PUBLISHING

RESEARCH ARTICLE
https://doi.org/10.1071/WR25178

WILDLIFE RESEARCH

Field comparison of three restraint techniques for deploying GPS collars on wild pigs (*Sus scrofa*)

Andrew J. Bengsen[A,*], Stuart J. Dawson[B,C], Sebastien Comte[D,E], Peter J. Adams[B,C], Darren Marshall[F], Lachlan Marshall[F], Troy Crittle[G], Lee Parker[A], Sierra Oakley[H] and Jordan O. Hampton[B,H,I]

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

***Correspondence to:**
Andrew J. Bengsen
NSW Department of Primary Industries and Regional Development, Vertebrate Pest Research Unit, 4 Marsden Park Road, Calala, NSW 2340, Australia
Email: andrew.bengsen@dpird.nsw.gov.au

Handling Editor:
Lyn Hinds

Received: 20 November 2025
Accepted: 25 April 2026
Published: 18 May 2026

Cite this: Bengsen AJ *et al.* (2026) Field comparison of three restraint techniques for deploying GPS collars on wild pigs (*Sus scrofa*). *Wildlife Research* **53**, WR25178. doi:10.1071/WR25178

ABSTRACT

Context. Spatial behaviour research involving GPS tracking is increasingly being used to support the management of wild (including feral) pigs (*Sus scrofa*) around the globe. Capturing and collaring pigs can have severe impacts on their health and welfare, but the implications of different capture and restraint methods practiced in large-scale studies remain unclear. **Aims.** We compared the effectiveness and animal welfare outcomes of three methods for restraining wild pigs for GPS collar deployment: (1) remote darting with tiletamine-zolazepam and xylazine (TZX), (2) pole syringe injection with tiletamine-zolazepam (TZ), and (3) manual restraint without chemical immobilisation. **Methods.** We retrospectively analysed data from 360 collaring events across three independent collaring programs in Australia. We quantified the durations of procedures, the frequency of adverse events (e.g. hyperthermia, mortality), and post-release movement patterns using a standardised animal welfare assessment framework. **Key results.** Manually restrained pigs experienced the shortest exposure to capture and handling stressors, and showed no increase in adverse outcomes compared to chemically immobilised pigs. Pigs darted with TZX had more variable induction and recovery times than those administered TZ via pole syringe, but the use of reversal agents (yohimbine, atipamezole) reduced overall handling time. Pole syringe immobilisation with TZ produced more consistent inductions but longer recumbency durations. Post-release movement patterns were similar across all methods, with minor behavioural disruptions for about 4 days. **Conclusions.** Manual restraint is a viable option for telemetry studies where experienced handlers are available and extended procedures are not required. When chemical immobilisation is desirable, animal welfare outcomes can be improved by using drug combinations with reversal agents and by applying careful monitoring and intervention. **Implications.** These findings support evidence-based refinement of wild pig capture protocols and highlight the importance of publishing animal welfare outcomes to inform best practice in wildlife research and management.

Keywords: animal welfare, capture protocols, darting, invasive species, Judas technique, sedation, stress, telemetry collar, wildlife handling.

Introduction

Wild pigs (including feral pigs and wild swine, hogs, or boar [*Sus scrofa*]) are one of the world's most widespread and damaging invasive mammals. In recent decades, their range has expanded rapidly, both within their introduced ranges (where domestic pigs have established feral populations) and within the native range of wild boar in Europe (Barrios-Garcia and Ballari 2012). As their disruptive influence on ecosystems and agriculture grows, so too does the need for effective management strategies (VerCauteren *et al.* 2024). One increasingly popular tool to support pig control efforts is remote telemetry, which offers valuable insights into the spatial ecology of wildlife, especially in novel or changing environments (Matthews *et al.* 2013). A recent flurry of publications describing pig collaring programs in Australia is evidence of the growing popularity of this approach (Bengsen *et al.* 2025; Kelly *et al.* 2025; Proboste *et al.* 2025; Smith *et al.* 2025).

