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WILDLIFE RESEARCH

Eye in the sky: observing wild dingo hunting behaviour using drones

Tahlia I. Pollock[A,*], Daniel O. Hunter[B], David P. Hocking[A,C] and Alistair R. Evans[A,D]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Tahlia I. Pollock
School of Biological Sciences, Monash University, Clayton, Vic. 3800, Australia
Email: tahliaipollock@gmail.com

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ABSTRACT

Context. The behaviours used by mammalian predators to track, kill, and consume prey are some of the most dynamic interspecific interactions in nature. However, they are often challenging to follow through the landscape and observe directly without disturbing the animals being watched. **Aims.** We describe the behaviours used by wild dingoes while hunting macropods in Namadgi National Park, Australian Capital Territory, Australia. **Methods.** Footage was initially captured by wildlife cinematographers on behalf of documentary programs and was made available for viewing after production. Hunting events were filmed from an altitude of >50 m by using a 'long lens' fitted to either a drone or helicopter. **Results.** We recorded a suite of hunting behaviours that would have been extremely challenging to observe from the ground via traditional methods. This includes some of the first video records published in the scientific literature of the behaviours used by dingoes to hunt and kill macropod prey, as well as some rare observations of mother and pup hunting dynamics. We did not observe any signs of disturbance as a result of filming for either predator or prey. **Conclusions.** The varied repertoire of predatory behaviours displayed by dingoes is similar to that documented in wolves and asserts them as a behaviourally complex top predator in the Australian landscape. In addition, we highlight the use of drones as a valuable approach for directly observing wild behaviours. They offer a minimally invasive and relatively inexpensive and accessible alternative to helicopters. This project is also a case study exemplifying the value of collaborations between filmmakers and researchers that enable the sharing of archival documentary footage for the study of wild animal behaviour. **Implications.** Future studies of wild animal behaviour should consider employing drones (at a safe distance and in accordance with published best practices and guidelines) as an additional tool to collect types of data that would be challenging using other methods.

Keywords: behaviour, dingo, drones, hunting, predation, predator, prey, UAVs.

Introduction

Hunting is one of the most dynamic behaviours displayed by animals in nature, but, as a result, it is also one of the most challenging to closely observe in the wild. During hunts, predators such as wolves (*Canis lupus*) can cover distances of up to 8 km (Crisler 1956), and cheetahs (*Acionyx jubatus*) can reach speeds of up to 100 km per hour (Sunquist and Sunquist 2002). As a result, these hunts can quickly move into different environments with variable landscape features (Ewer 1973; Mittermeier and Wilson 2009). Moreover, species can display a broad range of hunting behaviours; for example, wolves can wait in ambush for their prey, openly pursue it, dig it out of the ground, or even drown it (Mech *et al.* 2015). However, these hunting behaviours can be affected by changes in an animal's environment, including the unfamiliar noises, new scents, or changes to the landscape around them that can result from observation (Lehner 1998).

Common approaches for watching such behaviours are direct observation, camera traps, and helicopters; each has their own benefits and drawbacks. Direct observation usually involves the setting of 'hides' near key landscape features, allowing researchers to sit and wait until the animal they are interested in approaches (Lehner 1998). This is highly effective for certain observations; however, they are often limited by time constraints and the view of the researcher. Where it is not possible to sit and wait in person, camera-traps can be deployed. These motion-activated cameras are used in places frequented by animals and, once triggered, they record a video for a set amount of time or take a series of photographs. This technique has become a staple for generating presence/absence data, especially for rare animals of conservation concern in remote locations (Karanth 1995; Maffei *et al.* 2004; Rovero *et al.* 2008). However, the restricted point-of-view and short recording time can limit their utility because they provide only brief glimpses of wild behaviour.

Helicopters have proven extremely useful in capturing dynamic behaviours because they allow researchers to follow animals in real time (Mech and Boitani 2010). Natural history filmmakers in particular have embraced helicopters with stabilised cinema cameras, enabling stunning sequences of behaviour to be filmed from above (e.g. BBC series *Planet Earth* and *Seven Worlds, One Planet*). However, the complex logistics and high costs associated with this approach often puts helicopters outside the reach of most research budgets. Unmanned aerial vehicles, hereafter referred to as 'drones', provide many of the benefits of helicopters, while also being more accessible to researchers. Quadcopter drones, in particular, have recently been deployed in a wide range of settings to collect biological samples (Pirotta *et al.* 2017), monitor landscapes (Lyons *et al.* 2018), survey animal numbers (Hodgson *et al.* 2018; Lyons *et al.* 2018), and make observations of wild behaviour (Torney *et al.* 2018; Brunton *et al.* 2019; Robbins *et al.* 2019). Their use as a tool for wildlife research is rapidly increasing (Wirsing *et al.* 2022). While drones have their own limitations (e.g. flight time, payload weight, operation by trained pilot, and legislative requirements), they provide a viable option for making observations of dynamic behaviours that are otherwise extremely difficult to film, such as hunting.

