The important role of private wildlife organisations in facilitating scientific research: A case study of the Australian Dingo Foundation

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ABSTRACT

As we enter an era of global mass extinctions, it is important to tackle wildlife research and conservation from multiple fronts, including those made available by wildlife organisations, zoos and sanctuaries. Captive studies are particularly useful when studying free-ranging populations is difficult, and/or when controlled conditions are required. Yet, despite the significant role that they play in supporting research and conservation of species and ecosystems, they are rarely recognised in the scientific literature. Here we present a case study of the Australian Dingo Foundation (ADF), a private organisation and captive breeding facility that actively supports research and conservation efforts relating to the dingo (*Canis dingo*). Over the past decade (2010 to 2020), the ADF has facilitated research across eight research disciplines that include archaeology, behaviour, biology, cognition, evolutionary psychology, non-lethal management, reproduction and parental behaviour, and vocalisations. This has resulted in at least 21 published scientific studies which are summarised in this paper. As this case study demonstrates, captive facilities have the potential to contribute to the understanding and conservation of dingoes by providing practical alternatives to, and/or supplement studies of free-ranging populations. We conclude by outlining some of the implications and limitations of conducting research using captive dingo populations.

Key words: Science; research; conservation; captivity; zoos; sanctuaries; organisations; not-for-profit.

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Introduction

Not-for-profit wildlife organisations, zoos and sanctuaries provide a fundamental role in the conservation of many of Australia's native species such as the dingo (*Canis dingo*). Not only do captive populations provide opportunities to observe and engage with wildlife, they are actively involved in conservation education, wildlife tourism, breeding programs, and the facilitation and financial support of research (Tribe 2001; Tribe and Booth 2003). The contribution to the latter is particularly important, because research investigating the biology and behaviour of many free-ranging species is rarely possible, or at least very difficult.

There is a long history of utilising captive dingoes for research, the first of which were carried out by CSIRO in the 1970s, 80s and early 90's (Corbett 2001). These captive studies, led by ecologists Alan Newsome, Laurie Corbett, and Peter Catling, were used to complement their field studies on several aspects of dingo biology and behaviour. Work was directly carried out at their custom research facilities in Alice Springs, NT (Division of Wildlife Research; Figure 1) and Canberra, ACT (Arid Zone Research Institute). Funding for much of the early research with dingoes, including those carried out by the CSIRO, was provided by the Australian Meat Research Committee and the Australian Meat and Livestock Corporation, in an effort to "know thine enemy" (Newsome *et al.* 1972, p.1), and thus assist with eradication attempts. Contemporary funding for dingo research comes from a range of sources, and is conducted by scientists from around the world. These researchers represent a number of scientific disciplines, and assert that the dingo is a scientifically and culturally valuable species (Smith 2015). Research and the number of scientific publications focusing on the dingo has also increased dramatically over the past few decades (see Smith and Appleby 2015), including research involving captive dingo populations.

