HISSTORY® FERAL CAT BAIT

Report to: Australian Government, National Landcare Programme
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The following permits were obtained to conduct this work:

- The *Hisstory*® pen trial was conducted under Department of Biodiversity, Conservation and Attractions Animal Ethics Committee permit AEC 2016/32 "Efficacy assessment of encapsulated 1080 for use in the *Hisstory*® bait";
- Capture and radio-collaring of northern quolls was conducted under Department of Biodiversity, Conservation and Attractions Animal Ethics Committee permit AEC 2017/11 'Assessment of the hazard of the "*Hisstory*®" feral cat bait on free-ranging Northern Quolls (*Dasyurus hallucatus*)';

- The emetic trial was conducted under Department of Biodiversity, Conservation and Attractions Animal Ethics Committee permit AEC 2018/38 "Efficacy assessment of incorporating an emetic in the polymer utilised to encapsulate 1080 for use in the *Hisstory*® bait";
- The Department of Environment and Energy (Australian Government) determined that the field study aspect of the project (EPBC2017/8012) was not a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999*;
- The Australian Pesticides and Veterinary Medicines Authority granted a permit to allow research use and supply of an AgVet chemical product (PER82602);
- The Department of Biodiversity, Conservation and Attractions approved the use of meat baits containing '1080' to be used on Crown land (Ref: *Hisstory*® 001/2017).

Summary

Feral cats are a serious vertebrate pest having severe to catastrophic effects on native wildlife species. The broad-scale control of feral cats is difficult as they are found in very low densities and have large home ranges, making them difficult to locate. They are also extremely cautious in nature, making them hard to cost-effectively control with traditional measures such as shooting and trapping. Poison baiting, using *Eradicat®* or *Curiosity®* baits, for the control of feral cat populations has been recognised as the most effective broad-scale method throughout most of southern Australia. However, these two baits may present a hazard to some northern wildlife species, such as the northern quoll and varanid species either due to sensitivities to the toxicants used, or the form of presentation. By combining the 1080 toxicant used in *Eradicat®* with the robust *Curiosity®* delivery mechanism, i.e. encapsulating 1080 within the *Curiosity®* Hard Shelled Delivery Vehicle (HSDV), has provided a variant feral cat bait - *Hisstory®* - which should minimise the impact on northern Australian non-target species, while still providing effective control of feral cats.

To assess the utility of *Hisstory®* as a potential feral cat bait, the 1080-HSDV formulation firstly needed to be evaluated in pen trials on feral cats to provide information on toxicant efficacy. These pen trials demonstrated that the 1080-HSDV formulation is an efficacious toxicant formulation for feral cats with 100% of the cats collapsing and 97% of these animals progressing to death. At the same time, *Hisstory®* HSDV manufacture repeatability and reproducibility (and associated quality assurance and quality compliance protocols) were also confirmed.

Following positive results from these pen trials, a small-scale field trial, simulating aerial deployment of an encapsulated 1080 HSDV in a *Hisstory®* feral cat bait, was undertaken to quantify the potential risks to free-ranging northern quolls. This trial was conducted because it was considered important to validate the results of the earlier captivity trials with free-ranging northern quolls. Field efficacy trials are also required to inform an application to register the bait with the Australian Pesticides and Veterinary Medicines Authority. Results from this study demonstrated that the *Hisstory®* bait for feral cats is unlikely to present a significant hazard to free-ranging northern quolls.

The secondary objective of this trial was to demonstrate that feral cats would consume the bait in the field, as pen trials are 'illustrative', but not necessarily representative, of reality in-the-field. However, several problems were encountered during the planning and preparation phase of the project, resulting in this secondary objective not being achieved:

1. The trial site had to be moved at a late stage due to logistical problems;
2. Delays on provisions of necessary permits affected the timing of baiting. This meant baiting aircraft were unavailable, so the size of the trial area was reduced from 100 km^2 to 6 km^2 and refocused on northern quoll only.

The '1080' poison used in the *Hisstory* bait is highly toxic to canids as well as feral cats. It is likely that a technique that provides for broad-scale and effective control of feral cats will also have impacts on canid populations given the required bait density and similar sensitivity to the 1080 compound. Public response to the above field trial both from a number of local communities, Aboriginal Traditional Owners and non-Aboriginal people, in particular to the fate of wild dog/dingo hybrids in the baited area, has highlighted the need to develop a bait type that can be used in specific areas, that will minimise the risk to native species and also canids yet still provide effective control of feral cats. Although not originally designed for this purpose, the *Hisstory®* bait provides a potential solution now that it has been demonstrated to pose no significant hazard to northern quolls. Development of such a bait is essential if we are to effectively control feral cats across northern Australia without public opposition, particularly on lands where wild dog/dingo hybrids are considered an essential component of the ecosystem.

There are several rapid-acting emetics that cause dogs to vomit but have minimal effect on cats that could potentially be incorporated into the *Hisstory*® bait and provide a potential solution. From these, Apomorphine was selected as a primary agent for trialling to provide proof-of-concept that such agents could be incorporated into the *Hisstory*® HSDV formulation. In the trials reported here, the failure of the Apomorphine in the coating matrix of the HSDV formulation, core of the HSDV and finally within the bait matrix to induce emesis in captive wild dog trials was unanticipated. Apomorphine was present at therapeutic levels, which suggests that the Apomorphine was not being made available (dispersing) at a rate sufficiently rapid to trigger vomiting.

Progressing the development of feral cat baits with a minimised risk to canids remains an objective, with emesis to avoid intoxication likely the preferred means of achieving this objective. In the short-term, and based on the literature evaluated to date, the focus will be on the range of available histaminergic agents. In addition, and in the longer-term, comprehensive field trials will be undertaken to assess the efficacy of *Hisstory*® for feral cat control and the risk to canids.

Background

Predation by feral cats (*Felis catus*) has led to major declines in native wildlife populations including many threatened species. The Australian Government has declared the impacts of feral cats as a key threatening process on native wildlife species through predation under the *Environment Protection and Biodiversity Conservation Act 1999* and Threat Abatement Plans have been written to guide and coordinate the response (EA 1999; DEWHA 2008; DE 2015). This is certainly the case in northern Australia where the combined impacts of inappropriate fire regimes and invasive species are implicated as causal factors in native species declines (Woinarski *et al*. 2015). The management of feral cats in northern Australia is limited by the absence of a technique that facilitates landscape control. Current control techniques such as trapping, and shooting are only effective across areas of limited size because of the requirement for skilled labour and the time required. Poison baiting, using *Eradicat®* or *Curiosity®* baits, for the control of feral cat populations has been recognised, by most practitioners, as the most effective broad-scale method throughout most of southern Australia (Algar and Burrows 2004; Algar *et al*. 2007; Johnston 2010; Johnston *et al*. 2011; Johnston *et al*. 2014; Lohr and Algar 2020). However, these two baits may present a hazard to some northern wildlife species either due to sensitivities to the toxicants used, or the form of presentation.

Eradicat® Feral Cat Bait

The current "Threat Abatement Plan for Predation by Feral Cats" (DE 2015) recommends that 'broad-scale toxic baits targeting feral cats are developed, registered and made available for use across all of Australia, including northern Australia'. In Western Australia, the *Eradicat®* feral cat bait has been registered for the broad-scale control of feral cats. However, the regulatory bait label prohibits its use in areas where northern quoll (*Dasyurus hallucatus*) or their habitat may be present. The *Eradicat®* bait, which is directly injected with 4.5 mg of the toxin sodium monofluoroacetate (1080) could be consumed by northern quolls. The approximate Lethal Dose$_{50}$ data (LD$_{50}$), where LD$_{50}$ is the amount of toxin required to kill 50% of test animals (standardised to mg of pure 1080/kg), is 7.1 mg/kg for northern quolls (Twigg *et al*. 2003). Thus, consumption of one entire *Eradicat®* bait would form a lethal dose.

Curiosity® Feral Cat Bait

The *Curiosity®* bait, like *Eradicat®*, is a small, moist meat sausage but, unlike *Eradicat®* the toxin is encapsulated within a tough acid-soluble plastic pellet known as a 'Hard-Shelled Delivery Vehicle, or HSDV' (see Plate 1). The HSDV ensures that the toxin does not disperse into the bait matrix but is only released when the pellet breaks down in the acidic stomach of the cat. This method of delivering the toxin plays a key role in reducing the potential exposure of non-target species by exploiting the different feeding behaviours between feral cats and native wildlife. When feeding, feral cats are known to consume large food items. They do not, in general, masticate the food but, use their carnassial teeth as "shears", cutting prey up into large pieces, which they then swallow whole (Leyhausen and Tonkin 1979). Consequently, baits are consumed in portions, which include the HSDV. Conversely, captive and field studies have demonstrated that most native mammal and bird species process food items more thoroughly. Thus, they avoid exposure to the toxin by detecting and rejecting the HSDV when consuming the meat attractant (Marks *et al*. 2006; Hetherington *et al*. 2007; Forster 2009). Included within these studies are captive trials with dasyurid species, such as eastern quoll (*Dasyurus viverrinus*), northern quoll, spotted-tailed quoll (*D. maculatus*) and brush-tailed phascogale (*Phascogale tapoatafa*) (Forster 2009; Robinson 2010; Gigliotti 2011).