The dingo [here we use *Canis dingo*; however, species level taxonomy is contested, see Jackson *et al.* (2019) and Smith *et al.* (2019)] is Australia's largest terrestrial mammalian predator (Letnic *et al.* 2014). As a top predator, dingoes play an important role in Australian ecosystems, owing to their ability to suppress populations of the smaller introduced red fox (*Vulpes vulpes*) and regulate the abundance of grazing marsupials such as kangaroos (Colman *et al.* 2014; Hunter *et al.* 2018). Dingoes exist in most habitat types in Australia, including alpine grasslands, desert dunes, and tropical rainforests (Corbett 1995; Smith *et al.* 2019). This is, in part, due to their highly flexible generalist diet that includes mammals, birds, reptiles, insects, carrion from scavenged carcases, and even vegetal matter, the percentages of which vary with location and season (Brook and Kutt 2011; Corbett and Newsome 1987; Doherty *et al.* 2019). Dingoes are also known to employ a broad range of techniques for hunting and killing their prey (Smith 2015; Thomson 1992). Large prey, such as kangaroos, are captured via multiple methods, including slow stalk and ambush or open or extended pursuits (Shepherd 1981; Marsack and Campbell 1990), whereas smaller prey, such as rabbits, are captured via chase and pounce as well as actively digging them out of warrens (Marsack and Campbell 1990; Thomson 1992). Dingoes are predominantly solo hunters but have been observed to target larger prey in groups of two or more (Marsack and Campbell 1990; Thomson 1992; Corbett 1995; Purcell 2010*a*). They have also been observed to exploit their environment to aid in prey capture, such as, for example, operating in the vicinity of a watering hole to target drinking kangaroos, sometimes even entering the water in pursuit (Shepherd 1981; Purcell 2010*b*). Dingoes have even been observed displaying highly innovative prey handling behaviour, using crashing waves along the beach to entrap, drown, and kill an adult swamp wallaby (*Wallabia bicolor*) (Behrendorff 2018). However, no study thus far has provided video evidence of some of the key behaviours and strategies used to capture, kill, and consume large prey, likely owing to the challenges faced in recording such footage in the wild.

In this study, we report a series of direct observations of wild dingo hunting behaviour filmed using high-resolution cameras attached to either a helicopter or quadcopter drone. We propose that the use of drones to observe wild behaviour presents valuable new opportunities to study dynamic behaviours that are otherwise challenging to observe using traditional means.

Materials and methods

Study site

Observations were made in Namadgi National Park in the Australian Capital Territory situated in the south-eastern region of Australia (Supplementary material Fig. S1). Observations were made between 6 and 27 February 2019, 26 October and 5 November 2017, and 18 September and 23 October 2017. Co-author Daniel Hunter (DOH) was present for every day of filming and piloted the drone used for the field observations described in this study.

Animals observed

We observed a total of five dingoes hunting eastern grey kangaroos (*Macropus giganteus*) in this study. DOH distinguished the dingoes from one another via unique markings, and provided information on their approximate ages, sex, and social dynamics where possible; these are summarised in Fig. 1. Approximate age classes were defined as yearling pups ≤20 months and adults ≥21 months, as per Thomson and Rose (1992). Two adult dingoes were observed, one female (Dingo 1) and one male (Dingo 2), and three yearling

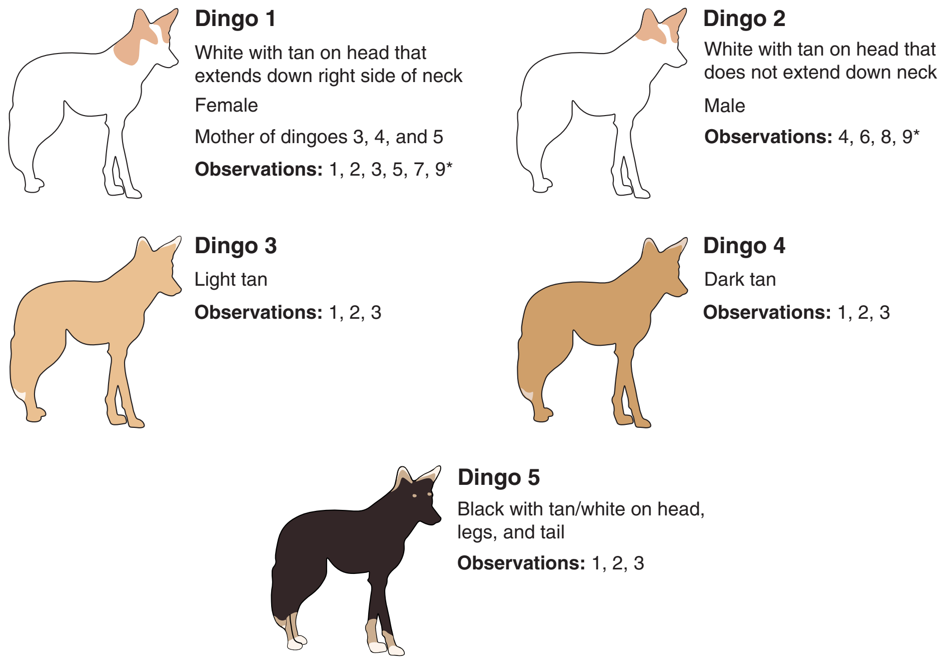

Fig. 1. Dingoes observed in this study, their distinguishing characteristics, and the observations they appear in. Approximate age classes are defined as yearling pups ≤20 months and adult ≥21 months, as per Thomson and Rose (1992). (*) indicates that we are uncertain whether it was Dingo 1 or Dingo 2 that appeared in Observation 9.

pups with unknown sexes (Dingoes 3, 4, and 5). On the basis of observations from previous filming trips, Dingo 1 was assumed to be the mother of Dingoes 3, 4, and 5. Individuals observed were likely to be pure dingo or dingo with some dog ancestry (>75% dingo), not feral dogs. This assumption is based on Cairns *et al.* (2022), who found that in the Australian Capital Territory, just over 80% of dingoes sampled were either pure dingo or dingo with some dog ancestry (>75%).

