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A portable low-cost remote videography system for monitoring wildlife

Sara M. Kross* and Ximena J. Nelson

School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

Summary

1. Remote videography allows continuous and reviewable recording of unique behaviours with minimal disturbance to focus individuals. It is therefore an excellent, although often unaffordable, method for observing the behaviour of wildlife in the field.

2. We describe a digital video-based remote videography design that costs under USD 900 and requires relatively minimal maintenance. The system is portable and can record continuously or when motion is detected.

3. Using the threatened New Zealand falcon as a model, in a single season of camera deployment we were able to record a number of unique events, including a new prey species for the falcon and the complete depredation of one nest.

4. Only 16% of potential recording hours were lost, the majority of which were as a result of battery failure (52% of failures) or the camera becoming dislodged (33% of failures).

5. This system will be useful for researchers in all fields who require a reliable, cost-effective means of recording wildlife behaviour in remote locations.

Key-words: behaviour, digital video applications, *Falco novaeseelandiae*, nest camera, New Zealand, remote monitoring

Introduction

As attested by numerous natural history documentaries, well-placed video cameras may permit observation of wildlife behaviour that is unattainable using traditional hide-and-observe methods; a benefit which is of particular importance when the animal in question is poorly understood or rare. Remote videography has applications in any study where behaviour is relevant, and has been used to study a wide assortment of animals, including mammals (e.g. Maniscalco, Parker & Atkinson 2006; Bloomquist & Nielsen 2009), reptiles (e.g. Hunt & Ogden 1991), insects (e.g. Stephanou *et al*. 2000) and even lobsters *Homarus americanus* (Jury *et al*. 2001), but has principally been deployed at bird nests.

In bird studies, video cameras are normally placed in or near the nests of focal individuals, providing an accurate record of both nestling (McDonald, Olsen & Cockburn 2005; Grivas *et al*. 2009) and parental behaviours (McDonald, Olsen & Cockburn 2005; Pierce & Pobprasert 2007). Owing to the nature of video, events can be reviewed repeatedly to gather detailed behavioural information. For example, close inspection of feeding bouts can provide information on food type, biomass and the timing of feeding events (Cutler & Swann 1999; Lewis, Fuller & Titus 2004; McDonald, Olsen & Cockburn 2005; Reif & Tornberg 2006). Remote videography also allows for positive identification of nest predators (Leimgruber, McShea & Rappole 1994; Brown *et al*. 1998; Cutler & Swann 1999; Pietz & Granfors 2000) and can identify non-predation events that might play a role in nest failure, such as potential predators visiting a nest but not predating eggs (Pierce & Pobprasert 2007), or the effect of human disturbances, such as chainsaw noise (Delaney, Grubb & Garcelon 1998).

Setbacks of remote videography include the potential impact of camera presence, human scent and human activity on the behaviours of the study species and any prey or predators nearby (Cutler & Swann 1999; McDonald, Kazem & Wright 2007). The majority of studies investigating the effect of cameras on predation rates have found that cameras have no effect (Leimgruber, McShea & Rappole 1994; Sanders & Maloney 2002; Pierce & Pobprasert 2007), or that the presence of cameras decreases predation rates, possibly because predators are wary of the presence of a camera (Herranz, Yanes & Suarez 2002; Richardson, Gardali & Jenkins 2009). However, camera placement can lead to increased nest abandonment (Pietz & Granfors 2000). Additionally, some systems are bulky

*Correspondence author. E-mail: saramaekross@gmail.com
Correspondence site: http://www.respond2articles.com/MEE/

and difficult to transport, whereas others require frequent visits to change batteries and download video.

A major drawback of remote videography is the prohibitively high cost of video systems leading to limited sample sizes (Brown *et al*. 1998; Lewis, Fuller & Titus 2004; Pierce & Pobprasert 2007). As video technology becomes more affordable, it is becoming possible for researchers to construct tailor-made camera setups that are as effective and often cheaper than commercial systems (King *et al*. 2001). We have developed a portable camera system modified from an original design used by the New Zealand Department of Conservation that is able to withstand harsh weather conditions, records and stores digital files, and can be left in remote locations for several days before changing the batteries. The design on which our model was based has been used to monitor and study some of New Zealand's rare birds, such as kokako *Callaeas cinerea wilsoni* (Innes *et al*. 1996) and black stilt *Himantopus novaezelandiae* (Sanders & Maloney 2002).

