A high-quality, self-assembled camera trapping system for the study of terrestrial poikilotherms tested on the Fire Salamander

Camera traps are commonly used in animal ecology (ROWCLIFFE & CARBONE 2008). Especially for larger vertebrates they have become a standard tool for biodiversity monitoring (TOBLER et al. 2008; PETTORELLI et al. 2010) and to estimate population size (MAFFEI et al. 2005; SOISALO et al. 2006). Most of the commercially available systems are triggered by contrast changes in the recorded image in the visible or infrared spectrum during the day. For night observations, passive infrared sensors (PIR) detect contrast changes in the infrared spectrum produced by the body temperature of homeothermic organisms. Many amphibians and reptiles have their main activity period during night hours, which precludes the use of sensors in the visible spectrum. Moreover, poikilothermy is common among amphibians and reptiles, rendering motion detection in the infrared spectrum unfeasible. Thermo-sensitive motion detection is the probable cause of the underrepresented application of camera trapping in herpetological research. As a further hindrance, many commercially available surveillance cameras come with sensitivity thresholds, set to prevent false triggers (SWANN et al. 2004). This impedes the detection of objects that, compared to typical targets of surveillance cameras, are small or slow moving – which are both typical to herpetological species. However, there are also successful applications of surveillance cameras with PIR sensors in herpetological studies, such as the work of BRESSI (2011) who documented *Hyla arborea* (LINNAEUS, 1758), *Bufo balearicus* (BOETTGER, 1880), *Lissotriton vulgaris* (LINNAEUS, 1758) and *Triturus carnifex* (LAURENTI, 1768) around a breeding pond. In a study analyzing movements of *Ambystoma macrodactylum* BAIRD, 1850 "1849" through amphibian road-tunnels, PIR sensors were used for motion detection. As only 19 % of all crossing individuals triggered the camera, the authors suggested alternative trigger mechanisms like weight triggers or light beam sensors (PAGNUCCO et al. 2011). Trigger mechanisms proposed in other herpetological studies include capacitance sensing devices (HIMSTEDT 1971) and again weight triggers (GUYER et al. 1997).

We constructed a camera trap with a light barrier trigger and tested its application during behavior studies of the Fire Salamander, *Salamandra salamandra* (LINNAEUS, 1758). First, we monitored the entrance of a burrow which was regularly frequented by salamanders. Second, we compared the camera trap with a commercial surveillance camera regarding its reliability. Third, we monitored the activity of Fire Salamanders near a pool where we previously had observed female salamanders depositing their larvae by combining a camera trap with a guiding fence.

Our study took place in the "Maurer Wald" (WGS84, 48,152°N, 16,241 °E), a part of the Vienna Woods, from October 20, 2011 to April 21, 2012. In the study area, the annual precipitation is 725 mm, with a maximum in June and the annual mean temperature is 8.5°C. Sub-zero temperatures usually occur from December to February (AUER 2011).

For the monitoring, a camera trap assembled from purchased components was operated, comprising a light barrier and a consumer digital camera, differing from most commercially available infrared triggered camera systems in which PIR sensors are used (SWANN et al. 2004). The system employed a light barrier that consisted of an infrared emitter and receiver in a single unit, and a reflector (model "Jokie", eltima-electronic, Kirchheim unter Teck, Germany). Regarding the camera, the main criterion was its functionality to be triggered by an external signal. Since scout cameras with an input socket for external signals are rather expensive (i.e., approximately 400 € for a Spypoint Tiny-W, G.G. Telecom, Victoriaville, Canada), we decided to use a less expensive consumer digital camera (Canon Powershot A570 IS; bought for 31.5 € from an internet shop; as long as this camera was available on the market, its original price was about 170 €), which we modified, implementing the firmware enhancement CHDK (Canon Hack Development Kit, http://chdk.wikia.com/ - last accessed on 12.05.2012). This software can be installed on several Canon compact cameras to allow the execution of simple programs and provides for external signal input through the camera's USB port.

The camera (mini-B USB port) was connected by cable to the sensor of the light barrier (2.5 mm TRS jack) (Fig. 1). In this circuitry, the light barrier acted as a switch that closed the triggering circuit when the light beam was interrupted. As an additional voltage source for the triggering circuit we used three AA batteries in series, which delivered a 4.5 V signal at the USB port when the circuit was closed. To integrate these batteries into the system, the positive terminal (anode) was connected to the VBUS pin (pin 1, usually red cable) of the mini-B USB connector and the negative terminal (cathode) to the ring of the TRS connector of the connecting cable. The tip of the TRS connector was connected to the GND pin (pin 5, usually black cable) of the mini-B USB connector. The installation of the CHDK enabled the camera to detect this triggering signal. In order to take two pictures at an interval of two seconds at every triggering event, a small program was written (obtainable from the corresponding author) to run on the CHDK enabled camera. The minimum time lag between two accepted trigger events was set to three seconds.