Eastern grey kangaroo adults can range in size from 19 to 85 kg for males and 17 to 42 kg for females (Coulson 2008), whereas yearlings are <8.8 kg (Poole *et al.* 1982). Adult kangaroos can sustain a hopping pace of 40 km per hour and achieve higher speeds over short distances (McCullough and McCullough 2000). Adult dingoes range in size from 12 to 22 kg for males and 11 to 17 kg for females and are able to keep up with kangaroos over short- and medium-distance chases (Corbett 1995). However, they appear to find it difficult to maintain the same speed over long-distance chases (Dawson 1995).

Footage

The footage analysed in this study was captured for the documentary programs *Seven Worlds, One Planet* (BBC Studios Natural History Unit production) and *Earth at Night in Colour* (Offspring Films/Apple TV+). Stills from *Earth at Night in Colour* used with permission from Offspring Films/Apple and stills from BBC *Seven Worlds, One Planet* used with permission from BBC. Since the video footage was captured with the intended use of documentary filmmaking prior to this study, it is considered archival footage. The examination of archival footage is not subject to institutional animal ethics requirements.

Drone footage of dingo hunting behaviour was captured by wildlife cinematographers DOH and Edward Saltau (ES). Helicopter footage from the BBC program was captured by Tom Crowley (TC).

Drone footage was filmed on a DJI Inspire 2 mounted with an Olympus M. Zuiko 45 mm F1.8 long lens on the DJI Zenmuse X5s gimbal and recorded in NTSC format at 30 frames per second. Observations 1, 2, 3, 4, 6, 8, 9 were captured using this set-up.

Helicopter footage was filmed on a Red Digital Cinema (Red Digital Cinema Camera Company, California, USA) camera fitted with a Canon CN20 long lens (50–1000 mm) on a GSS stabilised gimbal camera system mounted to the helicopter and recorded in RED code at various frame rates. Observations 5 and 7 were captured using this set-up.

Considerations when filming animal behaviour with drones

Drones offer unprecedented access to wildlife at an affordable cost to wildlife cinematographers and researchers. It is because of this that they have become a staple in field kits for both wildlife cinematographers and researchers alike. However, this new technology does have some unique challenges and ethical prerequisites, which all those who wish to fly drones near wildlife need to be aware of.

Paramount is the welfare of wildlife being observed. There are very few standardised ethical guidelines available to ensure animal welfare while filming with drones (Vas *et al.* 2015). However, research into this area is rapidly increasing (Wirsing *et al.* 2022). One key way to mitigate the effect of drones on wildlife subjects is the use of a 'long lens' on the drone to enable filming further away from wildlife subjects. For our observations, we used an Olympus M. Zuiko 45 mm F1.8 lens on the DJI Zenmuse X5s gimbal. The crop factor of this lens on the Micro 4/3 sensor is 2.0X, which makes this lens effectively 90 mm. In practise, this is a long lens that is excellent for observing wildlife such as dingoes and kangaroos because it means the drone is flying at an unobtrusive distance. Drones should never be so close to the wildlife subject, so as to alter their behaviour in any way, and this is why the use of 'long lenses' are essential. As camera technology improves into the future, we will increasingly be able to crop higher-resolution images to a greater extent to gain even more detailed close-up views of the animals.

Take-off and landing of the drone was performed away from animal subjects, as this has been shown to cause disturbance (Landeo-Yauri *et al.* 2021). When the dingoes were displaying hunting behaviours, the drone was always kept away from dingoes and kangaroos. If a chase eventuated, the drone was positioned so that it was observing either approximately perpendicular to the event or approximately directly above (at a minimum altitude of 50 m, predominantly ~75 m). This ensured that it did not disrupt the behaviours of wildlife subjects and is in keeping with Brunton *et al.* (2019), who recommended altitudes of 60–100 m to avoid disturbance when filming macropods. While documenting behaviours in the field, DOH, ES, and TC report that the dingoes and kangaroos did not visibly alter their behaviour in response to drone or helicopter activity. Additionally, in the footage analysed, there is no evidence that the dingoes or kangaroos became aware of the drone or helicopter.

The DJI Inspire 2 works best as a two-person system, whereby the pilot commands the direction, height, and speed of the drone, and the cinematographer controls the camera. This system is beneficial for operating near wildlife because it allows the pilot to be solely focussed on the position of the drone in a three-dimensional space and, thus ensuring it is not interfering with wildlife behaviour.

Flight times for the DJI Inspire 2 are rated at 27 min under ideal flying conditions. Temperature and altitude are both known factors that reduce the battery performance and rotor efficiency respectively. Namadgi National Park is often cool and altitudes are >500 m above sea level and so flight times were often <20 min depending on the conditions. These short flying times limited the extent to which behaviours could be filmed and, at times, the drone had to return-to-home before an observed behaviour finished. For safety and wildlife-welfare reasons, drones always initiated the return-to-home flight path with some battery power in reserve in the event of unforeseen circumstances requiring the drone to detour.

Using an experienced and legally qualified pilot (in Australia certification via the Civil Aviation Safety Authority 'CASA') with experience of the wildlife is essential to ensure wildlife subjects are not distressed and do not alter their behaviour in response to the drone. DOH was the pilot and ES was the cinematographer for the dingo and kangaroo drone footage used in this study. DOH is an experienced drone pilot, with over 200 h of flight time at the time observations were conducted. The pilot holds a Remote Pilot Licence (RePL) and a Remotely Piloted Aircraft Operator's Certificate (ReOC) as specified under CASA regulations. Additionally, DOH studied dingo ecology and behaviour as part of his PhD (Hunter 2018) and was well equipped to make these observations in a way that caused minimal disturbance to both dingoes and kangaroos.

