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RESEARCH ARTICLE

Para-aminopropiophenone (PAPP) in canid pest ejectors (CPEs) kills wild dogs and European red foxes quickly and humanely

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Abstract

Lethal control remains an important approach to mitigating the impacts of predators on livestock and threatened fauna. This occurs in Australia, where wild dogs (*Canis familiaris*) and European red foxes (*Vulpes vulpes*) are commonly subjected to broad-scale poisoning programs. Ongoing refinement of lethal tools has led to the recent development of manufactured poison baits containing para-aminopropiophenone (PAPP). Canid pest ejectors (CPEs) have also been recently registered for use and are a target-specific poison delivery device; yet, there has been no confirmation that PAPP delivered via ejectors will provide similar efficacy to PAPP delivered via manufactured baits. We tested the efficacy of PAPP in ejectors on wild dogs (1000-mg dose) and foxes (400-mg dose). Time-to-death, physical signs of poisoning and other related factors were assessed. Ten of 11 (91%) wild dogs used in controlled trials died within 3 h after PAPP administration; the mean time to unconsciousness was 65 min and the mean time to death was 84 min. Three of four (75%) foxes also died within 3 h after PAPP administration; their mean time to unconsciousness was 78 min, and their mean time to death was 121 min. Carcasses of eight deceased wild dogs and one fox were found during field trials, with distances between the nearest triggered ejector and the deceased animal ranging from 30 to 200 m. The presence of de-oxygenated blood in all necropsied carcasses and photographic evidence of triggered ejectors unequivocally demonstrated that using powdered PAPP in ejectors produces rapid anoxia and death in both wild dogs and foxes. Although anxiety and accompanying behaviours were observed in wild dogs (but not foxes), the use of PAPP offers a humane, additional option for the control of wild canids.

Keywords *Canis dingo* · Humaneness · Livestock protection · Human-wildlife conflict · Poison · Wild dog

Introduction

Predation on vulnerable wildlife and livestock is a major source of human-wildlife conflict globally, and predators are often controlled to mitigate their impacts. Ecological contexts and livestock production systems vary enormously around the world, as do the type of predator species that impact livestock and vulnerable wildlife. Predator control techniques and tools likewise vary enormously (e.g. du Plessis et al. 2018) and include both lethal and non-lethal techniques. Human societies are increasing their demand for livestock products (Thornton 2010; McLaughlin 2011; Tscharntke et al. 2012); at the same time, there is increased demand for improved welfare practices associated with livestock production and predator control (Petherick 2005; GAP 2009; Twigg and Parker 2010; van Eeden et al. 2017). This has led to a resurgence of interest in non-lethal predator control tools (Bergstrom et al. 2014; van Bommel and Johnson 2014; Smith and Appleby 2018) and the development of more humane and target-specific lethal control tools (Fisher et al. 2008; Eason et al. 2014; Read et al. 2014; Mallick et al. 2016).

Australia is one of the largest exporters of sheep, goats, and cattle in the world (www.fao.org), where production of these livestock species occurs over vast rangeland areas (Allen 2011; East and Foreman 2011; MLA 2017). Australia also has a rich and unique native fauna assemblage (e.g. Van Dyck and Strahan 2008), many of which are threatened by canid predators (Allen and Fleming 2012; Woinarski et al. 2015). All terrestrial predators in Australia are small by global standards and only two significantly affect livestock. At an average weight of just 15.7 kg (Allen and Leung 2014),

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dingoes and other wild dogs (*Canis familiaris*; Jackson and Groves 2015) are the largest extant terrestrial predator on mainland Australia, followed by European red foxes (*Vulpes vulpes*; ~ 6 kg). These canids are subjected to lethal control in many areas (Fleming et al. 2014), with broad-scale distribution of poisoned meat baits the primary strategy used to mitigate their impacts across the large areas that livestock are produced (Anon 2014; Fleming et al. 2014). A variety of poisons have been used throughout the history of canid control in Australia; yet, poison development and use have followed a steady course of continual refinement in pursuit of more safe, effective, and humane options (Allen and Hampton 2017). Strychnine was used in baits for many decades in the early twentieth century but was phased out and is now prohibited given the advent of sodium fluoroacetate (1080) in the 1970s. Since that time, 1080 has been and is still the principal toxin used to control wild dogs and foxes (APVMA 2008).