A desktop study by Buckmaster *et al*. (2014) identified that there are relatively few non-target vertebrate species in Australia that are likely to consume both the cat attractant and any HSDV contained therein. However, amongst the threatened vertebrate species present in northern Australia, northern quolls were identified as potentially being able to consume baits containing the

HSDV, even though earlier trials conducted with a number of captive northern mammal species including northern quoll; northern brown bandicoot (*Isoodon macrourus*) and black-footed tree-rat (*Mesembriomys gouldii*) (Gigliotti 2011) indicated that the HSDV was reliably rejected by these species. In these trials 21 northern quolls were presented with a non-toxic bait into which was inserted a HSDV, containing the biomarker Rhodamine B. Video recording was used to monitor the activity of the quolls in the pens without disturbing them. The northern quolls consumed the 21 baits presented. Searches of the pens resulted in the recovery of 20 of the 21 HSDVs. Although one was not found, there was no evidence of the HSDV having been consumed, as there was no Rhodamine B staining of scats. Thus, this study demonstrated that it was unlikely that northern quolls would consume the HSDV; noting that the feeding behaviour of animals in captivity may not truly reflect the behaviour of free-ranging individuals.

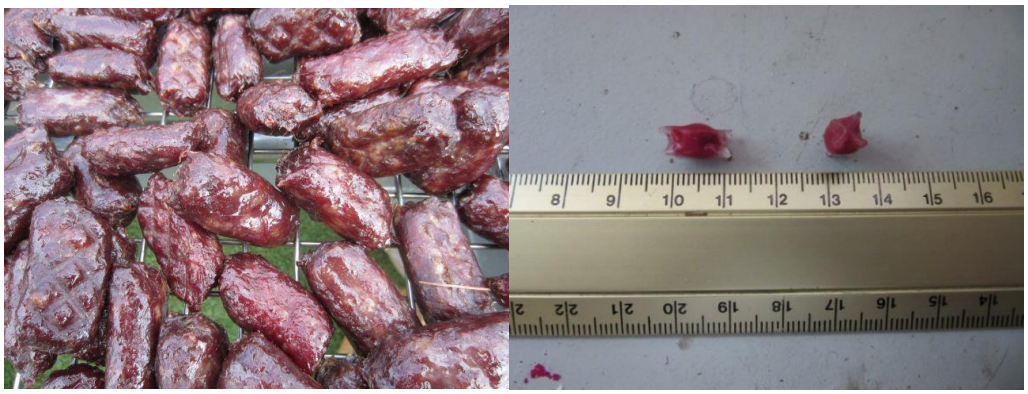

Plate 1. *Hisstory*® meat lure and acid-soluble HSDV that encapsulates the toxin.

The *Curiosity*® bait contains the toxin para-aminopropiophenone (PAPP), to which many native species are tolerant (NWR 2006; Fisher *et al*. 2008; Eason *et al*. 2010; Eason *et al*. 2014; Johnston *et al*. in press). However, there are certain wildlife species that are susceptible to PAPP, including varanids, and these species are not expected to reject the HSDV during eating (Frappell and Andrewartha 2006; Frappell 2007; references cited in McLeod and Saunders 2013). This hazard can be mitigated in southern Australia by limiting baiting to cooler months when reptiles are in torpor (Jessop *et al*. 2013; Johnston *et al*. 2019). This practice is not transferable to northern Australia where reptiles are typically active all year round. However, while reptiles are particularly susceptible to PAPP (Eason *et al*. 2014), they are reported to have a higher tolerance for 1080 than mammals (McIlroy 1984; McIlroy *et al*. 1985; Calver *et al*. 1989; King 1990).

Hisstory® Feral Cat Bait

It is anticipated that by using 1080 as the toxicant in the HSDV, it should be possible to minimise the impact on varanid populations and simultaneously avoid exposure to mammal species such as northern quolls. If successful, this would allow land managers to undertake large-scale feral cat baiting programs without impacting native species populations in northern Australia. This bait configuration, called *Hisstory*®, is essentially the same meat lure as *Curiosity*®, i.e. a 20 g kangaroo meat/chicken fat sausage, but includes a HSDV containing 4.5 mg of the toxicant 1080.

To assess the utility of *Hisstory*® as a potential feral cat bait, the 1080-HSDV formulation firstly needed to be evaluated in pen trials on feral cats to provide information on toxicant efficacy (death), overall reliability, timing to onset of symptoms post-bait consumption, and the time to first symptoms (vomiting), collapse and death. Video recordings showing the sequence of behaviours through these trials were also used as input to an assessment of the relative humaneness of the 1080-HSDV toxicant as per the guidelines in Sharp and Saunders (2011). Following positive results from these pen trials, a small-scale field trial, simulating aerial deployment of an encapsulated 1080 HSDV in a *Hisstory*® feral

cat bait, was undertaken to quantify the potential risks to free-ranging northern quolls. This trial was conducted because it was still considered important to validate the results of the earlier captivity trials with free-ranging northern quolls. Field efficacy trials are also required to inform an application to register the bait with the Australian Pesticides and Veterinary Medicines Authority (APVMA).

As 1080 poison is highly toxic to canids as well as feral cats, it is likely that a baiting program undertaken to achieve broad-scale and effective control of feral cats will also have impacts on canid populations. Thus, as well as the considering how best to mitigate the risks and hazards to endemic native species of feral cat baiting, the concerns of local communities, Traditional Owners and non-Aboriginal people about the fate of wild dogs and dingos (and their hybrids) (*Canis familiaris*) in areas where *Hisstory*® baiting may take place are also of prime importance. These concerns highlight the need to develop a bait type and baiting strategy that can be used in specific areas with the aim of minimising the risk to native species and also to canids, yet still provide effective control of feral cats.

There are several rapid-acting emetics that cause dogs to vomit but have minimal effect on cats that could potentially be incorporated into the *Hisstory*® bait. A literature review identified a number of potential agents that could be used as dog specific emetics (reference Scientec Report). From these, Apomorphine was selected as a primary agent for trialling to provide proof-of-concept that such agents could be incorporated into the *Hisstory®* HSDV formulation.

1. *Hisstory*® Pen Trials

1.1 Materials and Method

1.1.1 Study animals and husbandry

Data from five production runs of the *Hisstory*® HSDVs were collected to demonstrate manufacture repeatability and reproducibility to support a registration application with the APVMA. At the same time, for statistical robustness, a minimum of six animals was tested with doses from each of the five production runs to demonstrate repeatability and reproducibility of efficacy, i.e. a minimum 30 animals were required. The data from the entire cohort were then collated to enable determination of whether there was any individual mass (dose rate), gender or pregnancy status effects arising, and also whether any batch-to batch differences were apparent.

Thirty stray cats were trapped at rural rubbish tips in Western Australia, using Sheffield wire small cage traps. Cats were transported to the Wildlife Research Centre, Woodvale in their cages on the morning of capture. Cats were habituated to captivity for a period at least one week. During this time, the cats were housed outside in pre-trial pens that were constructed of cyclone wire measuring 3.0 x 5.0 x 2.0 m. Each pen contained a kennel to provide shelter. Enrichment included branches for scratching and climbing, and PVC pipes for hiding. Commercial tinned cat food and dried cat biscuits were supplied daily to each animal and water was available *ad libitum*. Human interaction was restricted to daily pen cleaning, feeding and monitoring of the animals' general health.

1.1.2 Efficacy trial

In general terms, the study protocol entailed: (a) health check; (b) housing in holding pens; (c) relocation to the test pen; (d) pre-test monitoring; (e) bait presentation; (f) post-test data collection (weight, sex and pregnancy status, vomit inspection); (g) video data review and (h) data collation and analysis. Cats were fasted for 8–24 hours prior to commencement of the trial, a fasting period long enough to ensure that the cats' stomachs were empty or nearly empty as food starts to leave a cat stomach within 30 minutes of being taken in by mouth (Briggs 1994). The cats were captured in a net and relocated ~100 m to the test pens measuring 1.9 x 0.5 x 0.5 m. These pens had mesh front and rear panels but were otherwise clad in steel sheeting. Remote monitoring was undertaken using infra-red illuminated cameras (QC8653, Swann Communications, Australia) located at each end of each test pen. The camera system was connected to a 16-channel digital video recorder (Omnivision, Melbourne, Australia) located in an adjacent building ~10 m from the test pens. This permitted constant viewing and image recording without disturbing the cats. A water bowl was provided in each pen. No play or other enrichment items were provided in the pens as these would obscure video monitoring, and additionally interfere with the movement of the cat and efficient conduct of the trial.

Cats were observed for a 30–360-minute period to ensure familiarisation with the test pen, i.e. until they appeared settled. They were then provided with a *Hisstory*® bait containing a single HSDV. The HSDVs were formulated according to the methods described in Australian Patent Application No. 2009202778 and were manufactured for the trial by Scientec (July 2015). The bait was placed ca. 1 m from the end of the pen so that it was readily observable in both video cameras. The time of (i) bait placement, then (ii) voluntary bait consumption was recorded. Once consumed, the pen was approached and visually checked to ascertain whether the HSDV has been consumed or rejected. If the HSDV has been consumed, no further food was provided, and the subject was remotely monitored to ensure the intoxication process progressed without any unanticipated occurrences. If the HSDV had been rejected during bait consumption, or the bait was not consumed, it was replaced with a new bait, with the rejected HSDV being recovered at the same time if feasible.

The cat was observed via video link for the duration of toxicoses. Behaviours observed and the time of those behaviours was recorded throughout. The vision was also recorded to facilitate later review. There were no instances where intervention or disturbance of the cat during toxicosis was necessary.

Specific events noted from each trial to provide a measure of efficacy included: the time of (a) bait presentation; (b) ingestion, (c) first indications of intoxication e.g. nodding, or unsteadiness, (d) collapse, and (e) time of death or recovery.

A nominal time of death was recorded by the cessation of chest movement as viewed on video and was subsequently confirmed via absence of corneal reflex and heartbeat. It was possible that this method might overestimate the time to death (Lindeman and Johnston unpub. data; Marks *et al*. 2009) but was more suitable than repeatedly disturbing the cat while alive. Lindeman and Johnston (unpub. data) found the stress reaction of the cat being disturbed could change the timing of events and possibly the outcome of pen efficacy trials.