Our study species, the New Zealand falcon, *Falco novaeseelandiae* (hereafter falcon), has been the subject of relatively little scientific research, despite its threatened status (Miskelly *et al*. 2008). New Zealand falcons nest in scrapes on the ground in remote and often mountainous regions and are highly aggressive towards intruders near their nest, often repeatedly striking them in the course of nest defence. Because of this, remote videography is an ideal method for studying the nesting behaviour of this species, and is well suited to study any animal that is territorial, highly susceptible to disturbance or is found in inaccessible locations. This camera system was designed with the aim to monitor the nesting behaviour and attendance of breeding falcons, the behaviour of falcon nestlings, the timing of feeding events and the prey species delivered to the nest. As the beginning of a long-term study, we dispatched four separate camera systems to monitor five nests over the 2008/2009 breeding season.

Materials and methods

Although many early remote videography studies have revealed previously unknown trends at bird nests (see Cutler & Swann 1999), cassette-based systems have limited storage and therefore require up to twice-daily trips to the site to change tapes, or require the use of time-lapse recording which significantly reduces the number of frames in which prey items or predators are visible for identification (Booms & Fuller 2003; Smithers, Boal & Andersen 2003). The recent integration of digital storage capabilities into video monitoring has allowed researchers to make the switch from videocassette-based systems to digital storage.

Our system uses an SVAT mini portable digital video recorder (DVR, Model CVP800; SVAT Electronics USA, Niagara Falls, NY, USA). The DVR is small (< 100 g), and records onto secure digital high capacity cards (SDHC) with a capacity of up to 32 GB, although 16 GB cards (A-DATA Turbo Class 6; A-DATA Technology Co., Taiwan) were used for this study. One potential drawback of digital video is large file size that can quickly fill up a device's room for storage. This system avoids this by automatically compressing all files using MPEG4-SP video and stores them in either NTSC or PAL video format as advanced systems format. At this compression rate, 10 s of daytime footage was stored in 1·2 MB, whereas nighttime footage required only 1·1 MB. At the former rate, the system will record 2·37 h of continuous footage for every 1 GB of storage, regardless of SDHC card size.

To preserve disc space and avoid erroneous recordings, we used only video motion detection recording at the falcon nests, but the DVR does have an option for scheduling certain hours of continuous recording throughout the day. The motion detection function works by detecting changes in colour and shape within the preset motion detection area on a 22 × 15 square grid that is superimposed over the camera image. The intensity of motion required to trigger the start of recording is measured by an image variation 'energy' threshold between 1% and 100% and can be set by the user. We set the motion detection threshold between 10% and 15%, and included the entire range of sight of the camera as our motion detection window to start recording as soon as an adult falcon entered the nest. We set video recording to 30 frames per second at 352 × 240 lines, but the DVR can record at lower frame rates and resolution to reduce file size and the camera is capable of recording at a maximum of 420 lines of resolution. All files were recorded with a time and date stamp. While we did not use audio recording, a microphone could easily be attached to the system and the DVR is capable of recording a single audio channel within the same file as the video at a sampling rate of 44·1 KHz (increasing file size by 13%).

The DVR was housed in a waterproof Pelican™ case (Model 1150; Pelican™ Products, Inc., Torrance, CA, USA) equipped with an automatic pressure equalization valve, and modified to include two waterproof Amphenol™ plug connections (series C16-1; Amphenol Corporation, Wallingford, CT, USA) for power and video input and output (Fig. 1). We used Amphenol™ plugs for all waterproof connections. To power the system, 12-Volt, 33 Ah deep-cycle gel batteries (Century Yuasa Batteries Pty Ltd, Carole Park, Queensland, Australia) were used because they do not leak potentially dangerous corrosive electrolytes during transportation, as wet-cell lead acid (car batteries) sometimes do (Reif & Tornberg 2006). The 12 V power from the battery was connected through the Pelican™ case to run along a two-pair shielded communication cable (25 m long × 32 mm wide) and to power the cameras within the nests (Fig. 1). This cable also relayed video from the cameras into the DVR. The DVR requires 4·5 V of power, so a fuse-protected DC–DC converter was included within the case. Batteries were connected to a 10-W monocrystalline solar panel (DSE NZ Ltd, Auckland, New Zealand) coupled with an automatic solar charge converter (Projecta SC005; Brown & Watson International Pty. Ltd, Knoxfield, Victoria, Australia) to keep the panel from overcharging or draining the battery.