Over the last 15 years, however, para-aminopropiophenone (PAPP) has been developed as another toxin for invasive species control in New Zealand (Eason et al. 2014) and Australia (Marks et al. 2004; APVMA 2015; Gentle et al. 2017; Meek et al. 2019). PAPP was registered for use against wild dogs and foxes in Australia in 2016 and is presently available only in the manufactured baits labelled DOGABAIT® and FOXECUTE®. In Australia, concern over non-target risks associated with broad-scale baiting (using any toxin) has also led to the importation and simultaneous development of canid pest ejectors (CPEs; hereafter ejectors). Ejectors are an Australian derivative of the 'M-44' or 'Humane Coyote Getter', which have been used for decades in the USA, South Africa and elsewhere. Ejectors are loaded with a small capsule (~ 1000 mg capacity) containing powder, paste or liquid which is ejected or expelled into the mouth of an animal that bites, tugs or pulls on the ejector with sufficient strength to trigger a delivery spring within the device (Hooke et al. 2006). Ejectors were registered for use in Australia in 2016, but initially only with capsules containing 1080.

In the continual effort to refine wild dog and fox control practices, maximise welfare outcomes for these controlled species and further reduce non-target risks (Marks et al. 2004), we trialled the use of PAPP powder in ejectors to evaluate whether capsules containing 1000 mg of PAPP powder (for wild dogs) and 400 mg of PAPP powder (for foxes) can be used within ejectors to quickly and humanely kill both species under both controlled and field conditions.

Methods

Permits and authorities

The dingo is considered native wildlife under the *Nature Conservation Act 1992* and is protected in some national parks. Elsewhere—including land where this project was undertaken—dingoes and other wild dogs are recognised pest species and are subject to lethal control in most jurisdictions. Foxes are declared pest species in all Australian jurisdictions. Approval to undertake the project was granted by the University of Southern Queensland's Animal Ethics Committee (AEC permit number: 16REA012). A 'Permit to allow research use and supply of an unregistered agvet chemical product' was also obtained from the Australian Pesticides and Veterinary Medicines Authority (APVMA permit number: PER83898). The project was conducted in accordance with these approvals. Permission to work on private land was granted by the landholder prior to commencing work.

Study sites and trial designs

Wild dog trials were conducted on Quinyambie Station in the Strzelecki Desert of north-eastern South Australia (within 100 km of − 30.129, 140.714). The site has a mean annual rainfall of ~ 160 mm and is composed of parallel sand dunes dominated by hopbush (*Dodonaea viscosa*), buckbush (*Salsola kali*) and a variety of grasses and burrs, including kerosene grass (*Aristida* spp.) and copperburr (*Sclerolaena* spp.; Kutsche and Lay 2003). Additional descriptions of the site can be found elsewhere (e.g. Newsome et al. 2001; Allen et al. 2014). Fox trials were conducted in various locations around south-east Queensland and central-west New South Wales.

This study comprised two separate, but interrelated trials. Trial 1 was designed to demonstrate that capsules containing 1000 mg of PAPP powder (for wild dogs) or 400 mg of PAPP powder (for foxes) can be used within ejectors to kill wild dogs and foxes under controlled conditions. Trial 2 used the same doses of PAPP powder within baited ejectors, but was primarily designed to confirm that wild dogs and foxes can also receive a lethal dose and be killed under natural field or operational conditions.

Trial 1

Trial 1 was conducted over 4 days in May 2017. Soft-catch foot-hold traps ('Jakes') were placed around two artificial livestock watering points. Traps were placed near cattle pads, vehicle tracks and other places where wild dogs were expected to travel on their way to or from the water point. Traps were checked at least once daily each morning. Captured wild dogs were restrained with a catchpole and offered an ejector containing 1000 mg PAPP powder. This was done using an ejector fixed on the end of an extended pole, and with the ejector bait head positioned in the mouth behind the canine teeth, the pole was gently pulled back until the ejector was triggered. Spillage of PAPP powder out of the side of the mouth sometimes occurred when animals moved their tongue or adjusted