To extend the operation time of the camera we used a 62 Ah car battery as an external power supply. The 12 V were converted to the operating voltage of the camera (3 V) using a commercially available car voltage adapter (CA 2000, Voltcraft, Hirschau, Germany) with a maximum output current of 2 A. Car battery and voltage converter were housed in a plastic box to protect them from environmental conditions. For the power supply of the light barrier, four AA batteries were used. An overview of the construction is given in Figure 1.

The camera was placed above the light barrier, facing downwards perpendicular to the ground surface for optimal image acquisition, to identify individual Fire Salamanders by their unique dorsal pattern (FELDMANN 1967). The camera was housed in a weatherproof plastic box (160 mm x 100 mm x 70 mm) with an opening for the lens at the bottom. The plastic box was semitransparent to enable the use of the camera's flash for nocturnal images. The light barrier was attached to the bottom of another plastic box (150 mm x 80 mm x 50 mm) with a regular tripod screw (1/4"). A hole in the side of the box allowed the beam of the light barrier to get to the reflector and back to the detector. An opening is not required when the plastic box is transparent. Preliminary trials indicated that the emitted IR beam (in idle periods reflected into the sensor) sometimes was so intense across short distances that it got reflected back into the sensor by the disrupting object itself, thereby precluding the release of a trigger signal. To eliminate this interfering effect, the light beam was weakened by three thin transparent plastic discs placed in front of the receiver/emitter; in turn the light barrier was set to "sensitive".

From October 20, 2011 to April 21, 2012 this camera trap system I (photo trap #I) was deployed for a total of 176 days at the entrance of a natural burrow. The burrow is located in a rich structured part of the forest with a trench system, and was identified as the main winter hibernation site of the local Fire Salamander population in a mark-recapture-study (LEEB in prep.). The light emitter/receiver and the reflector were mounted 20 cm apart with the light beam running approximately 1 cm above the ground. The plastic box with the camera was mounted on a tripod 39 cm above the ground (Fig. 2). The camera captured a field of view of approximately 38 cm x 34 cm. The camera was set to program mode with automatic flash (flash exposure compensation -2), the display was turned off, and light sensitivity (ISO) was set to 100. Image resolution was set to 2,592 x 1,944 pixels. The

Table 1: Picture trigger events assigned to five categories. Analysis based on the data obtained from a camera trap assembled by the first author (photo trap #I), first observation period (OP1) - October 20, 2011 to December 20, 2011; Vienna Woods.

Trigger event	*n*	%
Fire Salamander	3158	55.5
Leaf	1698	29.8
Unknown	426	7.5
Mouse	361	6.3
Other animal	46	0.8

Table 2: List of vertebrate species detected. Analysis based on the data obtained from a camera trap assembled by the first author (photo trap #I), first observation period (OP1) - October 20, 2011 to December 20, 2011; Vienna Woods. Photo pairs do not necessarily show different individuals.

Scientific name	Common name	Number of photo pairs
Apodemus sp.	Mouse	396
Bufo bufo	Common Toad	1
Cyanistes caeruleus	Blue Tit	1
Ichthyosaura alpestris	Alpine Newt	64
Rana dalmatina	Agile Frog	3
Salamandra salamandra	Fire Salamander	3301
Troglodytes troglodytes	Eurasian Wren	5
Vulpes vulpes	Red Fox	1

Table 3: Direct comparison of the commercial surveillance camera (SG560V) and a camera trap assembled by the first author (photo trap #I). Analysis based on the data obtained from the second observation period (OP2) - December 25, 2011 to December 29, 2011; Vienna Woods. Both cameras were set to take two pictures at an interval of two (Photo trap #1) and five (SG560V) seconds at every trigger event with a minimum time lag of three (Photo trap #1) and ten (SG560V) seconds between two accapted trigger events. Photo trap #1 was set to program mode with automatic flash (flash exposure compensation -2) and light sensivitiy (ISO) 100. In most cases shutter speed was 1/60 second. The shutter speed of the SG560V varies as the lighting conditions change and was 1/16 second during the night.