We used waterproof (IP68), colour cameras (Swann Security BulldogCam™ CCD) in NTSC video format with a 1/3″ charge-coupled device (Sony Corporation, Tokyo, Japan) with 420 lines of resolution. The cameras have automatic white balance, gain control and backlight compensation. Cameras had a focal length of 6 mm and at a distance of 1 m from the nest had a field of view of *c*. 40°. The camera's minimum focus distance is *c*. 7 cm. Cameras were equipped with 12 near-infrared light-emitting diodes (LEDs) and were able to record black-and-white video at night with a minimum of 0·8 Lux available. The light emitted from these diodes (at a wavelength of 850 nm) is not known to be visible to mammals or birds and previous studies have shown that their use does not affect nesting behaviour or predation rates (Delaney, Grubb & Garcelon 1998; Pierce & Pobprasert 2007), including among ground-nesting birds in New Zealand (Sanders & Maloney 2002).

To view the menu options, or the image being recorded, the DVR must be connected to a portable screen capable of accepting an RCA

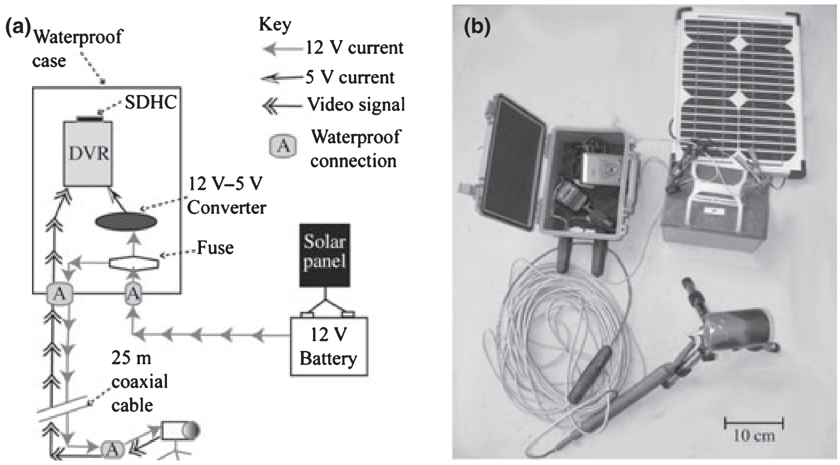

Fig. 1. (a) Schematic of our remote videography set up. Arrows indicate direction of power and video flow. Note, waterproof connections using Amphenol™ plugs. (b) Photograph of nest camera set up showing (clockwise starting in upper right corner) the solar panel, deep-cycle battery, waterproof video camera on tripod, 25 m of coaxial cable and waterproof case (open) containing digital video recorder (DVR).

connector. We used a portable DVD player (Model DVP-FX720; Sony Corporation) and attached it to the system only when the camera was being set up or when the SDHC card was changed. Consequently, a single portable DVD player was used for all cameras, cutting the cost of maintaining a separate viewer for each camera system.

Fieldwork was carried out in Marlborough, at the Northeast corner of New Zealand's South Island, in the vineyards and surrounding mountains of the Wairau (41·52°S, 173·872°E), Waihopai (41·66°S, 173·575°E) and Awatere (41·64°S, 174·073°E) valleys. The region is mainly arid, with mean rainfall during the October–February falcon breeding season ranging from 45·4 to 71·6 mm and often with extreme temperatures, reaching lows below −1·3 °C and highs above 34·3 °C (NIWA 2010). Falcon nests in the mountains were located in narrow, steep-sided valleys dominated by a mix of native and introduced grasses, and dense scrub consisting mainly of matagouri (*Discaria toumatou*), bracken fern (*Pteridium aquilinum*) and manuka (*Leptospermum scoparium*), while stands of red beech (*Nothofagus fusca*), silver beech (*Nothofagus menziesii*) and kanuka (*Kunzea ericoides*) were found on valley floors (Fox 1977; Brennan, Moller & Parkes 1993). Nests were only accessible by foot and access often required crossing streams, scaling rock faces and breaking through dense vegetation.