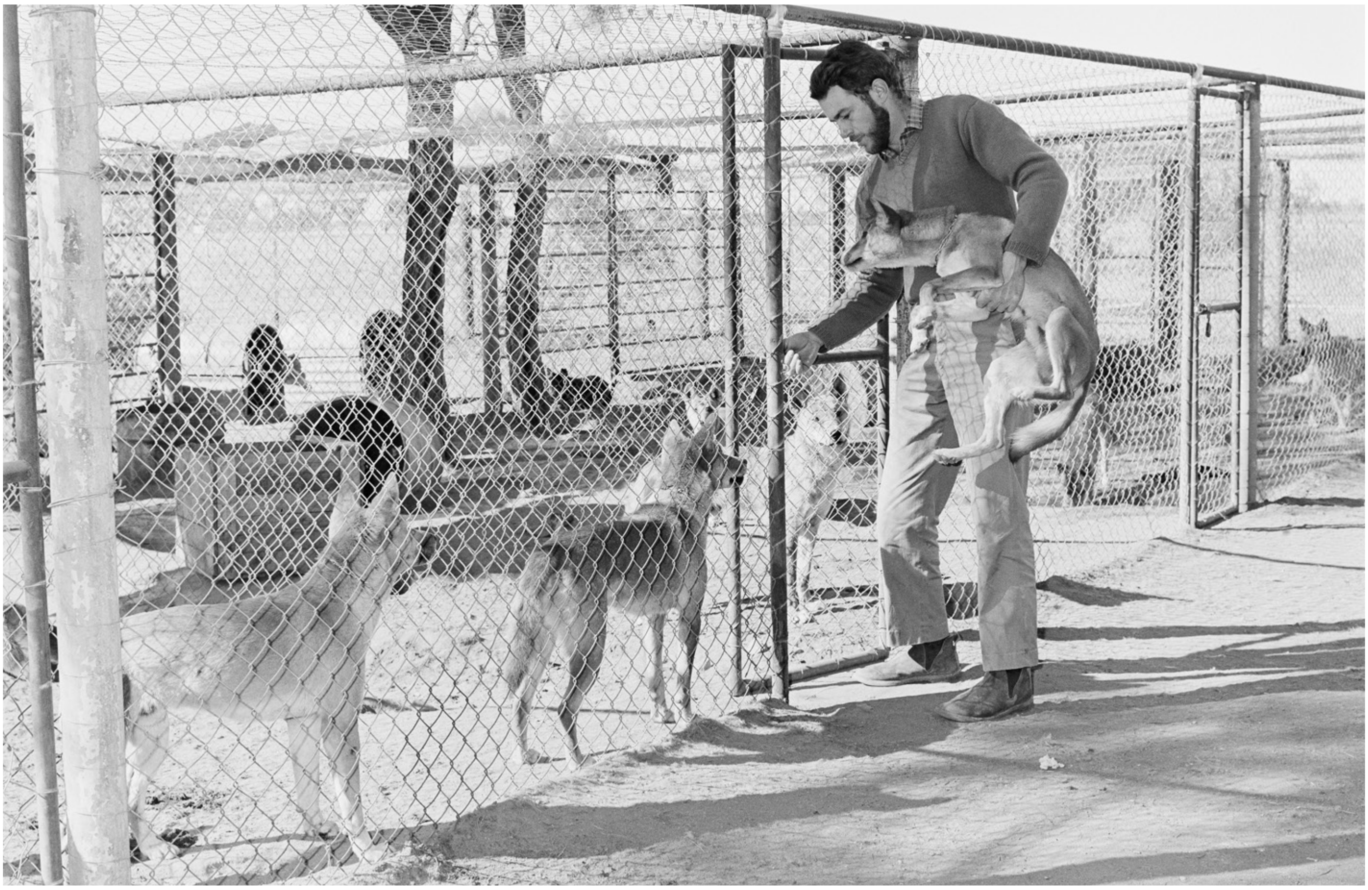

Figure 1. CSIRO experimental officer with captive dingoes held at their research center in the Northern Territory. Photo taken in 1967. Source: National Archives of Australia, A1200, L64195.

The benefits of captive research

Like most wild canids, dingoes are notoriously difficult to study in the wild because they are highly mobile, occupy large territories, are difficult to see in many environments, and are generally reclusive (Klinghammer and Goodman 1987; Morrant 2015). As such, the study of many aspects of biology and behaviour in the field become impractical and are better suited to captive situations where conditions can be controlled. In fact, a more complete understanding of behaviour can often be achieved when field observations are supplemented by, or aided by, observations conducted in captivity. To give an example, Allen (2015) used dingo paw prints left in sand plots to determine the impact of poison baiting programs on the abundance and age distribution of the resident dingoes. To facilitate this research, measurements of dingo paws from captive dingoes of known ages were collected and used as a reference sample. Much of our understanding of the social behaviour of wild canids was gained through captive wolves (Schenkel 1947) and later supported by field studies by Mech (1970). Similarly, a lot of early knowledge of dingo social behaviour was based on studies of captive populations and substituted with observations of free-ranging dingoes (Corbett and Newsome 1975; Corbett 1988). Captive research continues to add value to our understanding of wild canids (e.g. Kershenbaum *et al.* 2016; Gese *et al.* 2018).

In captivity, not only can housing conditions be manipulated and replicated, but the identification and selection of individuals is easier (including sex, age, body mass, ancestry, genetics). Scientists have greater power to take medical, physiological or observational samples from individuals with known life histories. To give an example, to estimate the food consumption of dingoes, Green (1978) required carefully controlled experiments with tame dingoes in laboratory settings. In the CSIRO facilities, researchers were able to extensively study dingo reproductive biology, behaviour and seasonality (Newsome *et al.* 1973; Catling 1979; Catling, Corbett, and Newsome 1992); to look at the impact and identification of dingo-dog hybrids, including genetics and coat colour (Newsome and Corbett 1982); and to develop age determination techniques and measure growth rates (Catling, Corbett, and Westcott 1991).

Captive environments also offer a valuable and cost-effective opportunity to test the behavioural responses of dingoes to non-lethal tools or strategies before large scale field testing. For instance, the effectiveness of an ultrasonic device as a deterrent (Edgar *et al.* 2007). Captive dingo populations have been used to test the behavioural responses of dingoes to dingo urine (Robley *et al.* 2015), and the anti-predator reactions of kangaroos to dingo urine (Parsons and Blumstein 2010). The collection of urine (including from known individuals) for such purposes would be virtually impossible in the wild from living animals, as would a controlled setting for determining its effect on behaviour.