Criterion compared. Number of	SG560V	Photo trap #I assembled by the first author
Photo pairs	247	354
Picture pairs showing Fire Salamanders	5	119
Picture pairs showing mice	132	137
Picture pairs not showing a triggering object	108	101
Pictures showing Alpine Newts	3	6
Identified individuals of the Fire Salamander	3	17
Fire Salamanders that could not be identified individually	4	3

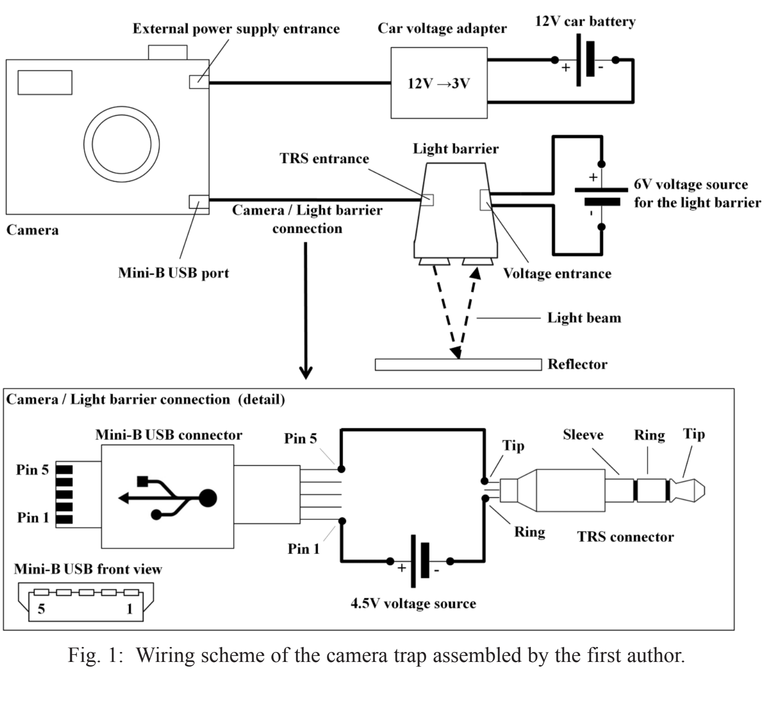

Fig. 1: Wiring scheme of the camera trap assembled by the first author.

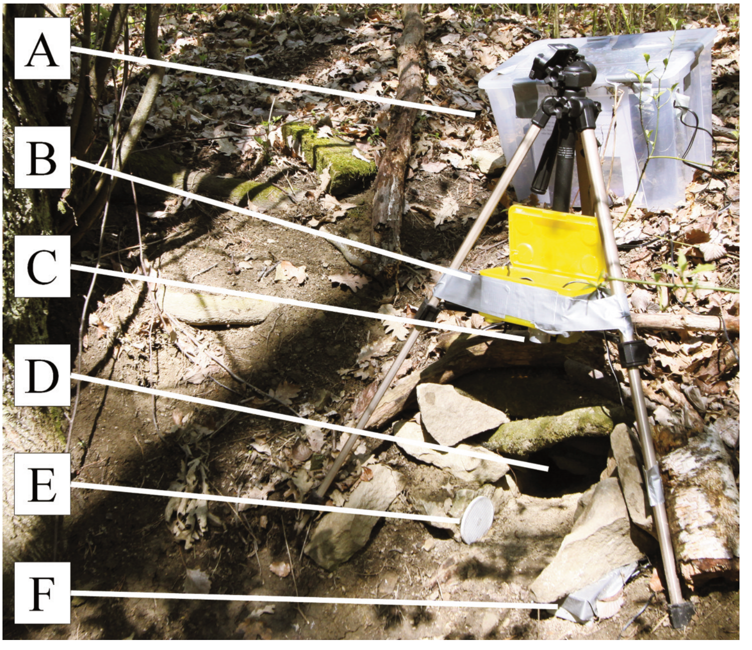

Fig. 2: Camera trap (photo trap #I) at the entrance of the burrow (hibernation site).
A - Plastic box containing car battery, voltage adapter and power supply for the light barrier. B - Plastic box housing camera and 4,5 V voltage source for the connection between camera and light barrier. C - Camera lens directed downwards. D - Entrance of burrow. E - Reflector of light barrier. F - Plastic box encasing light barrier.

camera was in the macro mode to allow for close distance focusing, and the focus was set manually with the autofocus turned off. All pictures taken from October 20, 2011 to December 20, 2011 (first observation period; OP1) were analyzed. The picture pairs taken at each trigger event were evaluated pairwise. The trigger events were categorized based on the alleged cue that had caused the camera to take pictures (Fire Salamander, mouse, other animal, leaf, unknown object passing by).