1.2 Results

Repeatability and reproducibility data for the production runs were achieved for the required chemical and physical attributes of the HSDV formulation [1080(Rh B)-HSDV] to meet quality assurance and quality compliance (QA/QC). These data included dose-mass of 1080 as determined by gravimetric analysis, pressure point failure of the coating matrix and overall solubilisation/dispersion data indicating consistency of the coating and core matrices. The 1080-HSDV structure contained a 1080 toxicant-core, which was an amorphous waxy solid. The resultant HSDV structure was hard, and exhibited good dimensional stability, flexibility, hardness and impact resistance (determined qualitatively) under ambient laboratory conditions. All AQ/QC conditions were met (reference: Scientec Report # 1046).

The trial cohort of cats comprised seven male, seven pregnant, and 16 non-pregnant females, including four that were lactating at (or had been immediately prior to) the time of testing in November/December 2016. In summary, consumption of the 1080-HSDV (*Hisstory*®) formulation resulted in 100% of the cats collapsing with 97% of these animals progressing to death. The data from the time of bait consumption to the specific behavioural events are presented in Table 1. Twenty-nine cats (97%) in this trial were observed to have vomited. Vomiting during the intoxication process was generally at or about the time of collapse. The time from collapse to death for the animal that was not observed to have vomited was not definitively less than certain of those that did vomit.

There was no significant difference in batch-to batch variability with repeatability and reproducibility of efficacy on feral cats between batches. Thus, the data demonstrate that the 1080-HSDV formulation could be manufactured *en masse* and provide consistency of performance with dose administered.

Table 1. Time from bait consumption to specific intoxication events

State	Mean ± SE (minutes)
Time to 1st symptom	228 ± 22
Time to collapse	308 ± 30
Time to death	500 ± 52
Time to vomit	248 ± 23
Time between vomiting and death	289 ± 38

1.3 Discussion

Pen trials of *Hisstory*® have demonstrated that the 1080-HSDV formulation is an efficacious toxicant

formulation for feral cats. At the same time, *Hisstory*® HSDV manufacture repeatability and reproducibility (and associated QA/QC protocols) were also confirmed. These data will be used as the basis for preparation of documentation for inclusion in a product registration dossier for submission to the Australian Pesticides and Veterinary Medicines Authority (APVMA). Following the success of these pen trials, the risk that the 1080-HSDV cat bait poses to northern quolls in field trials (Stage 2) was undertaken (see Section 2). Because pen trials are 'illustrative', but not necessarily representative, of reality in-the-field, comprehensive trialing to assess *Hisstory's*® effectiveness in-the-field for controlling feral cats are planned (Stage 3).

2. *Hisstory*® Field Trial

2.1 Materials and Method

2.1.1 Study site

The field study was undertaken in August through to early-October 2017 towards the end of the dry season in the Kimberley when prey is generally at its lowest. This would be the optimal time of the year, in this area, to bait feral cats because they are most likely to consume a bait when the abundance of food resources is depleted. The study was conducted in the King Leopold Ranges Conservation Park (KLRCP), located in the west of the Kimberley region, approximately 130 km east of Derby, Western Australia. The Ranges separate the main Kimberley plateau from the southern Fitzroy plains and consist of quartz sandstone intruded by dolerite (Burbidge *et al*. 1991). Elevations are up to 950 m above sea level and relief is up to 300 m. Mount Hart is located in the north-west corner of the Conservation Park (16°47'8" S, 124°55'16" E) where a number of rainforest gorges are surrounded by low ridges of rocky woodlands and open savannah grasslands. The Barker River passes through Matthew Gorge and is lined with dolerite boulders on both banks. The river exits the gorge and into savannah with the riparian zone. The Ranges support low open woodland with eucalypt species dominant, especially woollybutt (*Eucalyptus miniata)* and grey box (*E. tectifica*) (Burbidge *et al*. 1991). In sheltered or watered valleys and along creeks the open-forest vegetation becomes more diverse, including *Eucalyptus* sp., screw pines *(Pandanus* sp.), fan palms *(Livistona s*p.) and lebbeck trees (*Albizia lebbeck*) (ibid).

The study area at Mount Hart (Fig. 1) was chosen because of the known presence of northern quolls and logistical suitability for the field work. The size of the study site was 6 km^2 centred on Matthew Gorge as sufficient northern quolls were trapped in this area to provide for a statistically rigorous result.

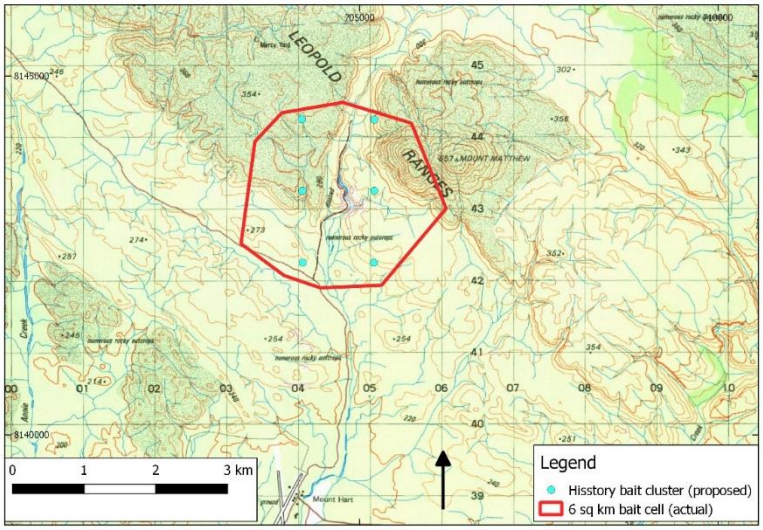

Fig 1. Study area within the King Leopold Ranges Conservation Park.

2.1.2 Northern quoll trapping and VHF radio-collaring

Northern quoll trapping was conducted using large Elliott traps (15 x 15.5 x 46 cm) (Elliott Scientific, Melbourne, Australia) and Hawkeye cage traps (Woodstream Corp., Lititz, Pa.; U.S.A.), with "universal bait[1]" with either sardines or fish oil added to the lure. Traps were set in the vicinity of Landscape Conservation Initiative (LCI) northern quoll monitoring sites (established in 2016, by I. Radford [DBCA]). The transects were near rocky outcrops and spaced at intervals of 20–30 m with up to 20 traps in a transect as per Morris *et al.* (2016). As a result of the high capture rate on day 2 at two of the transects, only three transects were required, two running parallel along rocky outcrops and a third in a gully tributary of Matthew Gorge (Fig. 2). Field inspection of other accessible areas to set traps were conducted on the afternoon of the first day and were deemed unsuitable due to their high-risk potential exposure to feral pigs (*Sus scrofa*), which were active in the area.

Trapped northern quolls were weighed, collared, sexed, microchipped with a Trovan transponder (Microchips Australia, Victoria, Australia) and when possible, morphometric measurements were taken. A VHF radio-telemetry collar series M1720 with mortality signal (ATS, Minnesota, USA) was fitted to each northern quoll caught that was mature and had a weight over 240 g. The collars weighed 9 g and were programmed with mortality mode following 12 hours of inactivity, i.e. switching from 40 to 80 ppm. All northern quolls were released at the site of capture.

[1] A mixture of oats and peanut butter. See appendix 1 of DBCA Standard Operating Procedure Cage traps for live capture of terrestrial vertebrates. https://www.dpaw.wa.gov.au/images/documents/plants-animals/monitoring/sop/sop09.2_cagetraps_v1.1.pdf

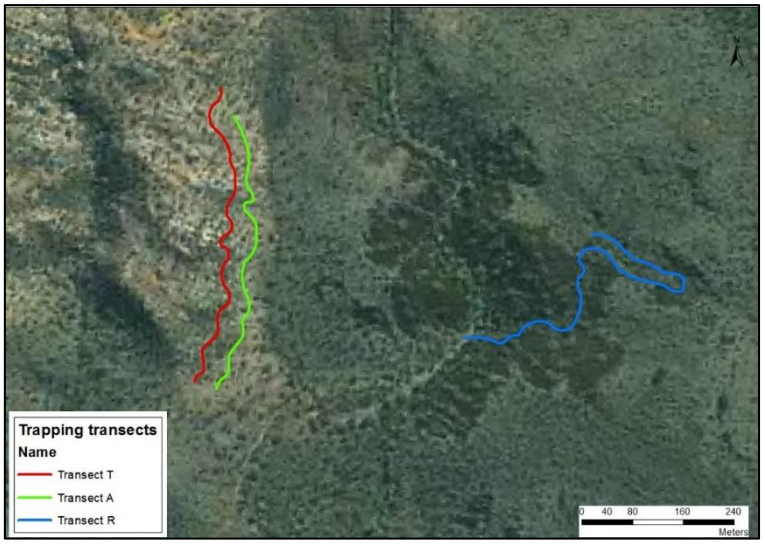

Fig. 2. The three northern quoll trapping transects operated for three nights in early August 2017 for capture and radio-collaring and Transects T (red) and R (blue) for three and two nights respectively in mid-September 2017 to the remove radio-collars.

2.1.3 Bait preparation and application

Three hundred *Hisstory*® baits were prepared by manually inserting a single HSDV containing 4.5 mg 1080. Immediately prior to being deployed, the *Hisstory*® baits were thawed and placed in direct sunlight. This process, termed 'sweating', causes the oils and lipid-soluble digest material to exude onto the surface of the bait. All baits were sprayed, during the sweating process, with a permethrin-based residual insecticide (Coopex®, Bayer Crop Science, Australia) at a concentration of 12.5 g/l as per the manufacturer's instructions. This process aims to reduce bait degradation by ant consumption, which may also deter bait acceptance by feral cats because of the physical presence of ants on and around the bait medium.