There are many questions regarding ethology and psychology that require well-socialised animals that can only be found in captive situations. Some argue that for certain behaviours (such as following social cues), wolves must be intensely socialised and kept separate from conspecifics for most of their first 4-6 months in order to get accurate results (suggested by Klinghammer and Goodman 1987, and adopted in the study by Miklósi *et al.* 2003). Research investigating dingo cognition and behaviour conducted by Smith and Litchfield (2010*a*; 2010*b*; 2013) and parental behaviour (Hudson *et al.* 2016; Hudson *et al.* 2019) were possible because captive populations provided a sample of individuals who were known, who were comfortable being in test situations and handled by staff, and a controlled environment for the experimental setup. In addition, captivity presents opportunities for ad hoc observations to occur, such as the use of tools (Smith *et al.* 2012).

Socialised dingoes also aid the process of taking biological samples in a stress-free manner, often avoiding the need for sedation. An example of this was the longitudinal study by Smith, Flavel, and Simpson (2016) who measured seasonal variation in cortisol. Not only does interacting with captive animals provide insights not otherwise practical in the wild (e.g., comparative studies of problem solving behaviour - Smith and Litchfield 2010*a*, 2010*b*, 2013), but failure to socialise captive wolves and dingoes for certain experiments may lead to erroneous results because the presence of humans, particularly in close proximity, might disrupt the animal's behaviour (Klinghammer and Goodman 1987).

Through wild rescue and captive breeding programs, populations held in private sanctuaries may provide a reservation of genetically 'pure' dingoes from regions around the country, should dingoes become endangered or absent. They may also be useful for reintroduction programs involving the release of dingoes into national parks (Ritchie *et al.* 2012; Newsome *et al.* 2015). Private sanctuaries with active breeding colonies, typically have skilled dingo handlers, who can likely offer valuable services and consultation for reintroduction and rewilding programs.

The Australian Dingo Foundation

There are a handful of private not-for-profit organisations scattered across the country that maintain captive dingoes and are dedicated to dingo conservation. As outlined by Smith and Watson (2015) these organisations make at least five key contributions. 1) The preservation of genetically 'pure' dingoes from regions across Australia (i.e., dingoes with no modern dog ancestry). 2) Provide a source of animals for displays at wildlife parks, and for future rewilding programs. 3) Raise community knowledge and awareness of dingoes and their conservation. 4) Act as government watchdogs and lobbyists. 5) Facilitate scientific research. The significance of these roles is largely under-acknowledged, particularly by the scientific community. With this in mind, we wish to draw attention to some of the positive and valuable roles that sanctuaries can play in aiding scientific studies and conservation efforts. One organisation, the Australian Dingo Foundation (and its affiliated Dingo Discovery Sanctuary and Research Centre), has provided an invaluable contribution to the scientific understanding of the dingo across multiple fields of research.

The Australian Dingo Foundation (ADF), established in 2006, is a not-for-profit organisation and Federally registered conservation charity. The ADF supports a captive population of dingoes at the Dingo Discovery Sanctuary and Research Centre (hereafter Dingo Discovery Centre). The Dingo Discovery Centre, established in 1990, is located on 40 acres in the foothills of the Macedon Ranges, Victoria (Figure 2). At any one time, the sanctuary houses around 40 genetically 'pure' and entire adult dingoes in custom-built enclosures. This includes a population of captive and wild born individuals from all regions of Australia. For a comprehensive summary of the housing and management of this population see Smith and Watson (2015).

The ADF and its volunteers play a significant role in dingo conservation through advocacy (e.g., organising petitions, lobbying government, social media presence), education (e.g., running sanctuary tours, puppy open days, fundraising events, community and school education sessions), and an active breeding program (e.g., maintaining several breeding lines, supplying zoos and wildlife parks with dingoes for exhibition). Through these activities they also facilitate and support non-invasive scientific research by making their captive dingo population available to national and international scientists. The Dingo Discovery Centre has been directly supporting genetic studies since its inception, and behavioural studies since the late 1990's (Wilton *et al.* 1999; Wilton 2001), and the ADF has supported dingo research by providing financial support through scholarships such as the 'NWG and Anne Macintosh Student Scholarship'.

The sanctuary maintains a healthy, entire, and diverse population of dingoes which enables them to suit the requirements of researchers from a plethora of research disciplines (for examples, see Figure 3). These include (but not limited to): animal behaviour (e.g., social behaviour and parental care), cognition (e.g., problem solving, higher order behaviour), evolutionary and comparative psychology, biology (e.g., microbiome, stress responses, urine chemistry), non-lethal management (e.g., testing efficacy of non-lethal biological deterrents), and genetic testing. To demonstrate this, in Table 1 we present a number of published scientific studies that resulted from research that took place or based on dingoes held at the sanctuary between 2010 and 2020. The list of

Figure 2. The Dingo Discovery Centre. (a) A section of the custom dingo housing (Photo: Bradley Smith). (b) Closeup of the enclosures (Photo: Bradley Smith). (c) A dingo in one of the exercise yards (Photo: Shari Trimble).

publications was sourced from the records maintained by the ADF, and the methodology and acknowledgements of each publication cross-checked to ensure the sanctuary or foundation was acknowledged as a contributor. It is likely that additional studies have been conducted at the sanctuary, but the results not published, and it is also possible that not all published outcomes are presented in the table (although none were deliberately omitted).