To compare our camera system with a commercial surveillance camera (ScoutGuard SG560V, HCO, Norcross, GA, USA) we tested both systems in a parallel set-up from December 25, 2011 to December 29, 2011 (second observation period; OP2). A similar surveillance camera (ScoutGuard SG550, HCO, Norcross, GA, USA) was used by BRESSI (2011) to monitor pond breeding amphibians. For the comparison we mounted the SG560V on a second tripod next to our self-constructed camera trap at a height to ensure a similar field of view as the camera of our system. The commercial camera trap was set to take two pictures per trigger event with an interval of five seconds and a minimum delay of ten seconds between two trigger events. The sensitivity of the motion detector was set to “high”. Settings such as shutter speed or light sensitivity (ISO) can not be changed. Shutter speed varies as the light conditions change and is 1/16 second during the night.

From March 5, 2012 to April 21, 2012 (third observation period; OP3) a second camera trap assembled by the first author (photo trap #II, same components as photo trap #I) was set up near a pool. Camera II was installed 28 cm above the ground in a hollowed tree trunk. The distance between the emitter/receiver and the reflector measured 16 cm across a cut passage in the tree trunk. For better weather protection a wood disc was mounted on top of the tree trunk with a hinge, and a lock for theft protection. To increase the probability of individuals to

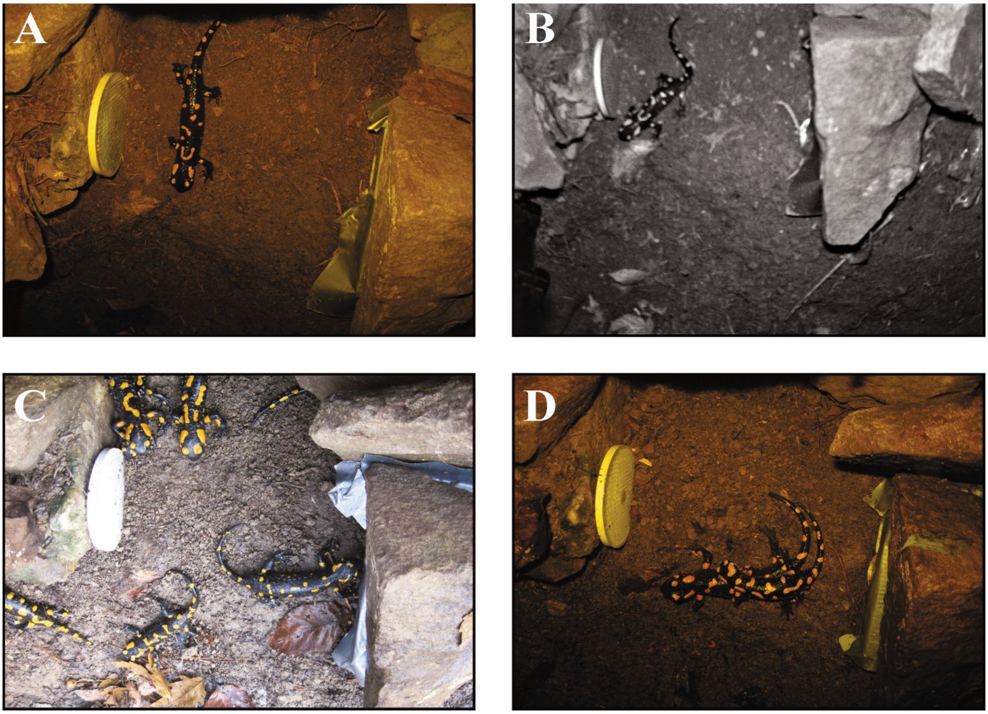

Fig. 3: (A-B) - Fire Salamander upon leaving the burrow on December 28, 2011. Compare the quality of the photos taken by photo trap #I, Canon Powershot A570 IS (A) and ScoutGuard SG560V (B), respectively, which refer to the same event. C - Seven individuals on one picture, taken on November 26, 2011. D - Two interacting Fire Salamanders.

pass through the light barrier, a guiding fence, 7 m in length and 30 cm in height (Fig. 4), was installed.