The bait cell size and location were determined from data of northern quoll home range use and size. A study by Cook (2010) of northern quolls on the Mitchell Plateau suggested that they remain within 1 km of their den sites. Based on den locations the mean home-range area estimate for males was <54.2 ha (SE ± 36.7 ha; range 2.4–421.4 ha). Females had smaller home ranges, with a mean area of 6.8 ha (SE ± 1.6 ha; range 0.8–15.3 ha). During the wet season, ranges of males overlapped extensively with those of other northern quolls of both sexes, but only with those of females in the dry season. The mean maximum distance between dens was 1,193 m for males and 440 m for females. However, not knowing where their dens were, capture points were used as the centroid for the 1 km radius. This resulted in the 6 km^2 (558 ha) baiting cell.

Previous aerial baiting exercises using *Eradicat*® baits have demonstrated that a rate of 50 baits/km^2 provides an optimal encounter rate for feral cats (Algar and Burrows 2004). The 50 baits fall within a 200 x 40 m area (Algar *et al*. 2013). The small size, 6 km^2, of the bait cell in this study meant that the charter of an aircraft was not warranted. As such, baits were distributed by hand in a manner attempting to simulate the aerial baiting pattern across the site. Six points were projected onto site mapping as a QGIS layer with these positions then transferred onto handheld GPS devices (Rino 650, Garmin Ltd, USA). Fifty baits were distributed by hand on 10 September by ground crew at each of the six sites while walking throughout this area. A GPS waypoint was created when each bait was dropped. The waypoint data were subsequently entered into QGIS and a Convex Hull was calculated to provide a measure of the distribution area at each cluster.

The area of spread of the *Hisstory*® baits at KLRCP varied (5,555–14,556 m^2) between the six clusters reflecting the procedure, topography, and vegetation at each site (see Table 2). The location of the bait clusters is presented in Fig. 3. Meteorological conditions following bait delivery varied little over the period 10–24 September with a maximum temperature of 37.0 °C (SE ± 0.3 °C), minimum temperature of 15.3 °C (SE ± 0.8 °C), and 0 mm rainfall.

Table 2. Area of individual *Hisstory*® bait clusters.

Bait cluster No.	Area (m^2)
1	6,438
2	14,556
3	8,259
4	5,555
5	13,573
6	9,276

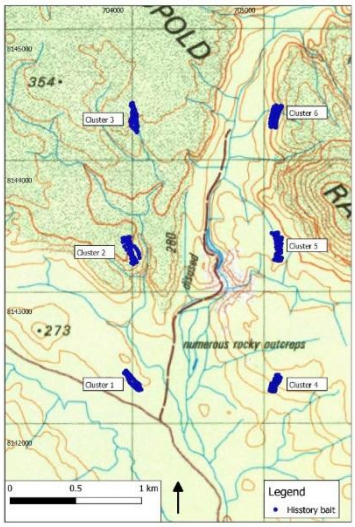

Fig. 3. Location of *Hisstory*® bait clusters.

2.1.4 Monitoring and recovery of radio-collars

Monitoring of collars was conducted opportunistically during the capture and collar fitting process, between 2–4 August 2017. A R1000 VHF receiver (Communication Specialists Inc., California, USA) fitted with an omni-directional whip antenna was used to determine the status of collared northern quolls, i.e. alive/dead.

Prior to the baiting, daily monitoring of all collars was conducted from elevated locations over the period 9–18 September 2017 using the R1000 receiver as well as Australia 26K receivers and three element yagi antenna (Titley Electronics, Ballina, Australia). An audio recording was made of collars to provide a permanent record of the status of individual northern quolls. The collars that had switched to mortality mode were recovered progressively using radio-tracking techniques during the period 10–16 September. When the location of the collar had been discovered, the surrounding area was searched for traces of northern quoll bones and fur. Photographs and notes were also taken of the site with observations about the potential cause of death recorded where possible. An endoscope USB drain inspection camera (Logan Arms Pty Ltd, Dandenong, Australia) was used to attempt to view and recover collars 361, 402 and 503 that were in mortality mode but could not be accessed. Collars that remained in 'alive' mode were not approached to avoid disturbing the animal.

Following baiting, recovery of collars from alive northern quolls was conducted through recapture trapping of Transects T and R (Fig. 2) using the Elliott traps. Traps were set 19–24 September 2017 with a maximum of ten traps set at any one time. This low trap set was to ensure there would be minimal time spent in traps for females that were assumed to be carrying young. On re-capture, individuals were weighed, the radio-collar was removed and an assessment of any impacts from wearing the collar was conducted. Females were checked for pouch young. Any new individuals were microchipped and basic morphometrics were recorded.

2.2 Results

Trapping of northern quolls was conducted from 2–4 August 2017 (102 trap-nights) with 27 individuals (16M, 11F) captured at a capture success rate of 32% (Table 3). The location chosen for capture was a 'Landscape Conservation Initiative' study site, which was last trapped in April 2017, and five individuals (2M, 3F) were re-captures from this work. Mean bodyweight for the 16 males was 432 g (SE ± 24 g) and for the 11 females was 308 g (SE ± 19 g) (see Appendix). All captures were on Transect T and R with the only capture on Transect A (see Figure 2) being a golden-backed tree-rat (*Mesembriomys macrurus*). Other non-target captures were two house mice (*Mus musculus*) and a Kimberley rock-rat (*Zyzomys woodwardi*).

Table 3. Summary of August northern quoll (nq) trapping results. Re-traps are defined as individuals caught previously during this trapping session and re-captures are individuals that have been caught and marked on other trapping trips.

Date	**2/08/17**	**3/08/17**	**4/08/17**	**Total**
Trap-nights	19	51	32	102
nq captures	2	14	17	33
capture success	11%	27%	53%	32%
nq (excluding re-traps)	2	12	13	27
capture success	11%	24%	41%	26%
nq (excluding re-traps and re-captures)	1	10	11	22
capture success	5%	20%	34%	22%

Sex ratios	**Total individuals**	**27**
male	59%	16
female	41%	11

Of the 27 northern quolls, all but three females were suitable for collaring, two were too small for the weight of the collar and the other had a large lesion on the back of her neck. Thirteen males and seven females were collared with VHF radio-collars (Table 4).

Table 4. Summary of northern quolls radio-collared. Individuals alive for the baiting component of the study are shown in grey rows.

Date trapped	Collar Freq. (151.xxx MHz)	Morphometric (sex, mass g)
2 Aug	542	F, 280
2 Aug	223	M, 550
3 Aug	381	M, 370
3 Aug	443	F, 240
3 Aug	262	F, 300
3 Aug	563	M, 370
3 Aug	361	F, 420
3 Aug	421	M, 520
3 Aug	343	M, 600
3 Aug	301	M, 340
3 Aug	462	M, 480
3 Aug	604	M, 280
3 Aug	582	F, 350
4 Aug	323	M, 460
4 Aug	241	M, 590
4 Aug	402	M, 350
4 Aug	281	M, 530
4 Aug	503	F, 340
4 Aug	524	M, 390
4 Aug	483	F, 330

The collar fitted to a female northern quoll trapped on 4 August (151.361) had switched to mortality mode when re-checked the second day after capture. All but two (Male 604 and Male 421) of the remaining 19 collars were detected transmitting in 'alive' mode on either 5 or 6 August. These two collars were subsequently detected during the next site visit suggesting that the animals had temporarily moved to a location where the VHF signal was obscured. The next status check was undertaken on the 9 September. A further 11 collars had switched to mortality mode (Table 3) leaving eight northern quolls (all six females and two males) considered to be alive prior to baiting (see highlighted individuals in Table 4). The locations where northern quolls were collared, and subsequent mortality mode recoveries are shown in Fig. 4 and described in Table 5.

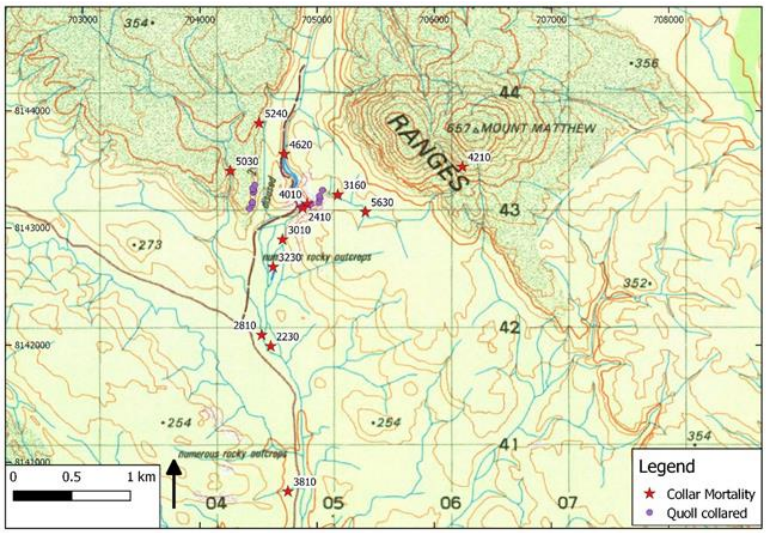

Fig. 4. Locations where northern quolls were collared and subsequent mortality mode recoveries.

Table 5. Mortality mode and recovery of northern quoll collars.