the orientation of their head. Therefore, to estimate the actual dose an individual received, we carefully emptied the entire contents of a capsule onto a clear surface for reference purposes and visually compared the amount of emptied PAPP from a full capsule with the 'spilled' amount of PAPP on the ground. After wild dogs had swallowed or licked their lips once or twice and we were confident that no additional PAPP powder would be spilled, we withdrew to observe the wild dog (still in the trap) from a distance until they appeared unconscious. After unconsciousness, wild dogs were approached and observed from a closer proximity. We recorded wild dog weight, sex, time to 'first down' (i.e. the time that wild dogs first sat or laid down), time to 'last down' (i.e. the time that wild dogs sat or laid down and never got back up again), time to unconsciousness, and time to death. We also recorded other physical signs of PAPP poisoning for each wild dog, including changes in the coloration of their gums, vocalisations, movements and other behaviours. Following death, a necropsy was performed in the field to ascertain internal indicators of PAPP poisoning. De-oxygenated (or very dark) blood occurred in all cases as expected (Henretig et al. 1988), with this indicator then used in trial 2 as confirmation for PAPP poisoning (described below).

A similar process to that described above was also followed for foxes. However, smaller traps were used (Victor #1.5) and fox trapping occurred over a 10-day period in October 2017. Any wild dog or fox that did not die within 3 h after PAPP administration was humanely euthanized by firearm.

Trial 2

Trial 2 was conducted over 4 days in February 2018. Environmental conditions at the time were poor; the study site had not received rain for some time, and of the > 100 wild dogs opportunistically observed during the trial, approximately 90 were in extremely poor body condition (i.e. score 1 or 2, as per the body scoring assessment method used in Behrendorff et al. 2016). Up to 50 ejectors containing 1000 mg of PAPP powder were placed around four artificial livestock watering points. Several ejectors were placed around each waterpoint, in pairs—one ejector used dried kangaroo meat as the bait head or lure type, and the other used dried venison. Ejectors were checked once or twice each day (in the morning, and sometimes again in the afternoon), and triggered or 'pulled' ejectors were reset as often as needed. The number of deployed ejectors was increased over days 1 and 2 and was decreased over days 3 and 4 when pull rates at a given waterpoint decreased. Reconyx HC600 camera traps were placed on up to 10 selected ejectors to obtain photographic evidence of wild dogs pulling ejectors. Animal footprints or tracks in the sand were used to determine the identity of the species responsible for pulling ejectors that were not monitored by a camera trap. Following each successful pull, a search was undertaken to locate the carcass of the deceased wild dog. Searches thoroughly covered an area no less than 300 m radius from the location of each pulled ejector. When a carcass was found, we recorded the wild dog's distance to the nearest pulled ejector and the sex, body weight, and body condition score. A necropsy was performed in the field to confirm the presence of de-oxygenated (or very dark) blood as evidence of PAPP poisoning.

Results

Trial 1

We captured and administered PAPP to 11 wild dogs, including three males and eight females (Table 1). Wild dog body weights ranged from 9.0 to 15.5 kg. PAPP spillage occurred on several occasions, and not all animals received a 1000-mg dose. Adjusted for body weight, dose rates ranged between 48.0 and 93.3 mg/kg (mean = 70.9 mg/kg). Ten of 11 (91%) wild dogs died within 3 h after PAPP ingestion. For these 10 dogs, the mean time to 'first down' was 14 min, the mean time to 'last down' was 39 min, the mean time to unconsciousness was 65 min, and the mean time to death was 84 min. One wild dog (dog 11) followed this same pattern and progressed to unconsciousness, but showed signs of recovery at 180 min after PAPP ingestion and was euthanised; this failure to die was not associated with a lower/reduced dose of PAPP (Table 1).

A total of four trapped foxes were offered PAPP capsules containing 400 mg of PAPP, and PAPP spillage occurred on two occasions (Table 1). Foxes weighed between 2.2 and 6.1 kg, and dose rates ranged between 52.5 and 250.0 mg/kg. Three of four (75%) foxes died within 3 h after PAPP ingestion. For these three foxes, the mean time to unconsciousness was 78 min, and the mean time to death was 121 min. Time to 'first down' was 9 min and 10 min, and time to 'last down' was 25 min and 40 min for two of the four foxes. One fox (fox 04) initially followed the same pattern and became lethargic, but showed signs of recovery at 180 min after PAPP ingestion and was euthanised; this failure to die was not associated with a lower/reduced dose of PAPP (Table 1).