During observation period 1 (OP1) the camera (photo trap #I) took 11,378 pictures. An overview of the trigger events is given in Table 1. On 3,301 photo pairs that showed Fire Salamanders, we identified 192 individuals, based on their unique dorsal patterns. Out of the total photos, 1,365 picture pairs showed two or more individuals (mean = 1.6; maximum = 7) (Fig. 3C-D). Some of the depicted salamanders were only partially visible in the images, which is why the identification of 351 individuals that were recorded was not possible. On 157 photo pairs, close interactions like matings or fights between two individuals were observed. Additionally to Fire Salamanders, mice, and several other vertebrates, as well as some invertebrates were detected during OP1 (Table 2). Images taken with photo trap #I in its original position but after OP1 also showed *Bombina variegata* (LINNAEUS, 1758), *Natrix natrix* (LINNAEUS, 1758) and *Zamenis longissimus* (LAURENTI, 1768).

During OP2, 494 photos were taken by the commercial camera trap while in the same time 708 photos were taken by photo trap #I. A comparison of both systems is shown in Table 3. During OP3, 380 pictures were taken by photo trap #II at the breeding pool, showing 28 individual Fire Salamanders. In 92.9 % of all detected movements, the initial migration was directed towards the pool. Two Fire Salamanders changed their walking direction in the field of view of the camera. Additionally *Rana dalmatina* (FITZINGER in BONAPARTE, 1839), *Rana temporaria* LINNAEUS, 1758 and *Bufo bufo* (LINNAEUS, 1758) were detected on their way to the breeding pool.

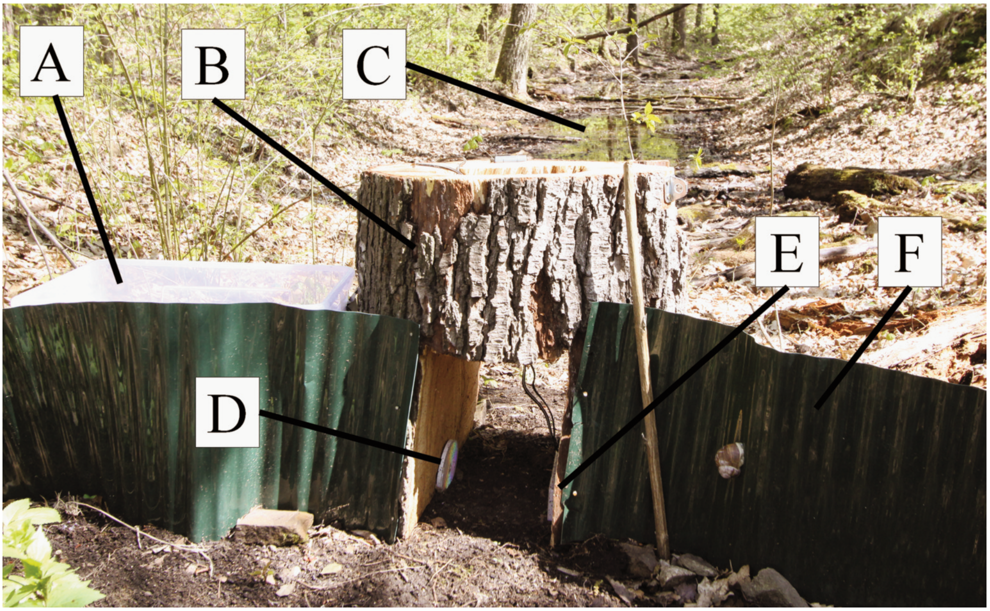

Fig. 4: Camera trap (photo trap #II) in operation from March 5 to April 21, 2012
(third observation period; OP3) and guiding fence (F) at potential larval habitat (C).
A - Plastic box containing car battery, voltage adapter and power supply for the light barrier.
B - Tree trunk with camera box inside. D - Reflector. E - Plastic box encasing light barrier.

Overall data shows that our camera traps reliably recorded salamander activities. During OP1, the camera of photo trap #I was primarily triggered by the study species. Our photo traps #I and #II together detected 85 % of the amphibian and two-thirds of the snake species known from the study area (missed species: *Lissotriton vulgaris* (LINNAEUS, 1758), *Coronella austriaca* LAURENTI, 1768), suggesting the general suitability of our system for monitoring herpetofauna diversity.

"Unknown" triggers occurred mainly during periods when high activity of mice was detected. We assume that, in these cases, mice triggered the camera, which then was released too slowly, due to shutter lag, to capture the moving animal in the image. The two-picture interval recording allowed us to determine the direction of movement for each individual. Based on the entry-and-exit-histories of individuals at the burrow, we were able to estimate the actual number of individuals inside the burrow at any given time (LEEB in prep.).