Date that mortality mode was detected	Collar Freq. (151.xxx MHz)	Recovered date	Location	Description	Northern quoll traces	Possible cause of death
5 Aug	361	5 Aug	705176 8143284	Boulder field	Not accessible	unknown
9 Sep	381	11 Sep	704751 8140751	Savannah grassland	Nil	unknown
9 Sep	323	13 Sep	704624 8142667	Riparian vegetation. 30 cm from river.	Nil	Bird?
9 Sep	241	10 Sep	704877 8143172	Boulder field	Entire desiccated carcass.	Die-off?
9 Sep	563	11 Sep	705412 8143137	Grassland. 3 m from dry creek	Collar harness chewed and broken	Bird?
9 Sep	402	10 Sep	704916 8143207	Boulder field	Desiccated carcass w/o head	Die-off?
9 Sep	421	14 Sep	706239 8143521	Under boulder, Mt Matthew	Small amount loose northern quoll fur	unknown
9 Sep	223	12 Sep	704604 8141991	Riparian vegetation	1 rib bone	Bird?
9 Sep	301	13 Sep	704705 8142901	In river	Nil	Bird?
9 Sep	462	16 Sep	704719 8143629	In river	Nil	unknown
9 Sep	281	12 Sep	704527 8142087	Riparian vegetation	Skull	Bird
9 Sep	524	14 Sep	704506 8143894	South facing slope	Loose northern quoll fur	Bird
15 Sep	503	15 Sep	704259 8143487	Under bedrock of waterfall	Nil	unknown

Additional observations about the recovery of specific collars are as follows:

Northern quoll 241 – This entire carcass was readily removed from under the boulder (see Plate 2).

Plate 2. Carcass of northern quoll 241 *in situ* and withdrawn from boulder pile.

Northern quoll 281 – A 'perching' branch was directly above the collar and was scratched suggesting a bird with talons had been gripping it. A small amount of meat and northern quoll fur was stuck to this branch (Plate 3).

Plate 3. Skull and collar from northern quoll 281. Note the perching branch above site.

Northern quoll 402 – A live northern quoll was observed from a distance of 10 m at the rock where this collar was located. This animal retreated under boulders when approached. A desiccated carcass without head or collar was located on a flat rock where the alive northern quoll had been sighted. The carcass was left *in situ* while a camera was retrieved. On return, some 20 minutes later, the carcass had been removed leaving a small amount of hair (Plate 4). It was not possible to recover the collar from location under a boulder. It is speculated that the live northern quoll dragged the carcass out from under the boulder and subsequently removed it while the camera was being retrieved.

Plate 4. Fur remnants on rock from carcass of northern quoll 402.

Northern quoll 503 – The collar (and presumably northern quoll carcass) was not recoverable being located in rock under a dry waterfall (strongest signal indicated by arrows in Plate 5). The collar switched to mortality mode on 15 September with recovery attempted the same day. The site was revisited on 24 September and the collar appeared to be in the same position. The endoscope camera was slotted into small caves and crevices in the rock to try and obtain confirmation of a carcass. The full length (approximately 2 m) was extended into a small diameter cave but the camera did not make the full extent. This cave appeared to extend towards the point on the ground that the signal was coming from, suggesting that perhaps the collar/northern quoll was deep within this cavity. It is possible that this animal consumed a *Hisstory*® bait as there was a bait cluster 100 m distant from this location (see Fig. 5).

Plate 5. Location of collar from northern quoll 503 following switch to mortality mode.

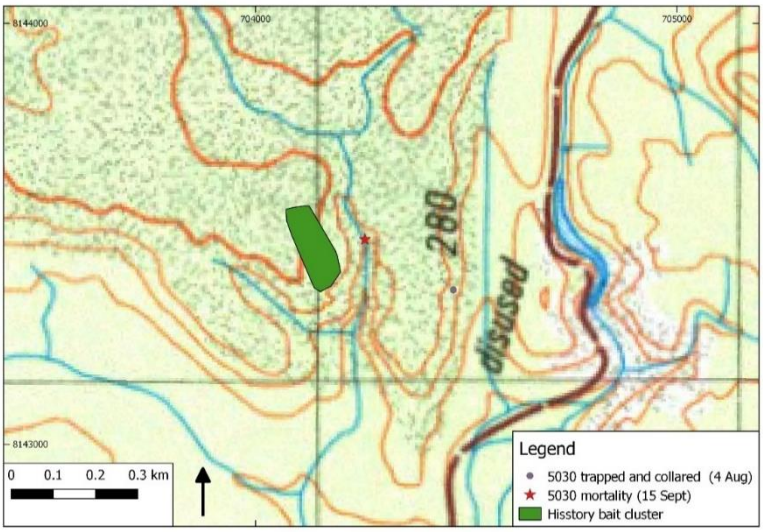

Fig. 5. Locations of closest *Hisstory*® bait cluster in relation to northern quoll 503.

Re-capture of the seven alive quolls was conducted 19–24 September 2017. Eleven individuals (4M, 7F) were captured (Table 6) including all collared animals within five nights of targeted trapping on Transects T and R (Appendix). Collars were removed and assessments were made of any irritation caused by collars. One individual (M 604) had a wound because of the collar however, when he was re-captured two days after collar removal the wound had scabbed and appeared to be healing well. Mean bodyweight for males was 420 g (SE ± 87 g) and females 305 g (SE ± 17 g) (see Appendix).

Two common rock-rats (*Zyzomys argurus*) and a shaded litter rainbow-skink (*Carlia munda*) were the only other captures.

Table 6. Summary of northern quoll trapping (nq) results during September.

Date	**20/10/17**	**21/10/17**	**22/10/17**	**23/10/17**	**24/10/17**	**Total**
Trap-nights	5	10	10	10	10	45
nq captures	3	3	3	4	4	17
Capture success	60%	30%	30%	40%	40%	38%
nq (excluding re-traps)	3	2	2	3	1	11
capture success	60%	20%	20%	30%	10%	24%
nq (excluding re-traps and re-captures)	1	0	0	1	0	2
capture success	20%	0%	0%	10%	0%	4%
Sex ratios					**Total individuals**	**11**
male			(includes 2 new males)		36%	4
female					64%	7

All females that had been collared were carrying their maximum of eight pouch young. These ranged from 11–21 mm for crown rump measurements or approximately 15–40 days old. The one other female that was captured was not carrying any young but based on the condition of her pouch (well developed and clean) it is assumed she would give birth this season.

2.3 Discussion

This small-scale study was intended to assess the hazard that the *Hisstory*® bait presents to a free-ranging northern quoll population. The trial was undertaken in the King Leopold Ranges Conservation Park in northern quoll natural habitat using a pattern typical of aerial baiting programs. Twenty northern quolls were trapped and fitted with radio-collars prior to application of *Hisstory*® baits. The northern quolls were then monitored for 14 days after baiting to determine whether any of the northern quolls died as a result of baiting. Unfortunately, only eight collared northern quolls were known to be alive when *Hisstory*® baits were distributed in the aerial baiting simulation. Of these, seven northern quolls were re-trapped and at the conclusion of the study along with a further three non-collared northern quolls. However, a female northern quoll died five days following application of the baits. The cause of death for this individual could not be identified as the collar was tracked to an inaccessible position in a rock cavity under a dry waterfall. Two hypotheses are posed: (i) it is possible that this animal consumed a *Hisstory*® bait as there was a bait cluster at 100 m distance from the collar location; and (ii) the northern quoll could have died from natural causes as a result of injury, pregnancy, disease and/or predation. Although the final sample size is small the study, in conjunction with earlier captive trials, was able to demonstrate that the *Hisstory*® bait for feral cats is unlikely to present a significant hazard to free-ranging northern quolls. A subsequent study by Heiniger *et al*. (2018) on Groote Eylandt, Northern Territory has also shown rejection of HSDVs by all free-ranging northern quolls (n=42) that consumed the *Hisstory*® bait.

The breeding season of northern quolls in the Kimberley is predicted to occur in May but will vary according to climatic conditions in the preceding wet season with late rainfall delaying breeding (K. Tuft pers. comm.). Data from the Mitchell Plateau in the Kimberley indicate that female northern quolls give birth to a single litter of young in July or August (Schmitt *et al*. 1989). Births were earlier on near coastal sites than on inland sites and by September all females were either carrying pouch young or were lactating (Schmidt *et al*. 1989). Further east, a three-year study in Kakadu suggests breeding occurs in May–June with 90% of all females with pouch young present in July and all females with young in August (Oakwood 2000). The amount of rainfall in the 2016/17 wet season was above average in the Kimberley, particularly in the west however, rainfall occurred in the typical cyclone season of November–March but with intense storm fronts causing high levels of rainfall in January. This timing of rainfall was expected to have had no influence on the onset of breeding yet, as field observations determined, breeding occurred up to two months later than expected. The age of pouch young in this study suggests that the earliest birth date was about 12 August. With gestation being approximately three weeks, mating would have commenced mid-July, which is more in line with data from further south in the Pilbara (K. Morris pers. comm.; cited in Woinarski *et al*. 2014).

The level of male die-off in northern quolls appears to be highly variable and often site-specific. For example, observations of populations at highly productive sites such as rivers have been shown to have relatively low male die-off rates (Begg 1981). In the present study, male die-off could have occurred approximately two weeks post-mating, potentially occurring as soon as they were collared. All radio-collars that were identified to be in mortality mode on 9 September, that is prior to baiting, were from male northern quolls. This suggests that a significant male die-off occurred this year, which unfortunately caused an unforeseen and dramatic reduction in northern quoll sample size. In hindsight it may have been prudent to only collar females but, with an unpredictable level of die-off, a sex-biased sample could also be criticised in a bait uptake study.

Whether those animals that died were predated as they became weaker or were scavenged as carcasses could not be determined. Predators, such as raptors, obviously played a role given the locations where collars were recovered and the presence of scattered fur and scratches on branches used as perches. Snakes have also been recorded predating northern quolls previously (Oakwood and Miles 1998) and we were confident that an adult king brown snake (*Pseudechis australis*) observed

foraging amongst the boulder pile was of sufficient size to predate northern quolls. A brown goshawk (*Accipiter fasciatus*), itself a potential predator of northern quolls, was observed to make two swoops on this snake before retreating to cover (Plate 6).