Cautions when using captive dingo populations for scientific studies

It is important when studying the behaviour of wild animals in captivity that they be kept in a way that maximises their opportunities for the expression of normal behaviour. One concern that has been raised about using captive populations for research, and their value to dingo conservation more broadly, is that captivity somehow changes the individual so it no longer truly represents the species. Corbett (2001) for instance, argued that a captive dingo ceases to be a dingo and is "just another dog" because selection pressure for certain traits can easily take place, both deliberately and inadvertently, and therefore could override the natural selection of wild characteristics. The impact of captivity, which include unnatural diets (even when foods are mimicked to provide adequate nutrition) and restriction of movement, is likely to be most significant in relation to morphological and physiological studies of dingoes that are born and raised in captivity (O'Regan and Kitchener 2005; Hartstone-Rose *et al.* 2014), particularly where selective breeding and multiple generations of captive-bred animals are used. Although in saying this, the appropriateness is entirely dependent on the purpose of the study. For example, captive-bred animals can provide a unique opportunity to assess the relative importance of environmental and genetic influences on morphology (O'Regan and Kitchener 2005); for examining human-animal relationships and interactions (e.g. Ward and Melfi 2015); and of course for studying captive welfare, behaviour and management (Hill and Broom 2009).

There are also some behaviours observable in captivity that may not translate to wild populations. For example, in wild canids, tool use has been observed in captivity (Smith and Litchfield 2012) but not in free-ranging populations. Although this provides insight into the cognitive potential of the species, the behaviour observed in captivity is likely to be a reflection of increased opportunity and energy to explore and manipulate objects within the environment. More realistic and ecologically valid examples of tool-use and higher order behaviours have been observed in the field in other canids (see Smith, Appleby, and Litchfield 2012 and references within), but such observations remain rare and difficult to capture.

Table 1. A list of publications grouped across eight discipline areas, that has resulted from research carried out at the Dingo Discovery Sanctuary and Research Centre (DDC) between 2010 and 2020. A brief summary of the background and/or aims, methodology, and main findings from each publication are provided.

Discipline	Title	Background/Aims	Methods	Findings	Reference
Archaeology	Dingo scat-bone 'signature patterns': An actualistic study and comparison of wild and captive scat-bone assemblages and interpretation of bone fragments from Witchcliffe Rock Shelter, south Western Australia.	To address the lack of data on carnivore modifications to skeletal fragments with focus on the dingo. Useful as a potential investigative tool at Holocene archaeological sites.	Scats from 25 captive dingoes from the DDC and 31 wild dingo scats were analysed for skeletal fragments. Tooth 'pits' and 'scores' were also measured on skeletal fragments.	Wild and captive dingo skeletal modifications were similar but dependent on prey consumed. Captive dingo scat contained fewer and smaller skeletal fragments than wild dingo scats. Both tooth-mark and scat techniques are best used in combination. Dingoes have characteristic tooth-marks, of which were identified on some skeletal fragments found in Witchcliffe rock shelter.	Reynolds, Dortch, and Balme (2016)
	Analysis of pit and score tooth-mark sizes from bones modified by Holocene Australian terrestrial fauna in relation to body size.	Comparative approach for archaeological material, using dingoes, devils, quolls, monitor lizards, dogs and human pit marks and scores left on bone.	DDC was used to pilot the methodology used in the larger study. Experimental feeding trials of captive animals, including analysis of 2895 tooth marks.	Devils and tiger quolls produced very large tooth marks in relation to their body size. Aussie fauna does not conform to international trends, that is, body weight does not correlate with tooth mark size. Carnivores that consume bone in their diet will have specific adaptations that will determine pit mark and score sizes left on bone fragments.	Koungoulos, Faulkner, and Asmussen (2018)
Behaviour	The function of play bows in *Canis lupus* and its variants: A comparison of dingo (*Canis lupus dingo*), dog (*Canis lupus familiaris*) and wolf puppies (*Canis lupus*).	To investigate the role of domestication on the function of behavioural play bows in canids.	Camera footage was taken of 5 litters (10 puppies total) interacting at the DDC. Play behaviour was observed and coded according to five criteria and compared with those of dogs and wolves.	The behavioural function of play bows (i.e. as a visual signal) is similar for dingoes, domestic dogs and wolves. Plays bows are more exaggerated, longer, and involve vocalisations in domestic dogs compared with dingoes and wolves.	Byosiere *et al.* (2018)
Biology	The effect of age, gender, and antibiotics on the canine gut microbiome.	To analyse the canid microbiome at different life stages, and how it is affected by factors like age and gender. To compare the microbe of domestic dogs and dingoes.	Scat samples from 101 domestic dogs and from 28 dingoes at the DDC were analysed for two main bacterial classes, *bacteroidetes* and *clostridia*.	Canid microbiome differences can be attributed to various factors, such as age. *Bacteroidetes/ prevotella* group and *clostridia coccoides* were found in Labradors and dingoes at different life stages.	Flavel (2012)
	Quantification of salivary cortisol from captive dingoes (*Canis dingo*) in relation to age, gender, and breeding season.	To better understand 'stress' and its implications on captive and wild dingoes. To obtain a reference range of dingo salivary cortisol levels.	Saliva samples were collected from 13 adult dingoes, and 8 dingo cubs from the DDC across several time points (across a day, development and seasonality).	Cubs had higher cortisol levels than adults. Adults did not differ, but males during breeding season had higher cortisol levels than females.	Smith, Flavel, and Simpson (2016)
Cognition	How well do dingoes (*Canis dingo*) perform on the detour task.	To test dingoes on a spatial problem-solving task. Previously tested wolves performed better than domestic dogs - a potential result of domestication.	A v-shaped version of the 'detour task' using four experimental conditions was tested on 20 dingoes at the DDC. Success, latency and errors detouring fence were measured.	Dingoes were proficient at completing the task with fewer errors and shorter delays than dogs. Wolves and dingoes are more capable at non-social spatial problem solving than domestic dogs.	Smith and Litchfield (2010*a*)