Results

General findings and observations made during the filming period

We observed dingoes hunting eastern grey kangaroos both as individuals and in packs or social groups on multiple occasions. Pack hunting events sometimes began with dingoes trotting abreast several metres apart through vegetation, creek lines and rocky outcrops. This appeared to flush potential prey from cover. Once prey was sighted, a chase would often ensue. Of the 10 or so instances where kangaroo chases were witnessed in a pack scenario, none appeared to be successful during the flight time available. Successful hunts by a solo dingo hunting kangaroos were witnessed on multiple occasions; most of these were conducted by a white female dingo (Dingo 1).

Predation events did occur during the night, which were determined by the presence of semi-consumed carcases in the morning that were not present in the evening of the previous day. One of the observation periods occurred during September and October 2017 and these cooler months were conducive to foggy mornings. Foggy mornings (and probably nights too) seemed to coincide with an increase in dingo hunting behaviour as determined by multiple partially witnessed hunts and kangaroo carcases. On several occasions, dingoes were observed returning to a carcase over the course of multiple days. It is uncertain whether these carcases were cached by dingoes in that particular location or whether the kangaroos were killed at that location and the dingoes were simply returning to carcases.

The macropod hunting tactic posited by Robertshaw and Harden (1986), where dingoes target kangaroo or wallaby mothers so that they eject their pouch young during the chase, was witnessed by the cinematographers on multiple occasions, but not filmed.

It is worth noting that during the filming windows, dingoes were observed hunting only kangaroo prey, despite the presence of red-necked wallabies (*Macropus rufogriseus*) and rabbits (*Oryctolagus cuniculus*) also being observed during the day.

Descriptions of predatory behaviour from video clips

We viewed a total of 7 min and 29 s of video footage, which documented hunting behaviour in five dingo individuals. Summarised in Table 1.

Mother with yearling pups

Observation 1, date 28 February 2019, location Namadgi National Park, observers DOH and ES, filmed with drone for Offspring Films/Apple TV+ production. Length 00:01:09:29 (viewed at 29.97 frames per second).

An adult white female dingo (Dingo 1) and her three yearling pups (light tan, dark tan, and black; Dingoes 3, 4, and 5) attempt to capture a large eastern grey kangaroo. At the beginning of the clip, the three pups are chasing after the large kangaroo (Fig. 2*a*). They corral it with the aid of a large tree, which acts as a fourth wall as they prevent escape from the other three sides (three dingoes; Fig. 2*b*, *c*). They keep the kangaroo corralled but do not attempt to engage with it, waiting until Dingo 1 arrives (from approximately 00:00:11:00 to 00:00:20:00). Once Dingo 1 arrives, she directly engages with the kangaroo, facing it front-on, while repeatedly making advances towards it, vocalising (appears to be multiple short barks (Clarke and Déaux 2013), although audio was not recorded to confirm), and jumping backwards

Table 1. Summary table of generalised behaviours documented, observations, and dingoes present.

Generalised behaviours observed	Observations	Dingoes
Group hunting		
Chasing prey	1, 2, and 3	Dingoes 1, 3, 4, and 5 present in all three observations
Hunting alone		
Ambushing prey	4	Dingo 2
	5	Dingo 1
Chasing prey	9	Either Dingo 1 or 2
Chasing and killing prey	6	Dingo 2
	7	Dingo 1
Eating prey	8	Dingo 2

Fig. 2. Dingo yearling pups (Dingoes 3, 4, and 5) chasing down and corralling large eastern grey kangaroo (*Macropus giganteus*) (Observation 1). Dingoes and kangaroo are indicated with coloured triangles, where pups (Dingoes 3, 4, and 5) are pink, green, and blue respectively, and kangaroo is yellow. (*a*) Three pups chase after kangaroo and (*b*, *c*) pups corral it. Not pictured: mother (Dingo 1) arrives (00:00:21:10) and interacts with kangaroo, while pups corral (00:00:34:14), kangaroo attempts escape (00:00:38:19), mother and pups block escape (00:00:39:05), and finally the kangaroo escapes (00:01:04:05). Footage viewed at 29.97 frames per second. (Stills from *Earth at Night in Colour* used with permission from Offspring Films/Apple).

and forwards in quick succession. The pups (Dingoes 3, 4, and 5) then change position and move to be opposite Dingo 1 and behind the kangaroo, to keep it from escaping in that direction. Then one of the pups (Dingo 3) breaks away from the others and circles anticlockwise around the kangaroo, first to be behind the mother and then continuing further, ending up at the rear with the other pups (Dingoes 4 and 5) again. As Dingo 1 repeatedly makes advances towards the kangaroo, it looks like she is trying to bite at its tail and back of its legs; however, the kangaroo maintains its position facing her. At approximately 00:00:36:00, the kangaroo attempts an escape, turning away from Dingo 1 and towards the pups (Dingoes 3, 4, and 5). The pups react by running in opposite directions to one another and the kangaroo is able to hop through the opening. Dingo 1 pursues the kangaroo biting at its tail and rear end; in response the kangaroo turns back around to face the Dingo 1. Dingo 1 resumes making advances towards the kangaroo, quickly jumping backwards and forwards while yapping, and again it appears that she is trying to bite the kangaroo on its tail/rear. While this is happening, the pups (Dingoes 3, 4, and 5) continue corralling the kangaroo, positioned predominantly behind the kangaroo and opposite Dingo 1. This continues from approximately 00:00:42:00 to 00:01:02:00, until the kangaroo rushes at Dingo 1 and breaks free. All four dingoes follow in pursuit and the clip finishes. The drone pilot (DOH) and cinematographer (ES) lost the kangaroo and dingoes from this point, but another cinematographer was able to film the chase as it continued towards him down a gully towards the homestead. The chase lasted another minute or so and the kangaroo was able to evade the dingoes.