Plate 6. Potential predators of northern quolls at Matthew Gorge, king brown snake (*Pseudechris australis*) and brown goshawk (*Accipiter fasciatus didimus*).

The northern quoll is listed as ''Endangered'' (under the *Environment Protection and Biodiversity Conservation Act 1999*) and is declining at a rapid rate mostly in association with the spread of the introduced cane toad (*Rhinella marina*), which poisons northern quolls when they attempt to eat it (Woinarski *et al*. 2014). Other factors impacting on northern quoll populations are inappropriate fire regimes and predation by feral cats (Woinarski *et al*. 2014). Feral cats have established populations across northern Australia and are implicated in contributing to the decline of a range of wildlife species along with altered habitat, cane toads and possibly also disease (Woinarski *et al.* 2010). The expansion of the cane toad into Western Australia is expected to lead to rapid decline of northern quoll populations as the invasion front progresses (O'Donnell *et al*. 2010). The development of the *Hisstory*® bait is expected to assist in the broad-scale control of feral cats, which may also allow northern quolls to better cope with other pending threats such as the arrival of the cane toad in the King Leopold Ranges and other northern quoll habitat in the western Kimberley.

Success with the *Hisstory*® cat bait is likely to benefit many native species across northern Australia. As well as the endangered northern quoll, rare and threatened species that are likely to benefit from the control of feral cats include: golden bandicoot (*Isoodon auratus*); golden-backed tree-rat; black-footed tree-rat; brush-tailed phascogale (*Phascogale tapoatafa kimberleyensis*) and nabarlek (*Petrogale concinna monastria*).

In summary, each of the various bait types have their specific limitations on where it is appropriate to use them because of the risk to native species. *Eradicat*®, containing the 1080 toxin, can be used in southern and central Western Australia as native species in these areas are tolerant to a cat-sized dose of 1080. *Curiosity*®, containing the PAPP toxin, poses a risk to varanids as they are sensitive to the toxin and are known to consume baits. However, field studies (Jessop *et al*. 2013) has shown varanids are much less active when temperatures are below 16 °C and the risk can be mitigated by baiting in the cooler months of central and southern Australia when mean maximum temperatures are expected to be ≤ 16 °C. Across northern Australia, the bait under development, *Hisstory*®, containing encapsulated 1080 mitigates risks to northern quolls and varanids. *Hisstory*® may also be suitable for use in Tasmania where Tasmanian devils (*Sarcophilus harrisii*) have a LD_{50} of 4.24 mg/kg to 1080

(McIlroy 1981) but are possibly susceptible to PAPP. Proposed use areas, across Australia, for the three feral cat bait types is illustrated in Fig. 6.

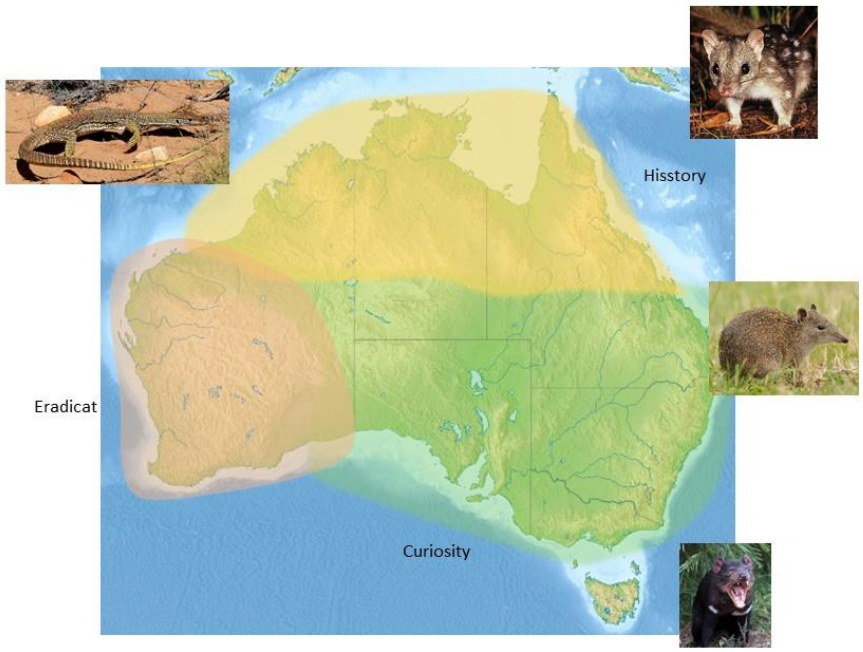

Fig. 6. Proposed use areas, across Australia, for the three feral cat bait types.

3. Emetic Trial

3.1 Materials and Method

In the first instance, trials of non-toxic baits containing the emetic (Apomorphine) were conducted on captive wild dogs, in the knowledge that the vomiting response to be observed would not necessarily result in sufficient 1080 being voided to ensure survival of the dog if the bait was toxic. These trials would, however, give confidence that inclusion of the emetic in the bait would evoke a vomiting response. If successful, field trials on wild dogs would then be undertaken. We were fortunate to find a small zoo that had three animals (1 male, 2 female) (see Plate 7) and would allow us to conduct the trial. Three trials were conducted: 1) apomorphine in the Hard Shelled Delivery Vehicle (HSDV) coating matrix; 2) apomorphine in the HSDV drug core and 3) apomorphine direct injected into the bait matrix. The captive wild dogs were offered a non-toxic bait at the normal time of feeding and were observed to consume both bait and HSDV. A dose of 9.75 mg apomorphine/bait, as recommended by veterinary authorities, was administered to each dog in each trial.

Plate 7. Captive female wild dog used in this study.

3.2 Results

A first trial of HSDV-baits containing the emetic (Apomorphine) formulated into the coating matrix of the HSDV was conducted with three captive wild dog/dingo hybrids (November 2019). None of the dogs vomited within the one hour of observation following consumption of the baits. Advice from the animal handlers was that there was no sign of vomiting having occurred after the one-hour observation period. One hour was considered a sufficient for observation because the polymer coating of the HSDV should dissolve in this time, i.e. allowing the contents of the core to be adsorbed by the animal. That is, if the bait had been toxic, the animal would have received a toxic dose within that hour.

Subsequent considerations identified the possibility of the emetic having undergone 'degradation' over time. At manufacture (July 2018), the HSDV coating matrix was colourless, and analysis determined Apomorphine as (i) present, (ii) at the levels anticipated, and (iii) without any apparent degradation. However, during storage, the coating (matrix) of the Apomorphine-HSDVs darkened (being quite 'black' at the time of use in November 2019). By comparison, the HSDV polymer coating prepared at the same time, but without admixed Apomorphine, remained 'colourless' (see Plate 8). The 'blackening' of the coating matrix is presumed to be a result of (some) *in situ* degradation (or irreversible complexation) of the Apomorphine. Given that, subsequent analysis of stored ('blackened') Apo-HSDV doses showed the Apomorphine as present and at the levels anticipated.

A second *in vivo* trial using freshly manufactured HSDVs containing Apomorphine in the coating matrix, was conducted (December 2019). Again, no vomiting resulted.

Plate 8. Apo-HSDVs, 'blackening' of the coating matrix on the left, clear HSDV (containing Rh B) on right.

Because the coating matrix and drug-core of the HSDV are separate entities, the emetic was admixed into the drug-core to (potentially) avoid degradation/complexation, albeit recognising that being within the drug-core the onset of emesis would likely be slowed due to the requirement that the HSDV coating matrix dissolve to allow release of the emetic. Concomitantly, emesis would need to occur before adsorption of any toxin. This consideration aside, a trial with Apomorphine in the drug-core was conducted (February 2020). Again, none of the dogs vomited within the one hour of observation following bait consumption.

Following failure of the Apomorphine within the HSDV to induce any vomit response, a trial was conducted (March 2020) with Apomorphine directly dosed into the bait medium. No dogs vomited.

These results show that although Apomorphine was present in the HSDVs at therapeutic levels, it was not sufficiently bio-available to trigger vomiting. The failure to induce emesis may, in part at least, be a result of the Apomorphine being bound up by (complexation with) the excipients of the coating matrix and/or drug-core. However, the non-result from the direct dosing of the attractant with Apomorphine is suggestive that the lack of bio-availability was not necessarily an issue with the HSDV formulation(s) *per se*.

The option under consideration at this stage of development of a *Hisstory*® bait to minimise the risk to canids is use of alternate emetic agents.

3.3 Discussion

In veterinary medicine, Apomorphine is known to induce emesis in dogs but not cats. As such, Apomorphine was selected as the specifically preferred agent for incorporation into the *Hisstory*® HSDV formulation with the aim of minimising the risk to canids (by inducing emesis) yet still being efficacious in cats. In the trials reported here, the failure of the Apomorphine in the coating matrix of the HSDV formulation, core of the HSDV and finally within the bait matrix to induce emesis in captive wild dog trials was unanticipated. Apomorphine was present at therapeutic levels, which suggests that the Apomorphine was not being made available (dispersing) at a rate sufficiently rapid to trigger vomiting.