Changes in gum colouration between the time of PAPP administration and death were minimal, but the presence of dark, 'chocolate' or de-oxygenated blood was observed throughout all tissues and viscera in all wild dogs during necropsy (Fig. 1). Signs of distress and anxiety between the time of PAPP administration and unconsciousness were also observed in all 11 wild dogs, and some animals appeared to drop in and out of consciousness as symptoms progressed. Rapid breathing was commonly observed, and breathing rates reached 200 breaths/min for dog 01 at the time of 'last down' (53 min after PAPP ingestion). Vocalisations characterised by

Table 1 Details of wild dogs and foxes killed in trial 1

Animal ID	Date	Weight (kg)	Sex	Dose received (mg/kg)	Time PAPP was administered	First down (min)	Last down (min)	Unconsciousness (min)	Deceased (min)	De-oxygenated blood
Dog01	14-May-17	15.1	F	53.0	7:02	22	53	93	124	Present
Dog02	14-May-17	12.0	F	83.3	10:14	24	45	60	74	Present
Dog03	15-May-17	15.0	M	63.3	7:27	1	38	46	52	Present
Dog04	15-May-17	12.5	F	78.4	7:53	1	46	71	87	Present
Dog05	15-May-17	9.0	F	55.6	9:31	20	42	47	86	Present
Dog06	15-May-17	14.5	M	69.0	9:48	22	35	53	59	Present
Dog07	16-May-17	15.5	M	48.4	8:38	8	30	112	124	Present
Dog08	17-May-17	13.0	F	73.1	8:54	25	41	45	60	Present
Dog09	17-May-17	11.0	F	88.2	9:10	10	33	64	83	Present
Dog10	17-May-17	13.0	F	74.6	9:25	5	24	60	91	Present
Dog11	17-May-17	10.5	F	93.3	12:50	20	65	107	N/A	Present
Fox01	14-Oct-17	1.6	F	250.0	10:18	10	25	75	132	[b]
Fox02	14-Oct-17	6.1	M	52.5	8:25	[b]	[b]	103	170	[b]
Fox03	18-Oct-17	5.8	M	69.0	15:55	[b]	[b]	55	61	[b]
Fox04	23-Oct-17	2.2	F	113.6	9:02	9	40	N/A	N/A	[b]

[a] Oral LD^{50} values for PAPP are 8.5 mg/kg for wild dogs and < 25.2 mg/kg for foxes (Eason et al. 2014)

[b] Not assessed

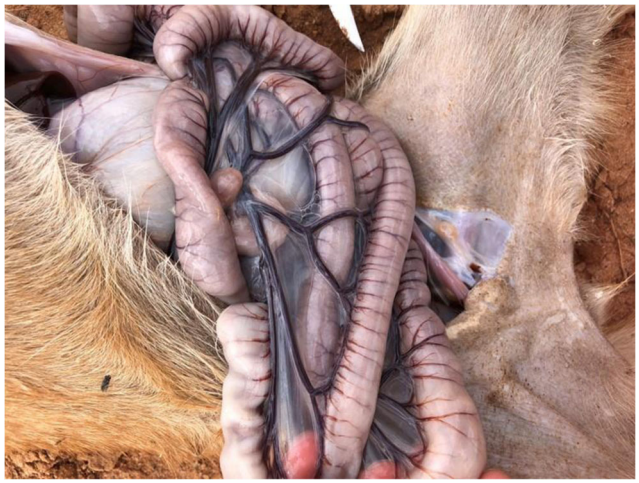

Fig. 1 The presence of dark, 'chocolate' or de-oxygenated blood in the mesentery tissue of a wild dog killed by PAPP poisoning, February 2018 (Photo: Benjamin Allen)

a laboured high-pitch howl, before running out of breath, was observed in all wild dogs. Paddling occurred in five wild dogs, and excessive salivation also occurred on some occasions. No such signs were observed in any of the four foxes; they simply appeared to quietly 'fall asleep and die' (see also Marks et al. 2004).