Observation 2, date 26 February 2019, location Namadgi National Park, observers DOH and ES, filmed with drone for Offspring Films/Apple TV+ production. Length 00:00:56:06 (viewed at 29.97 frames per second).

A family of dingoes (mother and three yearling pups; Dingoes 1, 3, 4, 5) are in pursuit of a mob of six or more eastern grey kangaroos. During the chase, the path of Dingo 1 is relatively straight and direct, deviating only to avoid a large tree at approximately 00:00:14:00 and again towards the end of the clip at 00:00:36:16 after pausing briefly. In contrast, the paths of the pups (Dingoes 3, 4, and 5) changes directions more frequently and crosses in front of Dingo 1's path multiple times (at 00:00:05:14, 00:00:09:07, 00:00:12:22, and 00:00:20:17). They run at individual kangaroos; at 00:00:19:21 a kangaroo runs in front of Dingo 1 and two pups (Dingoes 4 and 5), perpendicular to their path. Dingo 1 does not deviate; however, the two pups (Dingoes 4 and 5) change course and pursue the kangaroo (from approximately 00:00:20:00 to 00:00:28:00), after which they head directly back to Dingo 1. During the chase, the pups repeatedly fan out away from Dingo 1 and then back in. We ended our observation of this event without seeing the dingoes engage with the kangaroo targets.

Observation 3, date 26 February 2019, location Namadgi National Park, observers DOH and ES, filmed with drone for Offspring Films/Apple TV+ production. Length 00:01:18:00 (viewed at 29.97 frames per second).

A family of dingoes, mother (Dingo 1) and three yearling pups (Dingoes 3, 4, and 5) are in pursuit of a mob of 15 or more eastern grey kangaroos. The clip begins in open terrain, relatively free of vegetation or rocks. At approximately 00:00:45:00, the kangaroos encounter a road that is directly across their current path. The kangaroos head over the road and most continue straight onwards. However, a small number of kangaroos veer left after crossing over the road. The dingoes target these kangaroos and pursue them into the woodland. The pursuit itself continues for almost the entirety of the clip, where they slow down approximately 00:01:16:00 (clip runs for 00:01:18:00). For most of the chase, the paths of all dingos remain fairly constant, in contrast to Observation 2. The pups (Dingoes 3, 4, and 5) do not run at individual kangaroos or change direction abruptly and they do not cross the path of Dingo 1. Because the clip began with the dingoes already in active pursuit, the chase itself lasted for a minimum of 1 min and 16 s.

Dingo ambushing prey

Observation 4, date 20 February 2019, location Namadgi National Park, observers DOH and ES, filmed on drone for Offspring Films/Apple TV+ production. Length 00:00:10:25 (viewed at 29.97 frames per second).

An adult male dingo (Dingo 2) drops to the ground in an ambush attempt. The clip begins with the dingo trotting and looking around (presumably for kangaroos). At approximately 00:00:04:00, the dingo spots a kangaroo; it drops to the ground and waits for ~3 s. When the kangaroo is closer (approximately 10 m) the dingo jumps up in pursuit and, watching the kangaroo closely runs directly towards it from 00:00:08:00 to 00:00:10:00. It appears that the kangaroo changes direction in response to seeing the dingo at approximately 00:00:10:00. As this happens, the path of the dingo changes as well to run alongside the kangaroo.

Observation 5, date November 2017, location Namadgi National Park, observer TC, filmed from helicopter for BBC Studios Natural History Unit production. Length 00:00:17:22 (viewed at 25 frames per second).

An adult female dingo (Dingo 1) attempts an ambush. It begins with the dingo moving in the direction of group of five or more eastern grey kangaroos. At approximately 00:00:08:00, the dingo stops and waits (presumably after spotting an approaching kangaroo out of frame; Fig. 3*a*). At 00:00:09:16, a kangaroo appears (bottom right corner) and the dingo rushes towards the kangaroo, coming at it almost side-on (Fig. 3*b*). The kangaroo notices the dingo quite late (approximately 00:00:10:23), at which point the dingo is almost directly in front of the kangaroo (Fig. 3*c*). The startled kangaroo leaps over the dingo (Fig. 3*c*–*e*; 00:00:11:07–00:00:11:23), which is in a crouched position.

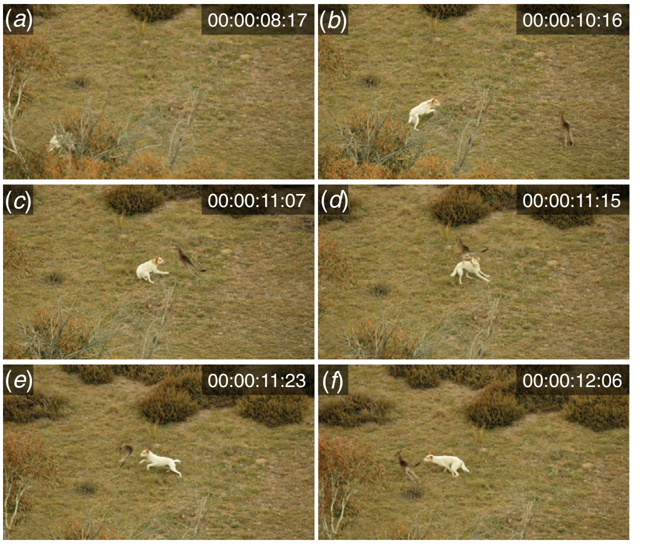

Fig. 3. Adult female dingo (Dingo 1) attempts ambush on yearling eastern grey kangaroo (*Macropus giganteus*) (Observation 5). (*a*) Dingo 1 is stationary waiting for the kangaroo (outside of the field of view of the camera), (*b*) when the kangaroo is close enough, Dingo 1 jumps up and runs towards it. The kangaroo notices the dingo and jumps over it (*c*–*e*). (*f*) Dingo 1 gives chase. Footage viewed at 25.00 frames per second. (Stills from BBC *Seven Worlds, One Planet* used with permission from BBC).