Progressing the development of feral cat baits with a minimised risk to canids remains an objective, with emesis to avoid intoxication likely the preferred means of achieving this objective. Emesis *per se* entails a series of co-ordinated changes in gastro-intestinal activity arising from 'irritant' and/or neural action (with the former likely resulting in neural activation). Importantly, a number of agents activate either or both mechanisms to act directly on higher centres of the brain, and thus affect the Chemo-Receptor Trigger Zone (CRTZ). In designing and developing a feral cat bait, which aims to minimise the risk to canids, activation of the CRTZ ahead of adsorption of the toxin, is required, i.e. such agent(s) must induce emesis at a rate greater than the rate of adsorption of the toxin. At the same time, such agent(s) must necessarily not be 'adversely affected' by stomach chyme, as appears to have been the case with Apomorphine (these studies). Achieving the former requirement will likely only be achieved with agents acting directly on the gastro-intestinal tract receptors to initiate neuronal activation of the CRTZ.

As indicated above, a number of agents other than Apomorphine, affect gastro-intestinal tract neurones to activate the CRTZ. Apomorphine was selected as the first agent for evaluation because of its known therapeutic use as an emetic in dogs (but having minimal efficacy in cats). However, as indicated, although Apomorphine was present in baits at therapeutic levels, it was not sufficiently bio-available to trigger vomiting. Given this, and that there are definitive difference in physiological and pharmacological attributes between canids and felids reported in the literature, it is proposed that further studies to develop a bait with minimal risk to canids be undertaken. In the short-term, and based on the literature evaluated to date, the focus will be on the range of available histaminergic agents. Differences in histamine receptor type and populations in cats and dogs have been reported (Legeza *et al*. 1984), with, specifically H_1 and H_2 receptors present in dogs, but not cats. As such histamine, and certain of its agonists, may be potent emetics in dogs, but not cats.

Another suggested method of reducing the risk of poisoning wild dog/dingo hybrid populations in specific areas would be to target habitat favoured by cats and that less preferred by wild dogs. However, there is growing evidence (e.g. Stobo-Wilson *et al*. 2020) that there is large overlap in habitat preferences of cats and wild dogs, with the exception of stone country (upland escarpments) where occupancy of wild dogs declines but that of cats increases. Furthermore, both cat and wild dog occupancy are positively influenced by frequent fire and habitat simplification (ibid). Consequently, it is unlikely that effective control of feral cats could be achieved at a landscape-level where wild dog/dingo hybrids are considered an integral component of a broad-scale ecosystem.

References

Algar, D. and Burrows, N.D. (2004). A review of Western Shield: feral cat control research. *Conservation Science Western Australia* **5**, 131–163.

Algar, D., Angus, G.J., Williams, M.R. and Mellican, A.E. (2007). Influence of bait type, weather and prey abundance on bait uptake by feral cats (*Felis catus*) on Peron Peninsula, Western Australia. *Conservation Science Western Australia* **6**, 109–149.

Algar, D., Bell, L., Cowen, S., Onus, M. and Rasmussen, D. (2013). *Eradicat*® Bait distribution from an aircraft. Unpublished Report to Western Shield. Western Australian Department of Parks and Wildlife. 5 pp.

Begg, R.J. (1981). The small mammals of Little Nourlangie Rock, N.T., III, Ecology of *Dasyurus hallucatus*, the northern quoll (Marsupialia: Dasyuridae) *Australian Wildlife Research* **8**, 73–85.

Briggs, H. (1994). Anatomy and Physiology. In: 'Veterinary Notes for Cat Owners'. (Eds. T. Turner and J. Turner.) pp. 111–154 (Random House: London)

Buckmaster, T., Dickman, C.R. and Johnston, M.J. (2014) Assessing risks to non-target species during poison baiting programs for feral cats. PLoS ONE 9(9) e107788. https://doi.org/10.1371/journal.pone.0107788

Burbidge, A.A., McKenzie, N.L. and Kenneally, K.F. (1991). Nature Conservation Reserves in the Kimberley Western Australia. Unpublished Report, Department of Conservation and Land Management, Western Australia.

Calver, M.C., King, D.R., Bradley, J.S., Gardner, J.L., and Martin G.R. (1989). Assessment of the potential target specificity of 1080 predator baiting in Western Australia. *Australian Wildlife Research* **16**, 625–638.

Cook, A. (2010). Habitat use and home-range of the northern quoll, *Dasyurus hallucatus*: effects of fire. Master of Science Thesis in Natural Resource Management. School of Animal Biology, Faculty of Natural and Agricultural Sciences, University of Western Australia.

DE (Department of the Environment) (2015). Threat Abatement Plan for Predation by Feral Cats. Commonwealth of Australia, Canberra

DEWHA (Department of the Environment, Water, Heritage and the Arts) (2008). Threat Abatement Plan for Predation by Feral Cats. Department of the Environment, Water, Heritage and the Arts, Canberra

Eason, C.T., Miller, A., MacMorran, D.B. and Murphy, E.C. (2014). Toxicology and ecotoxicology of para-aminopropiophenone (PAPP)–a new predator control tool for stoats and feral cats in New Zealand. *New Zealand Journal of Ecology*, **38(2)**, 177–188.

EA (Environment Australia) (1999). Threat Abatement Plan for Predation by Feral Cats. Environment Australia, Biodiversity Group, Canberra

Eason, C.T., Murphy, E.C., Hix, S. and Macmorran, D.B. (2010). Development of a new humane toxin for predator control in New Zealand. *Integrative Zoology* **5***,* 31–36.

Fisher, P., O'Connor, C.E. and Morriss G. (2008). Oral toxicity of *p*-aminopropiophenone to Brushtail possums (*Trichosurus vulpecula*), Dama wallable (*Macropus eugenii*), and Mallards (*Anas platyrhynchos*). *Journal of Wildlife Diseases* **44,** 655–663.

Forster, G. (2009). Non-target species uptake of feral cat baits containing Rhodamine B. B. Sci. (Hons) thesis. Department of Agricultural Sciences, Latrobe University, Bundoora, Victoria, Australia.

Frappell, P. (2007) Effect of PAPP on Methemoglobin levels in the Lace monitor, *V. varius*. Adendum to Consultancy Report on the Effect of Para-aminopropiophenone (PAPP) on Blood Properties of Rosenberg's Goanna, *Varanus rosenbergi*. Unpublished.

Frappell, P. and Andrewartha, S. (2006). Consultancy Report on the Effect of Para-aminopropiophenone (PAPP) on Blood Properties of Rosenberg's Goanna, *Varanus rosenbergi*. Unpublished.

Heiniger, J., Cameron, S.F. Gillespie, G. (2018). Evaluation of risks for two native mammal species from feral cat baiting in monsoonal tropical northern Australia. *Wildlife Research* **45**(6), 518–527.

Hetherington, C.A., Algar, D., Mills, H. and Bencini, R. (2007). Increasing the target-specificity of ERADICAT® for feral cat (*Felis catus*) control by encapsulating a toxicant. *Wildlife Research* **34**, 467–471.

Gigliotti, F. (2011). Response of northern Australian wildlife species to non-toxic *Curiosity* baits. Unpublished report for the Department of Sustainability and Environment. DOI: 10.13140/RG.2.2.29846.45125

Jessop, T.S., Kearney, M.R., Moore, J.L., Lockwood, T. and Johnston, M. (2013). Evaluating and predicting risk to a large reptile (*Varanus varius*) from feral cat baiting protocols*, Biological Invasions*, **15**(8), 1653–1663.

Johnston, M. (2010). The development of a humane felid-specific toxin and bait delivery system for feral cat control - final report 2008–10. Heidelberg, Victoria: Arthur Rylah Institute for Environmental Research Client Report, Department of Sustainability and Environment.

Johnston, M., Algar, D., O'Donoghue, M. and Morris, J. (2011). Field efficacy of the Curiosity feral cat bait on three Australian islands. In: Veitch, C.R., Clout, M.N. and Towns, D.R. (eds). Island Invasives: eradication and management. IUCN, Gland, Switzerland, pp 182–187.

Johnston, M., Algar, D., O'Donoghue, M., Morris, J., Buckmaster, T. and Quinn, J. (in press). Efficacy and welfare assessment of an encapsulated para-aminopropiophenone (PAPP) formulation as a bait-delivered toxicant for feral cats (*Felis catus*). *Wildlife Research*

Johnston, M., Bould, L., O'Donoghue, M., Holdsworth, M., Marmion, P., Bilney, R., Reside, A.E., Caldwell, D., Gaborov, R. and Gentles, T. (2014). Field efficacy of the Curiosity® bait for management of a feral cat population at Roxby Downs, South Australia. Arthur Rylah Institute for Environmental Research Technical Report Series No. 253. Department of Environment and Primary Industries, Heidelberg, Victoria.

Johnston, M., Gigliotti, F. and Trezise, J. (2019). Assessing consumption of *Curiosity*® baits by blotched blue-tongued lizards. *The Victorian Naturalist* **136**(6), 203–207.

King, D.R. (1990). 1080 and Australian fauna. Agriculture Protection Board Technical Series No. 8.

Leyhausen, P. and Tonkin, B.A. (1979). *Cat behaviour*. *The Predatory and Social Behaviour of Domestic and Wild Cats*. Garland STPM Press.

Legeza, V.I., Shagoian, M.G., and Kamynina, M.F. (1984). Mechanism of emetic action of adrenaline and histamine in the dog. *Farmakologiia Toksikologiia* **47(3)**,41–43.

Lohr, C.A. and Algar, D. (2020). Managing feral cats through an adaptive framework in an arid landscape. *Science of the Total Environment* https://doi.org/10.1016/j.scitotenv.2020.137631

Marks, C.A., Johnston, M.J., Fisher, P.M., Pontin, K. and Shaw, M.J. (2006). Differential particle size ingestion: promoting target-specific baiting of feral cats. *Journal of Wildlife Management* **70(4)**, 1119–1124.

Marks, C. A., Gigliotti, F. and Busana, F. (2009). Assuring that 1080 toxicosis in the red fox (*Vulpes vulpes*) is humane. II. Analgesic drugs produce better welfare outcomes. *Wildlife Research* **36**, 98–105.