Trial 2

A total of 30 ejectors were naturally triggered by wild dogs, and eight wild dog carcasses were recovered (three male and five female; Table 2). Body weights of recovered carcasses ranged between 5.3 and 14.5 kg (mean = 9.9 kg). Distances between the dead wild dog and the nearest triggered ejector ranged between 30 and 200 m (mean = 96 m). De-oxygenated blood was present throughout all eight wild dog carcasses (Fig. 1; Table 2). Physical evidence of distress was observed in five of the eight wild dogs recovered, including paddling ($N = 3$), defecation ($N = 3$) and vomiting ($N = 1$). Three dogs were observed triggering the same ejector on camera (on three separate occasions), and two of these dogs were subsequently found dead nearby. The first of these (Fig. 2) triggered the ejector at 16:32 on 9 February 2018 and was found dead 45 m away at 18:37 the same day (with evidence of paddling and defecation). The second of these (Fig. 3) triggered the ejector at 05:53 on 11 February 2018, was heard vocalising (like those observed in trial 1) at approximately 06:30, was found unconscious at 07:00 and died sometime between 07:00 and 07:41, indicating a time to death of no less than 67 min or no more than 108 min.

One fox was also observed on camera to trigger an ejector at 02:40 on 18 January 2018 at a separate study site in New South Wales and was recovered the following morning 50 m from the ejector. No non-target animals died or were even observed triggering an ejector at any time during the study.

Table 2 Details of recovered wild dog carcasses killed in trial 2

Tally	Date	CPE number	Sex	Weight (kg)	Body score (1–5)	Estimated dose (mg)	Distance (m)	Bait type	De-oxygenated blood
1	09-Feb-18	2	F	5.6	1	300	45	Kangaroo	Present
2	10-Feb-18	25	M	13.0	3	Unknown	100	Venison	Present
3	11-Feb-18	2	F	5.3	1	500	45	Kangaroo	Present
4	11-Feb-18	25	F	8.0	2	Unknown	200	Kangaroo	Present
5	11-Feb-18	31	M	13.0	2	Unknown	100	Unknown	Present
6	11-Feb-18	41	F	9.5	1	950	50	Kangaroo	Present
7	12-Feb-18	50	F	10.0	2	400	30	Kangaroo	Present
8	13-Feb-18	50	M	14.5	3	950	200	Kangaroo	Present

Discussion

The two trials demonstrated that PAPP powder can be used within ejectors to quickly kill both wild dogs and foxes under both controlled and field conditions. The controlled trial 1 demonstrated that clinical signs of poisoning progress quickly following ingestion and absorption of PAPP (Table 1). Wild dogs typically sat or laid down within minutes and were usually unconscious within an hour. The quickest time to death was 52 min, and the slowest time to death was 124 min. That eight wild dogs were found dead within 200 m of triggered ejectors in trial 2 (Table 2, Fig. 2) indicates that the rapid deaths observed in trial 1 were not a product of the controlled conditions (i.e. being trapped, and with an observer present), but were rather an outcome of PAPP poisoning. Further confirmation that PAPP kills wild dogs and foxes was obtained from camera trap data in combination with recovered carcasses. In two cases, we observed individually identifiable animals triggering ejectors and found them both dead nearby within 2 h (Figs. 1 and 2), supporting our observations of rapid time to death in trial 1. Additional confirmation was also obtained during necropsy. After absorption in the mucus membranes of the mouth and/or ingestion in the stomach, PAPP works by rapidly converting haemoglobin into methaemoglobin, creating anoxia and a lethal deficit of oxygen in cardiac muscle and the brain (Eason et al. 2014). De-oxygenated blood is very dark in colour (Henretig et al. 1988), and such 'chocolate blood' was present throughout all necropsied animals (Table 1, Fig. 1). Thus, first-hand observations from controlled trial 1 and physical evidence from field trial 2 unequivocally demonstrated that capsules containing 1000 mg (for wild dogs) and 400 mg (for foxes) of powdered PAPP can be used in ejectors to rapidly kill both species.