Spatial information gained from telemetry studies of wild pigs can be used to identify areas and habitat features where population control efforts should be most effective (Wilson *et al.* 2023*a*), predict optimal intensities for deploying control efforts (Wilson *et al.* 2024), and to dispel misconceptions that can prevent resource managers from taking effective action to control pigs (Mitchell *et al.* 2009). More recently, the emergence of One Health frameworks (Ghai *et al.* 2022) has prompted researchers to examine the implications of wild pig spatial and social dynamics for disease transmission risks (Proboste *et al.* 2025), and to examine responses to biosecurity interventions such as aerial shooting (Bengsen *et al.* 2025; Kelly *et al.* 2025). Telemetry is also central to the 'Judas pig' technique, in which collared pigs are used to locate groups of conspecifics to improve the efficiency of control efforts at low population densities (Taylor and Katahira 1988; McIlroy and Gifford 1997).

Deploying telemetry devices on wild animals often requires chemical restraint to ensure safe handling and optimised animal welfare impacts (Kreeger *et al.* 2023). However, the act of capturing and immobilising animals can have significant consequences for their behaviour, physiology and survival (Cattet *et al.* 2008; Brogi *et al.* 2019). As a result, there is growing scrutiny of the welfare impacts associated with both chemical immobilisation and the use of tracking devices (McMahon *et al.* 2011; McMahon *et al.* 2012; Mayberry *et al.* 2014). Importantly, not all immobilisation methods are equal; different drug combinations and delivery techniques can vary widely in their effects on animal welfare (Ellis *et al.* 2019).

A wide variety of methods for capturing and restraining wild pigs have been used, and current standards include methods that are sometimes considered unconventional or controversial (e.g. Sharp 2012; USDA APHIS 2021). Unconventional capture methods have included 'dogging', the pursuit and containment of pigs using trained dogs (McIlroy and Saillard 1989), including the deployment of dogs and human handlers from helicopters (Anderson *et al.* 2022), as well as physical restraint without drugs (Campbell *et al.* 2012). Unconventional telemetry methods include the use of harnesses instead of collars (McIlroy 1989; Gaston *et al.* 2008; Fischer *et al.* 2016; Theuerkauf *et al.* 2022), and glued pelt tags or ear tags (Kunnasranta *et al.* 2024). This variation complicates efforts to identify best practices and underscores the need for improved reporting and standardisation.

Internationally, most chemical immobilisation protocols for wild pigs involve combinations of tiletamine-zolazepam (TZ), xylazine, medetomidine, and ketamine (e.g. Fournier *et al.* 1995; Ellis *et al.* 2019; Morelli *et al.* 2021) (Table 1). Tiletamine and ketamine are dissociative anaesthetics, while xylazine and medetomidine are α-2 adrenoceptor agonists (α-2 agonists; Kreeger *et al.* 2023). While TZ is generally safe and effective, its lack of a reversal agent can lead to prolonged recovery times (Arnemo 2004; Mayberry *et al.* 2014; McGregor *et al.* 2016). Xylazine and medetomidine, often used to achieve sedation, can be reversed with antagonists such as atipamezole, tolazoline or yohimbine, offering greater control over recovery. The use of an additional sedative also allows for a lower TZ dose, enabling a more rapid recovery than would be possible with TZ alone (Cattet *et al.* 1999). However, both of these α-2 agonists carry risks of adverse cardiovascular effects including bradycardia, hypertension and peripheral vasoconstriction, which can cause hypoxaemia and inhibit thermal regulation (Kästner 2006; Lee *et al.* 2010; Einwaller *et al.* 2022). Both TZ and TZ with xylazine (TZX) are widely used for immobilising suids because they are readily available and simple to administer in the field, relative to other chemical treatments which may have more favourable outcomes with respect to recovery quality and post-recovery morbidity and mortality (Ellis *et al.* 2019). In the Australian context, the registered form of TZ (Zoletil$^{®}$) and all registered preparations of xylazine and medetomidine are Schedule 4 medicines (Therapeutic Goods Administration 2024). Many alternative chemicals used for immobilisation (e.g. most opioids) are Schedule 8 medicines, and therefore controlled drugs (Zabek *et al.* 2015).