Two Fire Salamanders were monitored when changing the direction of movement in the view field of photo trap #II during OP3. This indicates the camera trap's potential influence on the movements of the target organism. The Fire Salamanders may have noticed some difference in soil humidity inside (dry) and outside (humid) the light barrier. However, as both incidences occurred on the same day, there may have been other reasons for this behavior.

Comparison of our photo trap #I with the commercial surveillance camera showed that our system was more suitable for the detection of Fire Salamanders as only 18 % of the salamanders detected by our system were also photographed by the SG560V. Probably in all these cases the commercial surveillance camera was triggered by mice (and the registration of salamanders then was a mere ancillary effect), as one and the same Fire Salamander, due to the individuals' slow motion, usually appeared on more than one picture pair taken by our system. Moreover, as the Canon Powershot system featured macro mode and an integrated flash allowing for a short shutter speed, the picture quality was considerably better than of the SG560V camera (Fig. 3A-B) which lacked these accessories. Instead of a normal flash, the SG560V uses infrared illumination, so only black-and-white pictures can be taken during the night (Fig. 3B).

However, we also identified disadvantages of our system compared to commercially available camera traps. One major issue was the camera battery, which needs to be charged or changed periodically. The operational time of the battery depends on its type and storage capacity (Ah), the ambient temperature, the number and intensity of flash releases and the quantity of pictures taken. We changed the car battery operating the camera and the batteries of the light barrier at least every ten days, the batteries for the signal at the USB port once a month. In fact, the maximum operation time of the camera equipped with a 62 Ah car battery seems to be much longer, because it was working for 48 days without changing the battery in a climate chamber (4 °C; one picture every 3 minutes). To extend the operation time in remote areas where regular change of the batteries is difficult, solar panels with buffer batteries might offer a solution. Another problem arose from the light barrier employed, which produced only a single discrete trigger signal each time the light beam was interrupted. As a consequence, the camera was triggered only once during longer interruptions of the light beam. This, for example, can happen when an individual is sitting still right in front of the light barrier. The movement of other individuals/animals passing the light barrier during this time would not cause additional triggering signals to the camera, thus, freezing its operation as long as the obstacle keeps the beam interrupted. For continuous monitoring in behavioral studies a different light barrier model should be used that produces a continuous trigger signal whenever the light beam is interrupted. In such systems the duration of the interruption could be measured involving appropriate camera software, so differences between quick movements (typical for mice) and slower movements (typical for salamanders) could be detected. This would reduce the number of voided pictures. Another observation was that small objects that interrupted the light barrier could trigger a continuous series of pictures until the memory card was full. We assume that in these cases only a fraction of the light from the emitter of the light barrier reached the reflector, whereas the rest of the light was absorbed by the interrupting object. This phenomenon in combination with aerosols (e.g., fog), variation in the power of the light beam, or minimal movements of the object could have led to the disadvantageous triggering behavior. For example, during seven hours (October 22, 2011) and nine hours (October 27, 2011), 811 and 864 picture pairs were taken respectively, when a leaf interrupted the light beam "incompletely". Actually 98 % of all pictures of the category "leaf" in OP1 were caused by such incomplete interruptions. Additionally, the time delay between pictures can increase from normally 0.6 to a maximum of 13 seconds when many flashed pictures are taken in a row, since the shutter is not operative while the flash is charging. To counteract this problem one could increase the minimum delay time between two trigger events at the risk that actual movements of the study object could be missed.

In summary, our constructed camera trap could reliably detect and document salamander movements at a cost only slightly higher than commercially available camera traps, which yielded much less detections in a direct comparison and higher resolution pictures. All components of the system have independent functionality and could be used separately in future projects. As neither the housings nor the system components themselves are completely waterproof, the applicability of the system could be limited in very humid areas like rainforests. However, we believe our construction to be ubiquitously applicable to other study species with similar dimensions and motion patterns in arid and temperate regions. In cases of lateral or ventral color patterns, the camera could be mounted accordingly to allow for an optimal depiction of the individual patterns, while the light barrier could be mounted independently in the trajectory of the study species to ensure detection. For study species with hopping or flying motion, e. g., frogs or birds, two or more light barriers wired in parallel could be installed for reliable detection. Our results also indicate that the combination of a camera trap and a guiding fence is an alternative and less stressful method to pitfall traps (SCHLÜPMANN & KUPFER 2009) when individual identification of the study species is possible in the pictures.

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