The rapid action of PAPP on wild dogs and foxes observed in our trials was similarly observed in stoats (*Mustela ermine*) and feral cats (*Felis catus*) in New Zealand (Eason et al. 2014), which are two species that also possess the same metabolic pathway to enable orally administered PAPP to rapidly induce lethal methaemoglobinaemia. In that study, clinical signs of PAPP poisoning first appeared after 10–20 min for stoats and around 35 min for cats. Read et al. (2014) reported the deaths of 3 of 12 foxes and 14 of 16 cats after PAPP paste was applied to their fur and then ingested through oral grooming. In pen trials of PAPP capsules on foxes, Marks

Fig. 2 Camera trap imagery of **a** a wild dog triggering a PAPP ejector at 4:32 PM on 9 February 2018, followed by **b** the discovery of the same animal found dead 45 m away at 6:37 PM the same day (with evidence of paddling and defecation)

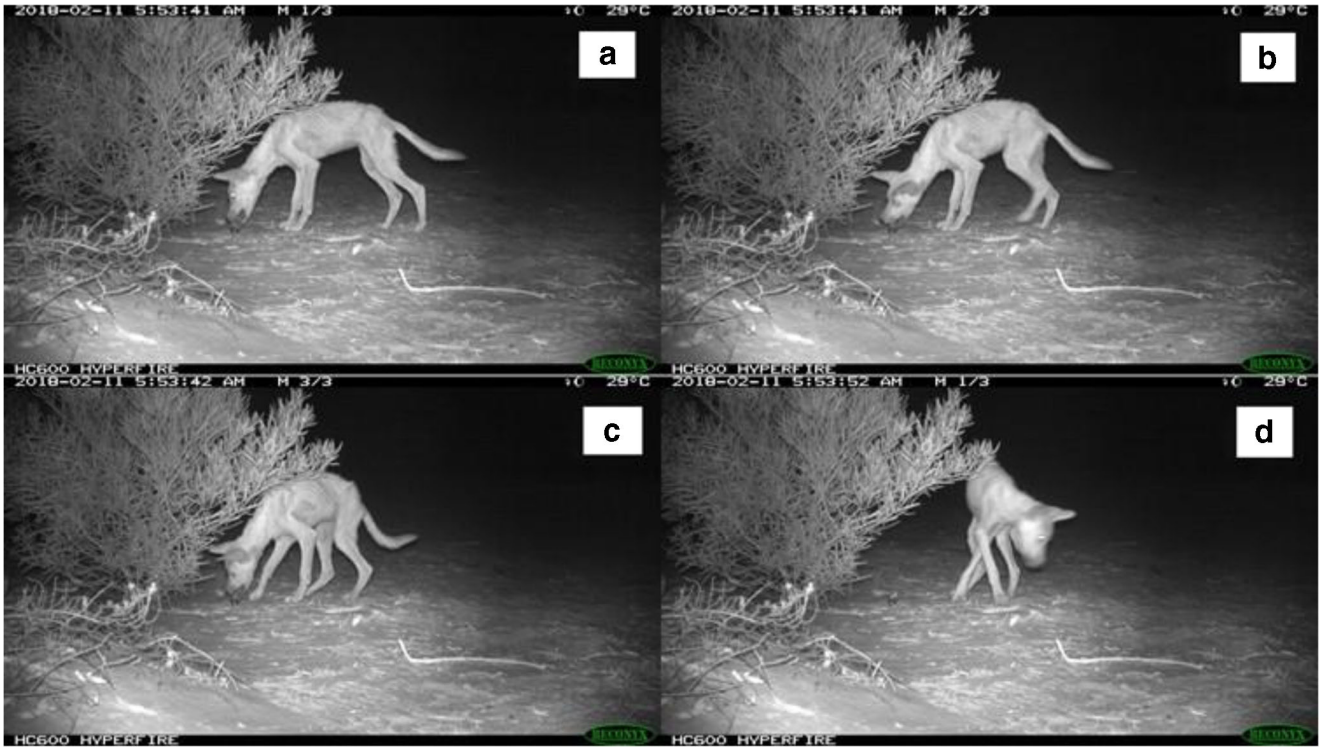

Fig. 3 A sequence of camera trap imagery showing a female wild dog triggering an ejector: the dog **a** approaches and bites the ejector with her incisors, **b** adjusts her mouth to get a better grip with her canines, **c** readjusts her stance in order to trigger or pull the ejector with sufficient force and **d** triggers the ejector and retreats (with evidence of spilled PAPP powder on the bait head)