The entire remote videography set up weighed *c.* 15 kg and fitted easily into a 50 L backpack. This system can be set up by only one person, but we always worked in teams of two to ensure the fastest possible system deployment, as our study species was easily disturbed and highly aggressive towards people. One person secured the camera in a location that provided a clear view of the chicks but did not interfere with the falcons entering and leaving the nest, or with regular nest activities. Meanwhile, the second person ran communication cable to a location where the setup would be stable and hidden from view by vegetation, *c.* 25 m from the nest, assembled the recording station and attached the viewer. At this point, the person remaining at the nest could be instructed as to the best camera angle and whether vegetation in front of the camera needed to be moved or trimmed. Once this was completed, we immediately left the nest area. To determine the impact of our presence at nests, we recorded the time required for camera set up as the time from the onset of nest defence behaviour until the time at which parents stopped defending the nest. All research was performed according to New Zealand Animal Welfare Act 1999 and the University of Canterbury Code of Ethical Conduct for the Use of Animals (University of Canterbury Animal Ethics Committee 2008/27R), and under the permission of the Department of Conservation (NM 23677 – FAU).

Each camera was checked every 3–4 days, at which point the battery and SDHC card were changed. We always attached the viewer to ensure the camera was still operating and to determine whether the camera had become dislodged, so any problems could be remedied immediately.

Video from the SDHC card was copied onto an external hard drive (Maxtor OneTouch 500GB; Seagate Technology, Scotts Valley CA, USA) archived by date. Files were watched individually using QuickTime Player (version 7·6·4; Apple Inc, Cupertino, CA, USA), permitting inspection from four times normal speed to frame-by-frame analysis. Files were backed up by burning them onto 4·7 GB writable DVD's (SRO8109; Transonic Industries Ltd, Hong Kong, China).

Results

The components for the recording system were purchased and assembled for a cost of $862 USD per system (Table 1),

Table 1. Price of components for each remote videography system (USD)

Component	Cost per camera (USD)
Waterproof, colour camera	114
Waterproof Pelican™ case	60
Deep-cycle gel battery	94
Solar panel	106
Solar charge regulator	41
DVR	199
16 GB SDHC card	51
Amphenol™ plugs	114
Coaxial cable (25 m)	36
Circuitry (including fuse protector and labour)	47
Total	862

Prices are converted from New Zealand Dollars (conversion date: 5 April 2010) and are rounded to the nearest dollar. Prices do not include shipping costs. Additional components used between all systems included a portable DVD player for field viewing, a battery charger, a portable hard drive, SDHC cards, spare batteries and tripods or other camera-mounting materials.
DVR, digital video recorder; SDHC, secure digital high capacity cards.

a considerably lower cost than that of most commercially available wildlife surveillance systems. Five nests were monitored in the first season of camera deployment. Cameras took an average of 11 min 48 s (±49·2 s SEM, $N = 5$) to set up from the time the falcons first started nest defence to the time the assembly was completed and the falcons stopped nest defence. At three of the nests, cameras were placed directly on the ground, at a distance of *c.* 0·5 m from the scrape. At the remaining two nests, falcons had been moved into 'barrels' that were raised off the ground to protect the nest from predators. At these two nests, the cameras were first placed on posts *c.* 1 m from the barrel, and then attached directly to the barrel entrance at a distance of 0·25 m from the nest interior. In two instances, one 'barrel' nest and one ground nest, the falcons returned to incubate eggs or brood chicks less than a minute after we left the nest and in another two, the falcons returned in under 3 min. At one ground nest, it took 65 min for the falcons to return to the nest. Only in the case of the fifth nest did the falcons appear to be disturbed by the camera, often examining it upon entering the nest for the first 3 days following camera placement, but they continued to care for and eventually fledge the chick in this nest. On a few occasions in each nest, the adult falcon appeared to catch its own reflection in the glass covering the camera lens. In these cases, the falcon would approach the camera to examine it and sometimes even try to pick it up, but in every case the falcon returned to normal activities within a few minutes.

Cameras were present for a total of 3431·84 h at the five nests, during which time motion could have set off recording. We were interested in recording all falcon movements within the nest. Using the 10–15% motion detection threshold, 21–49% of our recordings were triggered by the movements of vegetation and invertebrates. One of our primary interests was observing the delivery and handling of prey items ($n = 638$ events). For this, we were able to record video that gave us clear views of at least one defining part of each prey item for 94·8% of the feeding events. The small fraction of feeding events that were unable to be classified were because of a falcon obscuring the camera's view (2·1%) or because of poor contrast (3·1%).