The dingo tracks the movement of the kangaroo as it jumps over it, causing the dingo to change direction. When the kangaroo's feet are about to make contact with the ground again, at the end of the jump, the dingo leaps after it in pursuit (00:00:12:06; Fig. 3*f*). The pursuit is short and the chase unsuccessful.

Dingo hunting and killing prey

Observation 6, date 2 March 2019, location Namadgi National Park, observers DOH and ES, filmed on drone for Offspring Films/Apple TV+ production. Length 00:01:01:20 (viewed at 29.97 frames per second).

An adult male dingo hunting (Dingo 2) kills and carries off a yearling eastern grey kangaroo. The dingo appears ~3 s into the clip in fast pursuit of a kangaroo. Somewhere between 00:00:06:00 and 00:00:09:00, the dingo captures the kangaroo, while obscured by trees. It appears that the dingo grapples with the kangaroo until it may be dead (approximately 00:00:21:00), but again it is unclear because of the tree coverage as well as the camera panning away. The approach of another kangaroo (appears bottom left of the clip at approximately 00:00:17:00), making its way through the tree line towards the dingo startles the dingo causing it to drop its prey and run in the opposite direction towards the top right tree line. The dingo realises it is another kangaroo and trots back over to the dead/dying kangaroo. After looking around, the dingo starts to grapple with the kangaroo again picking it up in its jaws and biting around the neck/chest area. Holding the kangaroo in its jaws the dingo spins around twice and then pins the kangaroo down against the ground with jaws around its chest/neck and holds it for 2–3 seconds. The dingo then picks up the kangaroo and repositions its jaws twice before carrying it into the forested area.

Observation 7, date November 2017, location Namadgi National Park, observer TC, filmed from helicopter for BBC Studios Natural History Unit production. Length 00:00:34:27 (viewed at 30 frames per second).

An adult female dingo (Dingo 1) hunts and kills a yearling eastern grey kangaroo. The clip begins with the dingo in direct pursuit of a yearling kangaroo, which is running after another adult kangaroo. Initially, the chase is over flat terrain; however, at 00:00:03:00 the camera pans forward towards the rocky terrain and trees ahead. Both kangaroos run toward the uneven terrain and as the yearling attempts to jump over some of the rocks it trips, tumbles over twice, and recovers (between 00:00:10:41 and 00:00:12:19). Likely disoriented from the fall, the kangaroo then abruptly changes direction, first deviating right, and then almost doubling back around on its original path. During this time the dingo has made up ground and is much closer behind the kangaroo. At 00:00:15:31, the kangaroo trips again falling into a rock. It manages to get back up, but as it attempts to get away the dingo grabs it in its jaws (Fig. 4*a*, *b*). The dingo bites the kangaroo around the neck/chest in mid-air (Fig. 4*b*, *c*) and then brings the kangaroo to the ground, pinning it between its jaws and the ground (Fig. 4*d*).

Fig. 4. Adult female dingo (Dingo 1) kills yearling eastern grey kangaroo (*Macropus giganteus*) (Observation 7). In (*a*) Dingo 1 leaps towards and (*b*, *c*) bites the kangaroo around the neck/chest region before (*d*) pinning it to the ground. Footage viewed at 29.97 frames per second. (Stills from BBC *Seven Worlds, One Planet* used with permission from BBC).

Dingo eating prey

Observation 8, date 2 March 2019, location Namadgi National Park, observers DOH and ES, filmed with drone for Offspring Films/Apple TV+ production. Length 00:00:09:20 (viewed at 29.97 frames per second).

An adult male dingo (Dingo 2) is eating the kangaroo it captured in Observation 6. The dingo is eating from what appears to be the chest area. It is not crouched or sitting but standing with their legs slightly splayed and biting and pulling upwards in an attempt to tear off pieces of prey. Entry into the chest area of prey is not widely recorded, more commonly initial entry is via the abdominal area.

Dingo chasing prey

Observation 9, date 22 March 2019, location Namadgi National Park, observer DOH and ES, filmed with drone for Offspring Films/Apple TV+ production. Length 00:01:53:15 (viewed at 30 frames per second).

A lone adult dingo (either Dingo 1 or 2; the drone was not close enough to determine with certainty) searches for and pursues a mob of five or more kangaroos. The clip begins following the dingo at a light run. At approximately 00:00:08:00, the dingo slows to a trot while looking around (presumably scanning for kangaroos). The dingo then pauses and looks behind before moving forward again, this time at a walk. While walking, the dingo is constantly looking around. At 00:00:48:00, the dingo spots something (assumed to be a kangaroo out of frame) and breaks into a fast-paced run. Between 00:00:48:00 and 00:00:56:00, the camera pans up and two kangaroos are visible, one runs off to the left of frame (00:01:00:00) and the other is ahead of the dingo (00:01:07:00). As the chase continues, more kangaroos are visible (approximately five individuals at 00:01:25:00) before the footage cuts away (00:01:27:00). As the footage cuts away, we are unable to say exactly how long the pursuit lasted for.

Discussion

Filming from above gave us a unique perspective of the dingoes as they moved through the landscape, and proved to be an effective tool for directly observing dynamic hunting behaviours in the wild. By deploying drones and a helicopter, we were able to record and document a suite of hunting behaviours in dingoes that would have been challenging to observe via traditional methods. The behaviours recorded spanned the entire predatory sequence, including chasing, prey capture, killing, and consumption, some of which were videoed and reported in the scientific literature for the first time (e.g. killing of macropod prey and mother and pups hunting).

