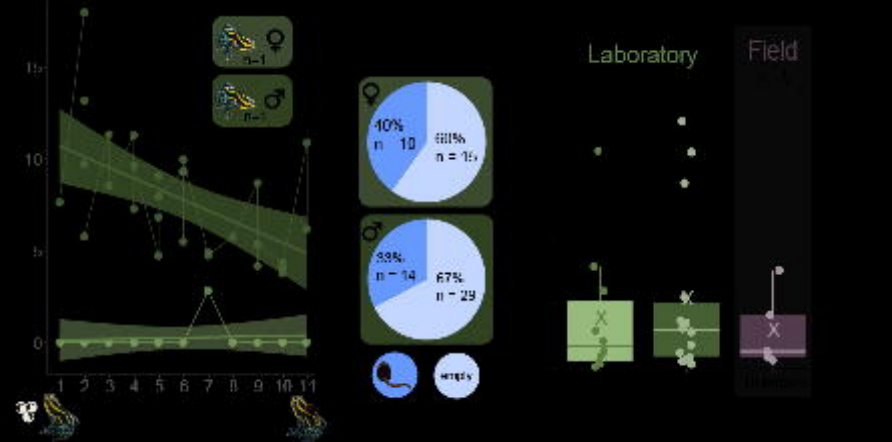
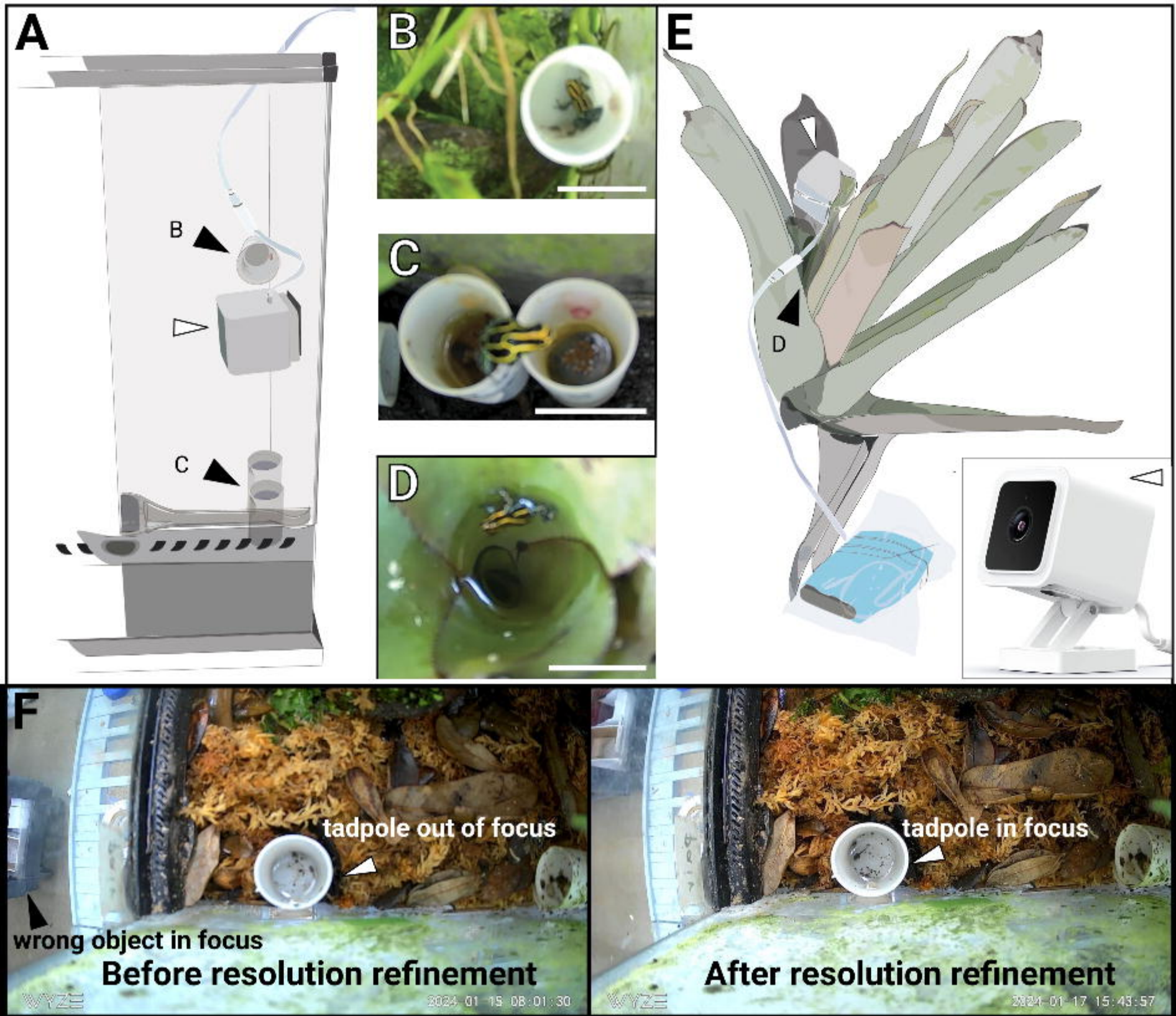

A
Tadpole Nursery
Father Frog
Intruder Frog
B
Tadpole
Fishing Spider
C
Frog
Water Dish
D
Frog
Canopy Branch (1.45 m)



Laboratory
Field
40%
n = 10
67%
n = 29


A
B
C
B
C
D
E
D
F
tadpole out of focus
wrong object in focus
Before resolution refinement
tadpole in focus
After resolution refinement