et al. (2004) report that foxes collapsed within 14–25 min and that death occurred an average of 43 min after triggering the ejector. Meek et al. (2019) used PAPP within lethal trap devices (LTDs) and PAPP-cloths attached to the jaws of soft-catch foot-hold traps and reported that average time from wild dog capture to mortality was 68 min for LTDs and 78 min for cloths. As anoxia progresses, PAPP-poisoned animals typically become lethargic and sleepy and eventually fall unconscious and die. Our results are in general agreement with the results of Marks et al. (2004), Read et al. (2014), Meek et al. (2019) and similar studies (reviewed by Eason et al. 2014), in that the more 'serious' symptoms such as spasms and convulsions do not occur. However, we did observe vocalisations in all wild dogs, paddling in many, and defecating and vomiting on one occasion (see also Meek et al. 2019). Breathing rate likely increases as a result of oxygen deficiency and the occasional paddling of recumbent animals may have been failed attempts of semi-comatosed animals to right themselves. Well-understood knowledge of the relatively humane mode of action of PAPP (e.g. Marks et al. 2004; Eason et al. 2014; APVMA 2015) and our observations of such physical signs indicates that these behaviours and signs are not related to pain, but are rather a response to heightened anxiety as the effects of PAPP progress.

Though we successfully recovered eight carcasses from 30 triggered ejectors in trial 2, which is far more than is usually discoverable when using 1080 (e.g. Bird 1994; Bird et al. 1997), we were surprised we did not discover more carcasses given the rapid action of PAPP and the usually meandering behaviour of wild dogs around waterpoints (Allen 2012). The absence of additional carcasses could be due to four reasons. First, not all triggered ejectors may have delivered a lethal dose. We cannot discount this possibility given the results of trial 1 (dog 11 and fox 04) and the observation that unless the ejector and the mouth are appropriately aligned, not all animals pulling the ejector will receive all the ejected contents of the capsule. Failure to receive a dose or sub-lethal dosing is possible if animals do not bite the ejector properly. Second, individual dogs may have triggered multiple ejectors. Ejectors were placed relatively close together around waterpoints, so it is highly likely that individual dogs may have triggered multiple ejectors before succumbing to the effects of PAPP. Given this, it is likely that < 30 carcasses would have been available for recovery. Third, wild dogs could have received a lethal dose but died outside the 300-m radius search area. This is entirely possible given the speeds that wild dogs can travel (Allen et al. 2014), with dogs being more than capable of travelling more than 300 m in the ~ 30 min between triggering an ejector and 'last down'. Fourth, the emaciated wild dogs frequently seen at the site during trial 2 were observed cannibalising the carcasses of all PAPP-killed dogs, removing almost all evidence of the carcasses within hours. In one case, a whole carcass was reduced to just the skull (minus the mandibles) within 36 h (a day, a night and a day). In another case,

we placed a camera trap on a whole wild dog carcass staked in position. A single wild dog consumed ~45% of the carcass during the first night, and assisted by corvids another wild dog consumed another ~45% of the carcass in two sittings between 12:46 and 13:38 the next day (when it was 47 °C in the shade), pausing only for a short drink between sittings. Given these observations (see also Allen 2010; Meek and Brown 2016) and our careful placement of ejectors to ensure alignment of the mouth during triggering, we believe that the majority of the (up to) 22 carcasses not found were the result of the last three of these four possibilities.

These results have important implications for the management of wild dogs and foxes in Australia. Ejectors are a target-specific device suitable for delivering toxins to wild dogs and foxes, but at present, they can only be used with capsules containing 1080. Our confirmation that capsules containing powdered PAPP can also be used in ejectors to quickly and humanely kill wild dogs and foxes should provide confidence in their use once PAPP becomes available in this form.

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Compliance with ethical standards

Approval to undertake the project was granted by the University of Southern Queensland's Animal Ethics Committee (AEC permit number: 16REA102). A 'Permit to allow research use and supply of an unregistered agvet chemical product' was also obtained from the Australian Pesticides and Veterinary Medicines Authority (APVMA permit number: PER83898). The project was conducted in accordance with these approvals. Permission to work on private land was granted by the landholder prior to commencing work.

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