Battery failure occurred on 10 occasions and caused a loss of 492 h of filming which was 14% of the total deployment time. This is comparable with other systems, with published ranges from 11% to 39% (Sabine, Meyers & Schweitzer 2005; Grivas *et al.* 2009). Of all camera failures, 52% were because of battery problems. Camera displacement (by the falcons, possums, livestock and humans) accounted for 33% of failures and the other 15% were presumed to be mechanical problems. On 4 of the 10 battery-induced failures, footage stopped late in the evening and then restarted again the following day, owing to the solar panel recharging the battery to a point where it could run the system – this resulted in an additional 8 days of footage being recorded that would have otherwise been lost. The system draws 3·21 W of power during daytime recording and 3·73 W of power when the LEDs are operating at night. We did not insulate our batteries, and fluctuations in temperature, especially cold-evening weather, could have lessened their efficiency.

A negligible number of files (< 50 of *c.* 100 000) were lost as a result of file corruption. As is the case with any raw data, backup of files and storage in multiple locations is a necessary precaution. Depending on the amount of activity in a nest, between 1 and 4 days worth of video could be backed up on a single DVD, however, DVDs were only used as temporary backup as they are known to degrade over time and should not be used for permanent storage of data. External hard drives are a more reliable medium with which to store data long term.

This technology has already shown considerable promise, as it has permitted us to observe not only everyday behavioural processes within falcon nests (Fig. 2a and b; Videos S1–S2, Supporting information), but also numerous behavioural events that would have otherwise been unknown or difficult to substantiate (Video S3 and S4, Supporting information). For example, we recorded a non-predation event in which a young brushtail possum (*Trichosurus vulpecula*) entered the nest at night and was chased away by the female falcon. We also recorded the complete depredation of the nest by a feral cat (*Felis catus*) which was recorded on 15 December (we presumed it killed one chick that night based in the chick's absence in subsequent footage) and then on 17 December (the cat was recognizable by a notch in its right ear), when it killed the remaining two chicks over a period of 10 h (Fig. 2c; Video S3, Supporting information). Finally, we obtained footage of an adult falcon feeding its young with a common gecko (*Hoplodactylus maculatus*), a previously unknown prey item for this species (Fig. 2d; Video S4, Supporting information).

Discussion

Our system is ideal for monitoring wildlife in most field conditions and, in addition to permitting observation in inaccessible areas (such as the interior of a falcon nest), is capable of recording behaviours in detail and over periods of time that would be unobtainable using traditional observation methods. The camera system can be easily transported and maintained in the field, and construction of the camera system can be tailored to fit the needs of the researcher: for example, a video camera fitted with a macro lens could be substituted if the researcher were interested in examining invertebrate behaviour. Importantly, the cost of USD ≈850 is low compared with most commercially available systems. This has significant flow-on effects, such as the ability to increase sampling numbers and the concomitant increase in reliable information on the behaviour of animals in natural habitats. Indeed, video has been shown to be a more accurate method of assessing raptor diet than indirect methods, such as analysing prey remains and castings (Lewis, Fuller & Titus 2004; Reif & Tornberg 2006), and because field observers often suffer from fatigue, video is considered more accurate than direct observation from hides (Delaney, Grubb & Garcelon 1998).

An important aspect of our design is the ability to leave the camera in the field for 4 days at a time between maintenance visits. Compared with other remote videography systems that require more frequent visits, sometimes multiple times a day, this significantly lowers the impact that human presence may