Discipline	Title	Background/Aims	Methods	Findings	Reference
	Dingoes (*Canis dingo*) can use human social cues to locate hidden food.	To test the responsiveness of dingoes to human social cues, as they have a unique evolutionary history that may shed light on canid evolution.	The 'object-choice task' was tested on 7 dingoes at the DDC to see how they respond to 9 different human social cues. Success resulted in approaching container being referred to by human.	Dingoes passed 6/9 human social cues. Dingo performance was more akin to wolves than dogs, suggesting domestication may influence the comprehension of human gestures.	Smith and Litchfield (2010*b*)
	Spontaneous tool-use: An observation of a dingo (*Canis dingo*) using a table to access an out-of-reach food reward.	To document the cognitive abilities of two captive dingoes, and the first case of tool-use in the Canidae family.	Two male dingoes at the DDC were observed and recorded exhibiting higher order behaviours. 1) Sterling moved a table in the enclosure to reach an otherwise unobtainable treat. 2) Teddy opened a gate latch to get to his mate when he was separated from her.	Observations of tool-use extend to canids. Highlights the dingoes potential for 'intelligent' behaviour adds insight into their cognitive abilities and potential.	Smith, Appleby, and Litchfield (2012)
	Looking back at 'looking back': Operationalizing referential gaze for dingoes in an unsolvable task.	To find out whether dingoes look-back for human assistance when faced with an unsolvable task. Previously tested canids included domestic dogs and wolves. Domestic dogs looked back to humans for assistance, wolves did not.	A 'rope-pulling task' was tested on 12 dingoes at the DDC, with a solvable trial, followed by an unsolvable one. Behaviour in response to unsolvable condition coded.	Dingoes do not rely on humans for assistance during tasks in the same way as dogs. A variety of 'look-backs' was observed in dingoes but was not likely associated with seeking human assistance. This resulted in the refinement of the definition of a 'look-back'.	Smith and Litchfield (2013)
Evolutionary psychology	The evolution and development of inequity aversion.	To investigate the expression of 'judging fairness' or 'inequity aversion' in dogs and dingoes. To determine whether this is a result of a cooperative mechanism found in social canids, or a result of domestication.	An 'inequity aversion task' was tested on 72 dogs and 11 dingoes at the DDC. Unfamiliar human handlers and unfamiliar dog or dingo 'confederate partners' were used. Trials involved absence/presence of food. Video recordings were coded and analysed; sensitivity to presence/absence of food, response time and looking at human handlers.	Both canid species did not express 'inequity aversion'; not sensitive when only 'confederate partner' received food. May not be a cooperative mechanism in social canids. Looking at human handlers was more prevalent in dogs than in dingoes.	McAuliffe (2013)
	Exploring the evolutionary origins of overimitation: A comparison across domesticated and non-domesticated canids.	To investigate the origins of learning via 'copying' or 'overimitating' in humans. To establish whether or not overimitation is a shared learning skill with dogs, which have close social bonding with humans. Dingoes used as a comparison to dogs.	Three experimental trials used on 40 dogs and 13 dingoes at the DDC. 1) Transparent puzzle box, lever not needed to obtain treat. 2) Non-transparent puzzle box, lever not needed to obtain treat. 3) Transparent puzzle box, lever needed to obtain treat.	No evidence for overimitation in dogs or dingoes. Dingoes may be better at finding aspects of the puzzle that are irrelevant, compared to dogs. Overimitation appears to be a unique form of learning in humans.	Johnston, Holden, and Santos (2016)