McIlroy, J.C. (1981). The sensitivity of Australian animals to 1080 poison. II Marsupial and eutherian carnivores. *Australian Wildlife Research* **8**, 385–399.

McIlroy, J.C. (1984). The sensitivity of Australian animals to 1080 poison. VII. Native and introduced birds. *Australian Wildlife Research* **11**, 373–385.

McIlroy, J.C., King, D.R., and Oliver, A.J. (1985). The sensitivity of Australian animals to 1080 poison. VIII. Amphibians and reptiles. *Australian Wildlife Research* **12**, 113–118.

McLeod, L. and Saunders, G. (2013). Pesticides used in the Management of Vertebrate Pests in Australia: A Review. Published by the NSW Department of Primary Industries.

Morris, K., Cowan, M., Angus, J., Anderson, H., Garretson, S., Palmer, R., Williams, M. and Pearson, D. (2016) Baseline monitoring for northern quoll and Rothschild's rock-wallaby at *Eradicat®* baited and unbaited sites, Pilbara Region WA. Department of Parks and Wildlife, Perth.

NWR (2006). New canid toxicant. PAPP non-target hazard assessment: Data summary and interpretation (Volume 1 of 3). Progress Report 4: EC470. East Malvern, Victoria, Nocturnal Wildlife Research Pty Ltd.

Oakwood, M. (2000). Reproduction and demography of the northern quoll, *Dasyurus hallucatus*, in the lowland savanna of northern Australia. *Australian Journal of Zoology*, ***48*(5)**, 519–539.

Oakwood, M. and Miles, G.L. (1998) Predation of a marsupial carnivore by an olive python (*Liasis olivaceus*) and a king brown snake (*Pseudechis australis*). Herpetofauna **28(1)**, 19–21.

O'Donnell, S., Webb, J.K. and Shine, R. (2010). Conditioned taste aversion enhances the survival of an endangered predator imperilled by a toxic invader. *Journal of Applied Ecology* ***47*(3)**, 558–565.

Robinson, S. (2010). Assessment of the potential of wildlife species to a bait delivered toxicant developed for feral cat control using a non-toxic bait marker. Appendix 2 in Johnston, M (2010). The development of a humane toxin and bait delivery system for feral cat control - final report 2008–10. Arthur Rylah Institute for Environmental Research client report, Report to the feral cat toxicant and bait development team. Heidelberg, Victoria: Department of Sustainability and Environment.

Schmitt, L.H., Bradley, A.J., Kemper, C.M., Kitchener, D.J., Humphreys, W.F. and How, R.A. (1989). Ecology and physiology of the northern quoll, *Dasyurus hallucatus* (Marsupialia, Dasyuridae), at Mitchell Plateau, Kimberley, Western Australia. *Journal of Zoology*, **217**, 539–558.

Sharp, T. and Saunders, G. (2011). A model for assessing the relative humanness of pest animal control methods (Second edition). Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, ACT. New Millennium Print.

Stobo-Wilson, A.M., Stokeld, D., Einoder, L.D., Davies, H.F., Fisher, A., Hill, B.M., Mahney, T., Murphy, B.P., Stevens, A., Woinarski, J.C.Z., Djelk Rangers, Warddeken Rangers and Gillespie, G.R. (2020). Habitat structural complexity explains patterns of feral cat and dingo occurrence in monsoonal Australia. Diversity and Distributions, DOI: 10.1111/ddi.13065.

Twigg, L.E. (1994). The occurrence of fluoroacetate in Australian plants and tolerance to 1080 in indigenous Australian animals. In: Proceedings of the science workshop on 1080. (Eds. A.A. Seawright, and C.T. Eason). The Royal Society of New Zealand, Miscellaneous Series 28. 178 pp.

Twigg, L.E., Martin, G.R., Eastman, A.F., King, D.R. and Kirkpatrick, W.E. (2003). Sensitivity of some Australian animals to sodium fluoroacetate (1080): additional species and populations, and some ecological considerations. *Australian Journal of Zoology* **51**, 515–531.

Woinarski, J.C.Z., Armstrong, M., Brennan. K., Fisher, A., Griffiths, A.D., Hill, B., Milne, D.J., Palmer, C., Ward, S., Watson, M. and Winderlich, S. (2010). Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia. *Wildlife Research* **37(2),** 116–126.

Woinarski, J.C.Z., Burbidge, A.A. and Harrison, P.L. (2014). The Action Plan for Australian Mammals 2012. CSIRO Publishing Australia.

Woinarski, J.C.Z., Burbidge, A.A. and Harrison, P.L. (2015). Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences of the United States of America* **112**, 4531–4540.

Appendix. Northern quoll captures at Mt Hart, 2017.

Date	Trap No.	Northing	Easting	Collar Frequency	Trap Type	Sex	*New/ Re-capture/ Re-trap	Personal Identification Transponder	Weight (g)	Pouch comments
2-Aug	T02	8143165	704425	151.542	Elliott	F	R	6000139526	280	
2-Aug	T09	8143367	704469	151.223	Elliott	M	N	00076ff384	550	
3-Aug	T02	8143165	704425	151.343	Elliott	M	N	000769b94b	600	
3-Aug	T03	8143196	704446	151.542	Elliott	F	RT	6000139526	320	
3-Aug	T04	8143220	704447	151.223	Elliott	M	RT	00076ff384	530	
3-Aug	T06a	8143303	704454	151.301	Cage	M	R	6000142584	340	
3-Aug	T07	8143313	704463	151.462	Elliott	M	N		480	
3-Aug	T07a	8143329	704459	151.604	Cage	M	N	000768a9dc	280	
3-Aug	T08	8143337	704449	151.582	Elliott	F	R	6000138850	350	
3-Aug	R01	8143181	704861	151.381	Cage	M	N	000769bbec	370	
3-Aug	R03	8143199	704919	151.443	Cage	F	N	00076fefdd	240	
3-Aug	R05	8143202	704984		Cage	F	N	000768aa12	240	
3-Aug	R06	8143218	705014	151.262	Cage	F	N	000769b7c5	300	
3-Aug	R07	8143251	705023	151.563	Cage	M	N	000769b345	370	
3-Aug	R14	8143280	705179	151.361	Cage	F	N	00076ff475	420	
3-Aug	R20	8143272	705019	151.421	Cage	M	N		520	
4-Aug	T07a	8143329	704459	151.301	Cage	M	RT	6000142584	320	
4-Aug	T08	8143337	704449	151.281	Elliott	M	N	000769900a	530	
4-Aug	T09	8143367	704469	151.503	Elliott	F	N	0007696ce2	340	
4-Aug	T11	8143439	704472		Elliott	F	R	6000137885	390	
4-Aug	T14	8143543	704439	151.524	Elliott	M	N	000768B2aa	390	
4-Aug	T15	8143572	704452	151.483	Elliott	F	N	000768ac05	330	
4-Aug	R01	8143181	704861		Cage	F	N	000769b927	230	
4-Aug	R02	8143180	704887	151.323	Cage	M	R	6000143821	460	
4-Aug	R03	8143199	704919	151.381	Cage	M	RT	000769bbec	430	

4-Aug	R04	8143204	704950	151.241	Cage	M	N	000768a6a7	590	
4-Aug	R07	8143251	705023		Cage	F	RT	000768aa12	210	
4-Aug	R08	8143284	705027	151.421	Cage	M	RT		630	
4-Aug	R09	8143323	705046	151.402	Cage	M	N	00076961b4	350	
4-Aug	R13	8143259	705174		Cage	M	N	000769af6a	370	
4-Aug	R14	8143280	705179		Cage	F	N	000769b6cc	270	
4-Aug	R16	8143306	705113		Cage	M	N		390	
4-Aug	R19	8143309	705017		Cage	M	N	0007699078	460	
20-Sep	Q03	8143226	704464	151.542	Elliott	F	R	6000139526	340	8PY; CR 15 mm
20-Sep	Q03	8143226	704464		Elliott	M	N	000769c330	300	
20-Sep	Q04	8143251	704466	151.582	Elliott	F	R	6000138850	280	8PY; CR 19 mm
21-Sep	Q03	8143226	704464	151.343	Elliott	M	R	000769694b	650	
21-Sep	T06a	8143303	704454		Elliott	F	RT	6000138850	290	
21-Sep	T07	8143313	704463	151.604	Elliott	M	R	000768a9dc	270	
22-Sep	T07	8143313	704463		Elliott	F	R	6000137885	370	no PY; small red teats
22-Sep	T09	8143367	704469		Elliott	F	RT	6000138850	340	
22-Sep	T13	8143504	704456	151.483	Elliott	F	R	000768ac05	350	8PY; CR 11 mm
23-Sep	R01	8143181	704861		Elliott	F	R	000768aa12	240	8PY; CR 18 mm
23-Sep	R03	8143199	704919	151.443	Elliott	F	R	00076fefdd	280	8PY; CR 21 mm
23-Sep	R04	8143204	704950		Elliott	M	RT	000769b94b	620	
23-Sep	R09	8143323	705046		Elliott	M	N	000769b677	460	
24-Sep	R01	8143181	704861		Elliott	M	RT	000769b94b	610	
24-Sep	R05	8143202	704984	151.262	Elliott	F	R	000769b7c5	280	8PY; CR 20 mm
24-Sep	R07	8143251	705023		Elliott	M	RT	000769b677	430	
24-Sep	R20	8143272	705019		Elliott	F	RT	00076fefdd	320	

***New** is defined as an individually not previously caught, **Re-trap** is an individual that has been caught previously during this trapping session and **Re-capture** is an individual that has been caught on a previous trapping trip, (i.e. in April I. Radford).