Novel behaviours observed

Two separate kills made by the two adult dingoes (Dingoes 1 and 2) were recorded, both of which targeted yearling kangaroos (Observations 5 and 6). In each observation, as the kangaroo is brought down, the dingo directs bite(s) towards the chest and neck region, clamping its jaws over this area before pinning the animal to the ground with its jaws (Observation 5). Smaller prey such as rabbits have been observed to be snapped up and shaken (Corbett 1995); however, until now, direct video records showing exactly how dingoes kill macropod prey are extremely limited in the published literature (Behrendorff *et al.* 2018). For example, a curious documented instance of 'drowning' (multiple undocumented observations have been made too; Behrendorff 2018). This direct observation of killing behaviour videoed in this study is the first account for wild dingoes published in the scientific literature. Although similar videos do exist on platforms such as YouTube and direct observations have likely been made by land managers or First Nations Peoples, they are not in a citable format. Observation 5, in part, supports previous inferences based on examination of recovered prey remains. Past necropsy of macropod (Shepherd 1981) and dingo carcases (from intraspecific killings; Behrendorff *et al.* 2018) infer a 'bite and shake' mode of killing that is targeted to the chest/neck region. Unlike with smaller prey such as rabbits, we did not witness any shaking. Considering the kangaroo's size, it is likely to be more effective to inflict crushing bites in and around the chest and neck area.

We also reported the first direct video observations of group predatory behaviour between a dingo mother (Dingo 1), her yearling pups (Dingoes 3, 4, and 5), and their prey. Observations 1, 2, and 3 show the mother and pups hunting together, either targeting a single kangaroo (Observation 1) or chasing multiple kangaroos (Observations 2 and 3). In Observation 1, we can see the mother (Dingo 1) play a leading role, directly interacting with the kangaroo, more so than the pups do. This may be an example of social learning between mother and pups, something that has previously been recorded only when hunting rabbits (Corbett and Newsome 1975), but has been extensively studied in other predators such as the wolf . In wolves, not all components of hunting and foraging behaviour are innate; for example, where to find food and how to kill (Packard 2003). These behaviours are learned over time via observation and experience (Mech 1988, 1991; Fentress 1992). Wolf pups often join hunts and are able to learn the more subtle aspects of hunting and killing (Packard 2003). It is possible that Observations 1, 2, and 3 give a glimpse into the social habits of hunting dingoes; however, more data are necessary to explore this further.

Strategies for overcoming fast prey

The kangaroo prey targeted by dingoes in this study are fast and agile, which presents a challenge for dingoes. However, we observed dingoes employ a number of strategies to help target their macropod prey. One of these was ambush. We recorded two ambush attempts (Observations 4 and 5; Dingoes 1 and 2). In each instance, on seeing the approaching kangaroo, the dingo became still, waited for it to move closer, and then attempted an ambush. Dingoes ambushing their prey has been previously documented; however, no video recordings had been reported until now in the published literature (Marsack and Campbell 1990). Ambushing prey is useful as the predator is not required to outrun their prey, merely catch up with it over a short distance. It is also a way to encourage tripping or avoidance behaviours that may hinder escape. We can see an example of this in Observation 5; as the dingo jumps up, the startled kangaroo deviates from its path and is, momentarily, off balance.

Another way for a predator to overcome prey faster than themselves is by chasing it towards tripping hazards, such as, for example, rocky outcrops, forested areas, or physical barriers (Mech *et al.* 2015). We observed that when dingoes were in open pursuit of macropod prey, the chases often moved into rocky ground (Observation 7), forested areas (multiple observations made by filmmakers, but not filmed), or even man-made structures such as fences and roads (Observation 3). The result of this is best illustrated in Observation 7, where the adult female dingo (Dingo 1) pursues a yearling kangaroo. The chase moves from open ground towards a rocky outcrop and when attempting to navigate the rocky area, the kangaroo trips. As the kangaroo is attempting to right itself, the dingo is able to close the distance between them and make a successful kill. It appears that the dingoes in this study used the landscape around them to their advantage; however, more observations are needed to confirm this. Driving kangaroos towards these potential hazards may hamper their speed giving the dingo a greater chance of hunting success.

Prey selection is another strategy often employed by predators (Ewer 1973). One of the groups most often targeted are juveniles; for example, brown bears (*Ursus arctos*) and deer fawns (Garshelis 2009), wolves and bison (*Bison bison*) calves (Mech 1970), or cheetah and Thomson's gazelle (*Eudorcas thomsonii*) calves (Sunquist and Sunquist 2009). By targeting smaller, slower, and comparatively inexperienced juveniles, predators are able to avoid the challenges posed by large, fit, and healthy adult prey. In each kill or ambush attempt (Observations 4, 5, 6, and 7), the target prey was a yearling kangaroo. Although not entirely consistent with previous studies that have reported that dingoes 'farm' young macropods by harassing a mother kangaroo until she ejects her joey (Robertshaw and Harden 1986), we observed a preference towards smaller individuals by dingoes during field observations.