Discipline	Title	Background/Aims	Methods	Findings	Reference
	Uncovering the origins of dog–human eye contact: Dingoes establish eye contact more than wolves, but less than dogs.	To explore interspecific communication using human-dingo eye contact. Dingoes were tested to gain further insight into canid domestication, given their unique evolutionary history.	Duration of eye contact made by dingoes was recorded over a 5-minute period with 23 dingoes at the DDC. Familiarity was also tested to see if eye contact changed according to whether or not the dingo knew the handler.	Dingoes established eye contact more than wolves, but less than dogs. Human-canid eye contact may have developed at the onset of domestication. Prolonged eye contact may have evolved later, especially toward familiar humans, as observed in domestic dogs.	Johnston *et al.* (2017)
Non-lethal management	How guardian dogs protect livestock from predators: Territorial enforcement by maremma sheepdogs.	To determine how maremma dogs maintain territories inclusive of livestock. That is, whether they do so directly when livestock are threatened, or indirectly (through sound and scent).	Dingo vocalisation recordings (howling) and urine samples were taken from dingoes housed at the DDC. Sound and scent tests were carried out on two sheep properties with 4 GPS collared maremma sheepdogs on each. Cameras were also set up to record maremma behavioural responses.	Dingo vocalisation playbacks and scent elicited behavioural responses in maremma sheepdogs. If 'threat' was inside range, they left sheep in pursuit of 'threat'. If 'threat' was outside range, they just barked, and scent marked. Thus, protection appears to extend beyond the immediate vicinity of livestock, so they do maintain a larger territory.	van Bommel and Johnson (2015)
	Dingo semio-chemicals: Towards a non-lethal control tool for the management of dingoes and wild dogs in Australia.	To assess the viability of the use of semio-chemicals, extracted from dominant male dingo urine, as a non-lethal tool in dingo/wild dog management.	Urine collected from 6 sexually mature males at a private property. Semio-chemicals specific to dingoes were extracted from the above urine samples and used to test the responses of 14 dingoes at the DDC.	Identification of 27 chemicals were found to be unique to dingoes. Dominant male urine will cause a behavioural response. Utilisation of extracted semio-chemicals from male dingo urine appears to be a valuable non-lethal tool.	Robley *et al.* (2015)
	Fladry as a non-lethal deterrent for dingoes.	To determine how captive dingoes responded to fladry (a rope line with brightly coloured flags).	Exposed 10 dingoes at the DDC over three experimental trials to a 6x6m exclusion zone lined with fladry.	Minor behavioural reaction. Fladry may offer a cost effective, temporary barrier, but aversive effects likely to dissipate quickly.	Smith *et al.* (2019)
	Automated shepherds: Captive dingo responses to sound and an inflatable, moving effigy.	To test whether a novel acoustic deterrent and effigy are effective non-lethal deterrents.	Exposed 12 dingoes at the DDC to two conditions (loud gun shots, and an inflatable moving effigy). Success determined if dingoes were prevented from eating from food bowls.	Acoustic deterrent was not effective. Inflatable effigy highly effective, and remained so over multiple exposures (9/36 accessed food across trials).	Smith *et al.* (2020)
Reproduction and parental behaviour	Variation in reproductive traits of members of the genus *Canis* with special attention to the domestic dog (*Canis familiaris*).	To compare the parental and reproductive strategies of domestic and wild canids.	Literature review used to gather parental and reproductive data for all canids. Captive breeding records collected at the DDC over ten years were used as part of the comparison between wild and domestic dog reproductive timing.	Highlighted the different reproductive strategies between domestic and wild canids across multiple domains. Dingoes more akin to wild than domestic canids. Dingoes mate during decreasing daylight (southern hemisphere), and wolves during increasing daylight (northern hemisphere).	Lord *et al.* (2013)