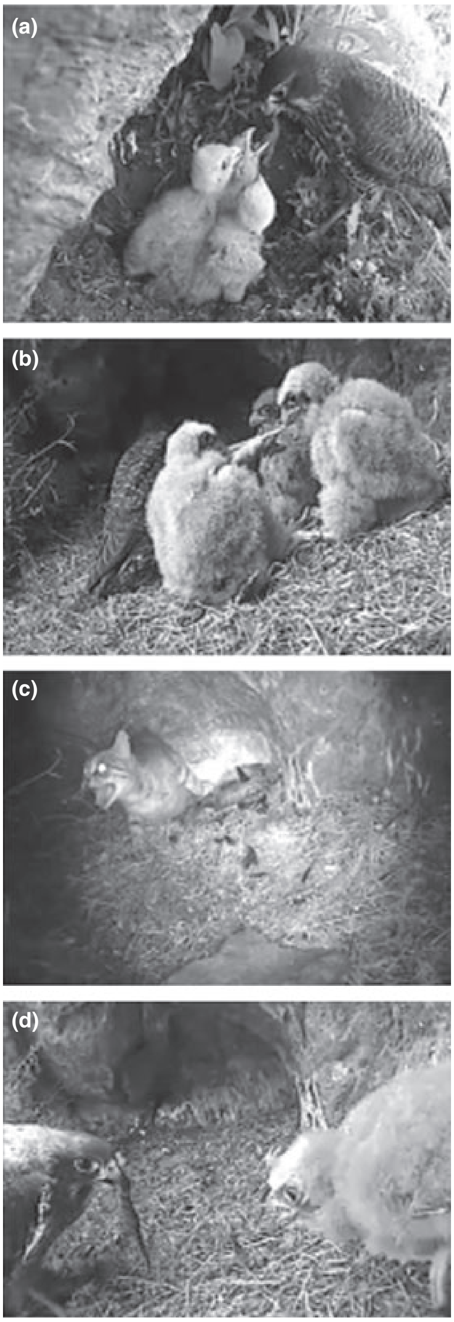

Fig. 2. Still images taken from video footage at New Zealand falcon nests over the 2008–2009 breeding season in Marlborough, New Zealand. (a) Female falcon feeding her chicks, (b) three chicks fight over a field mouse brought into the nest by the male parent, (c) Feral cat hissing at parents (not in frame) after killing all three 28-day-old nestlings (Video S4, Supporting information), and (d) a common gecko (*Hoplodactylus maculatus*), a new prey item for this species, being offered to a nestling (Video S3, Supporting information). All images except (c) have been converted to grey scale.

have on the focal animals, as well as drastically reducing the number of human hours needed for this aspect of the research. In the case of easily disturbed or aggressive animals, such as our study species, it is of particular benefit to use a system that requires infrequent maintenance visits.

One concern we had was the length of time that it took for the falcons to return to the fifth nest. This may have been due to the chick's age and its parents' previous experience. Unlike all other nests sampled, a chick had been removed from this nest only 2 days prior to camera placement as part of a local conservation project. Additionally, when the camera was placed in the four other nests, the falcons were either incubating eggs or brooding chicks < 5 days old, whereas at the fifth nest the parents were caring for a single chick that was *c*. 12 days old, an age at which chicks have begun to thermoregulate and no longer need constant brooding (Fox 1977). Importantly, none of the nests were abandoned because of the presence of the camera; however, it is important to note that the presence of cameras may have both obvious and discrete disturbance effects on the behaviours of the study species in question (McDonald, Kazem & Wright 2007). In our case, cameras were all located < 1 m from the nest, and falcons appeared to accept them. Nevertheless, we have noted all interactions with the camera for use in our future analysis of falcon behaviour. Because cameras were not visible from outside the nest, it seems very unlikely that the cat that depredated one of the nests perceived the camera within and was attracted to it. Furthermore, even within the nest, the footage clearly showed that the cat ignored the camera, suggesting it did not play a role in nest predation.

Video is engaging, entertaining, and can generate interest and empathy for the subject. Because digital video can be easily disseminated through outlets, such as popular media and the Internet to reach a wide audience, it can be used as an educational tool to promote conservation. For example, our video of normal falcon behaviour within nests and of depredation of falcon chicks by the feral cat has already been used in schools to encourage falcon conservation and better predator control, as well as being aired on New Zealand national television.

As an affordable and customizable remote videography system, our design can be implemented across a variety of taxa and in a range of field conditions at adequate sample sizes. Video is a desirable means of collecting behavioural information in animals ranging from invertebrates in the field to wild birds, livestock and companion animals (Wratten 1994). This system is ideal for researchers in any field needing to obtain detailed information on the behaviour of rare or inaccessible species with minimal disturbance to the focal individuals. Continued use of remote videography in the field of wildlife management will inevitably lead to further discoveries of new behaviour, while the ease of dissemination of digital video will aid in conservation initiatives and education.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Video S1. Video clip showing both adult New Zealand falcons at a nest during the incubation period.

Video S2. Video clip showing female New Zealand falcon feeding her nestlings.

Video S3. Video clip showing female New Zealand falcon feeding a common gecko (*Hoplodactylus maculatus*), a new prey item for the falcon, to a nestling.

Video S4. Video of a feral cat killing two 28-day old New Zealand falcon nestlings. Video has been edited from a two-hour event. All three nestlings from this nest were killed by the same feral cat.

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