Similarities in hunting behaviour between dingoes and wolves

The range of hunting behaviours displayed by dingoes in this study, as well as those documented in the literature, draws a number of parallels with another top canid predator, the wolf (Thomson 1992). Wolves also openly pursue prey either alone (Mech 1970; Mech *et al.* 2015) or in groups (Mech 1970; Mech *et al.* 2015) and sometimes over large distances (Crisler 1956; Mech 1966, 1997; Wikenros *et al.* 2009). They can ambush their prey (Kelsall 1968; Mech 1970, 2007) and use the landscape around them to chase prey towards tripping hazards (Haber 1977; Mech *et al.* 2015). Wolves are also known to use areas where their prey frequent [e.g. beaver ponds or hare burrows (Mech *et al.* 2015)], just like dingoes operating in the vicinity of a watering hole to target drinking kangaroos (Shepherd 1981). Wolves have even been observed killing prey after pursuing it into a body of water (Nelson and Mech 1984), a common predator avoidance strategy (Crisler 1956; Mech 1966, 1970; Peterson 1978; Nelson and Mech 1981). The macropods that dingoes target also employ it (Behrendorff 2018); just like wolves, dingoes will enter the water in pursuit of prey (Purcell 2010*b*) and have even overcome and drowned their prey on occasion (Behrendorff 2018). Moreover, young wolves often accompany older wolves on hunts to learn aspects of predatory behaviour (Mech 1991; Packard 2003). We also observed evidence of social learning of hunting behaviour in the dingoes (mother: Dingo 1; pups: Dingoes 3, 4, and 5; Observations 2, 3, and especially 1). Where wolves and dingoes differ in predatory behaviour is in the size and social cohesiveness of their packs and the maximum size of prey targeted. Wolves often occur in large groups with strong social bonds and are able to take down adult elk or moose (Mech and Boitani 2010; Mech *et al.* 2015), while and dingoes are often found alone, or in smaller, less socially cohesive groups and may target adult red or eastern grey kangaroos (Corbett 1995). The similarities in predatory behaviour shared between dingoes and wolves described, helps highlight the dingo as an adaptable and behaviourally complex predator.

The utility of drones for observing animal behaviour

Drones offer an enhanced perspective, one which enabled us to make some of the novel observations in the study, including patterns of running and formation during a hunt (Observations 1, 2, and 3), corralling of prey by multiple predators (Observation 1), and, possibly, chasing towards tripping hazards (Observation 7). These observations could be captured only from above. With binoculars or camera lens on the ground, we simply would have lost visual line of sight owing to the undulating terrain. The size, flexibility and remote-piloting capabilities of drones allow researchers and cinematographers to follow animals over the landscape, which can include isolated and extreme environments, from central Australian deserts to the sub-Antarctic (Robbins *et al.* 2019). Drones have been integral for observing unique behaviours as well as collecting novel data samples in difficult-to-study species; for example, group feeding in leopard seals (*Hydrurga leptonyx*), sampling humpback whale (*Megaptera novaeangliae*) 'whale blow', surveying Australian sea lion (*Neophoca cinerea*) and fur seal (*Arctocephalus pusillus*) populations, and estimating body mass and condition in pinnipeds (Krause *et al.* 2017; Pirotta *et al.* 2017; Robbins *et al.* 2019; Sorrell *et al.* 2019).

Arguably what makes drones so useful, especially for researchers, is their cost and availability, with drones costing considerably less than helicopters, and being more readily available. This puts them within the scope of research budgets. An even more cost-effective strategy (and the one employed here in this study) is collaborating with natural history filmmakers, such as Daniel Hunter, Edward Saltau, and Tom Crowley, and their associated institutions (Offspring Films, Apple TV+, and the BBC Studios Natural History Unit), to access pre-existing archival footage. Filmmakers frequently make unique observations of animal behaviour, but often these do not reach the scientific community in a published and citable format. The observations of dingo hunting behaviour described in our study demonstrate the utility of researchers and filmmakers working together to share these behavioural observations in multiple formats. However, as with most new technologies, there are important drawbacks to be considered. Currently, the utility of drones is severely hindered by battery life. For example, flight times for the drone used in this study are rated at 27 min under ideal conditions; however, lower temperatures at Namadgi National Park affected the flight times, which were often <20 min. As a result, at times filming had to stop before an observed behaviour finished. As drone technology improves into the future, longer and longer sequences of behaviour will be able to be captured.

Conclusions

In this study, we were able to follow dingoes through the landscape as they hunted macropod prey. Use of both drones and a helicopter enabled us to publish some of the first video records of their dynamic predatory behaviours. We documented a suite of wild behaviours that spanned the entire predatory sequence, some of which were reported in the scientific literature for the first time. Viewing these behaviours from above gave us unique insights into how dingoes target, hunt, and kill their macropod prey. Moreover, the varied repertoire of predatory behaviours we observed in dingoes draws a number of key parallels with wolves and helps cement them as an adaptable and behaviourally complex predator functioning within the Australian ecosystem. Insights such as these would have not been possible without the use of drones. They allowed us to capture these highly dynamic behaviours in a minimally invasive way that was relatively inexpensive and accessible (especially when undertaken in collaboration with natural history film productions). This project is a case study exemplifying not only the utility of drones, but also the value of collaborations between film-makers and researchers, which enables the sharing of archival documentary footage for the study of wild animal behaviour. Future studies of wild animal behaviour should consider employing drones as an additional tool to collect types of data that would be challenging using other observational methods. In addition to integrating drone use with other pre-existing monitoring methods. For example, using GPS (global positioning system) tracking to accurately locate individuals before deploying a drone to video behaviours of interest. Or filming individuals fitted with accelerometers to collect important biomechanical data that can be correlated directly with wild behaviours. A more integrated approach combining drones with existing technologies opens up exciting opportunities for the study of animal behaviour.

Supplementary material

Supplementary material is available online.

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Author affiliations

[A]School of Biological Sciences, Monash University, Clayton, Vic. 3800, Australia.

[B]School of Biological, Earth and Environmental Sciences, University of New South Wales, NSW, 2052, Australia.

[C]Zoology, Tasmanian Museum and Art Gallery, Hobart, Tas. 7000, Australia.

[D]Geosciences, Museums Victoria, Melbourne, Vic. 3001, Australia.