Discipline	Title	Background/Aims	Methods	Findings	Reference
	Pattern of nipple use by puppies: A comparison of the Australian dingo and the domestic dog.	In relation to suckling behaviours in altricial young, previously studied domestic dog puppies exhibited no suckling pattern but kittens do. Aim was to determine whether the difference was due to domestication.	Video cameras placed inside the den of 4 dingo litters (12 puppies total) at the DDC. Suckling behaviour (including nipple use, time and duration of suckling) was observed and coded according to 4 measures. Previously collected data on dog litters was also used.	No difference in suckling behaviour was found between domestic dog puppies or dingo puppies. No indication that the lack of suckling order is a trait of domestication, rather reflects a difference in lifestyles between canids and felids.	Hudson *et al.* (2016)
	Diurnal pattern of pre-weaning den visits and nursing in breeding pairs of captive dingoes (*Canis dingo*).	There is a lack of research looking at early parental care in canids. This paper aimed to understand the level of maternal and paternal care provided to pre-weaned cubs.	Continuous camera monitoring inside and outside of 4 breeding pairs and their litters at the DDC. Study examined the behaviours (such as mother/father time in den, nursing time) from birth to 3 weeks.	Evidence of bi-parental care in dingoes, and the lack thereof in domestic dogs that may be attributed to a shift in reliance on humans. Mothers spent most of their time in the den nursing, especially at night. Fathers slept on top of the den, seemingly to keep guard.	Hudson *et al.* (2019)
Vocalisations	The bark, the howl and the bark-howl: Identity cues in dingoes' multicomponent calls.	To investigate the acoustic structure of 'bark-howls' and the behavioural signal 'bark-howls' represent in dingoes.	Dingo 'bark-howl' recordings were collected from two sanctuaries, including the DDC. Wild dingoes were tested in WA, with recordings played during the day/night. 'Bark' and 'howl' components were acoustically measured for individuality.	The 'howl' and 'bark' components were both individually distinctive - the former to a higher degree. The 'bark' segment may function as an initial alert to obtain the receivers (i.e. family member) attention. Individuality of this vocalisation may inform level of reliability to the receiver. 'Bark-howls' may function as alarm calls, signalling to receivers to be vigilant.	Déaux *et al.* (2016a)
	Concatenation of 'alert' and 'identity' segments in dingoes' alarm calls.	To further investigate the function of 'bark-howls' in dingoes. Aspects studied included behavioural responses to level of familiarity, attention levels and vigilance behaviours.	Dingo 'bark-howl' recordings were used from two sanctuaries in NSW. A familiar, unfamiliar and bird recording was tested on 18 dingoes at the DDC. Camera footage was taken and coded according to three behavioural responses; no. of looks, movement towards speaker and vigilance.	Dingoes were able to distinguish levels of familiarity using the 'howl' component; they were more responsive to unfamiliar 'howls' (potential threat) than familiar 'howls'. 'Bark' components served to initially attract receiver's attention, regardless of familiarity. Dingoes were observed to always be vigilant when a 'bark-howl' was heard, supporting its function as an alarm call.	Déaux *et al.* (2016b)

Another example is dominant female infanticide, as reported by Corbett (1988). Corbett (1988) asserted that dominant female infanticide was the primary mechanism through which dingo populations were regulated. The main benefit being that mature females that no longer had young (after their pups had been dispatched by a dominant female) retained the capacity to suckle and supplementally feed the dominant female's dependent young, increasing the chances of their survival. However, dominant female infanticide has only been observed in this single captive population. It is more than likely that the conditions of the study site (limited enclosure size, increased aggression, and lack of opportunity for individuals to disperse) gave rise to this abnormal behaviour, or at least the commonality of it being observed. To date, dominant female infanticide has not been reported in wild dingo populations, and in fact, there are more examples of where it does not occur (e.g., Smith and Vague 2017).

One final concern when using captive populations for behavioural experiments is the tendency to prefer individuals who are suited to (or tolerate) captivity and human interaction. For example, they do not show fear response to the experimenter, equipment or testing

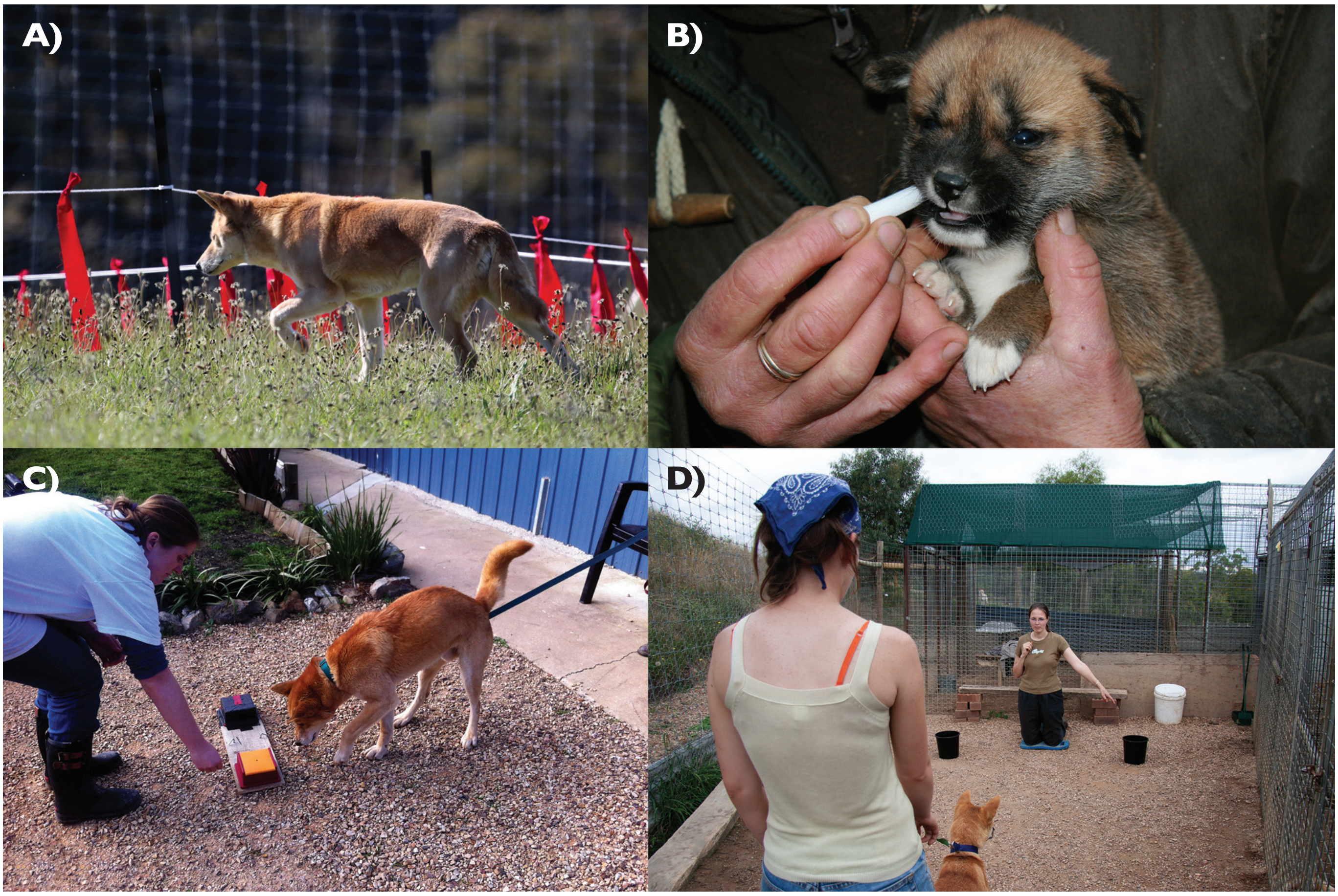

Figure 3. A sample of research studies conducted at the Dingo Discovery Centre. (a) Testing the response of dingoes to fladry- Smith *et al.* 2019. (b) Cortisol sample being taken from a 3-week-old dingo cub- Smith, Flavel, and Simpson 2016. (c) A dingo completing a problem solving task, with Dr Angie Johnston from Yale University. (d) Testing whether dingoes can follow human social gestures- Smith and Litchfield 2010*b* (Photo credits: Bradley Smith).

scenario. This is particularly pertinent with dingoes, where many in captivity remain timid and exhibit sensitivity to novelty (neophobia) and are almost always excluded from testing (Smith 2015). Excluding such individuals can produce cleaner data (e.g., less failures), but can also lead to false interpretations of cognitive ability (Miklósi, Topál, and Csányi 2004). Sample sizes of captive studies also remain low and tend to use samples from only one sanctuary/colony (see methods column in Table 1). Sample size limitations, and the potential for sanctuary specific behaviours (reflective of the samples history and genetics, as well as the conditions of the sanctuary) should be acknowledged.

Despite these important considerations, we argue that the impact and influence of captivity are likely to be inconsequential to several disciplines (Smith and Watson 2015). As shown in Table 1, there are many studies that can be undertaken with captive populations that have few issues or concerns relating to external validity, or appear skewed due to captivity. Given the difficulty in studying free-ranging dingoes, captive populations remain a valuable resource for scientific studies. For example, observing parental behaviour in dens is difficult in the wild (especially with replicates), but can be conducted in captivity with ease, and in many ways, and does not appear to have much impact on the expression of naturalistic parental behaviour. Where possible however, care must be taken to limit the influence of captivity to experiments, limitations acknowledged, and caution used when extrapolating findings to free-ranging populations. Ideally, all captive based studies should be complemented and verified with studies conducted in wild populations.

Conclusion

By highlighting the contribution of one organisation, we have shown that a wealth of knowledge can, and will continue to be gained about the dingo from captive based studies across a number of discipline areas. Any of the issues related to captive based research can be mitigated with sound experimental design, and/or acknowledgements of limitations where applicable. There are many exciting research opportunities and possibilities with captive dingoes that can help ensure the long-term future of the species. For example, facilitating the testing of effective non-lethal approaches to mitigate dingo-livestock conflict, which remains one of the biggest challenges to dingo conservation. We conclude by encouraging the recognition, utilisation and support of private wildlife sanctuaries and organisations in Australia.

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