Ultimately, the reliability of telemetry data depends on animals remaining healthy and returning to normal behaviour after release. Factors such as handling time, drug regime, and capture technique are known to influence animal behaviour following capture and collaring (Brogi *et al.* 2019; Stiegler *et al.* 2024), but species-specific responses remain poorly understood. To address this gap, the present study compares the effectiveness and welfare outcomes associated with three methods used to restrain and collar trapped wild pigs.

Using the animal welfare assessment framework proposed by Hampton *et al.* (2016), we evaluate procedure durations and adverse event frequencies across three restraint approaches: remote darting with TZX, pole syringe injection with TZ, and manual restraint. We also assess post-release movement patterns to determine whether capture method influences spatial behaviour in the weeks following release. We conclude with recommendations to improve both the outcomes of interventions involving restraint of wild pigs, and the value of future studies for continuing to advance the consideration of animal welfare in research activities.

Materials and methods

Study areas

Data were collected retrospectively from ecological research projects that deployed GPS tracking collars on feral pigs at multiple sites across Australia. All Australian wild pig populations have originated from the release or escape of domestic pigs (Bengsen *et al.* 2017). Study animals will therefore be referred to as feral pigs hereafter. Projects were grouped into one of three programs based on the capture methods used. Program A involved remote chemical immobilisation using a

Table 1. Chemical immobilisation regimes applied to wild pigs that are described in the published literature, ordered from most to least recent.

Country	Drugs	Doses (mg/kg)	Animal demeanour	Route of administration	Sample size (*n*)	Reference
Australia	None – manual restraint	NA	Free-ranging animals caught in traps	NA	73	Bengsen *et al.* (2025)
Australia	Tiletamine-zolazepam	4.0	Free-ranging animals caught in traps	Syringe pole	16	Bengsen *et al.* (2025)
Australia	Tiletamine-zolazepam	1.0*	Free-ranging animals caught in traps	Syringe pole	59–72	Wilson *et al.* (2023*a*), Kelly *et al.* (2025)
Finland	Medetomidine	0.11	Free-ranging animals caught in traps	Dart pistol	17	Miettinen *et al.* (2023)
	Tiletamine-zolazepam	3.75				
	Ketamine	1.5				
New Zealand	None – manual restraint	NA	Free-ranging animals caught with dogs from helicopters	NA	15	Anderson *et al.* (2022)
France (New Caledonia)	Xylazine	3.4	Free-ranging animals caught in traps	Syringe pole	3	Theuerkauf *et al.* (2022)
France	Medetomidine	0.15	Free-ranging animals caught in traps	Syringe pole	7	Morelli *et al.* (2021)
	Ketamine	5.0				
France	Medetomidine	0.2	Free-ranging animals caught in traps	Syringe pole	7	Morelli *et al.* (2021)
	Tiletamine-zolazepam	2.0				
France	Medetomidine	0.1	Free-ranging animals caught in traps	Syringe pole	7	Morelli *et al.* (2021)
	Ketamine	5.0				
	Butorphanol	0.2				
United States	Medetomidine	0.06	Captive animals	Hand injection	14	Ellis *et al.* (2019)
	Midazolam	0.3				
	Butorphanol	0.3				
United States	Butorphanol	0.72	Captive animals	Hand injection	14	Ellis *et al.* (2019)
	Azaperone	024				
	Medetomidine	0.27				
United States	Xylazine	2.5	Captive animals	Hand injection	6	Ellis *et al.* (2019)
	Tiletamine-zolazepam	4.4				
United States	Xylazine	1.8	Free-ranging animals caught in traps	Dart rifle	148	Lavelle *et al.* (2019)
	Tiletamine-zolazepam	3.6				
United States	Tiletamine-zolazepam	0.04**	Free-ranging animals caught in traps	Dart rifle	21	Fischer *et al.* (2016)
Australia	Xylazine	2.2	Free-ranging animals caught in traps	Syringe pole	12	Shapiro *et al.* (2016)
	Tiletamine-zolazepam	4.0				
Spain	Medetomidine	0.05	Free-ranging animals caught in traps	Blowpipe dart	42	Barasona *et al.* (2013)
	Tiletamine-zolazepam	3.0				
United States	Xylazine	2.2	Free-ranging animals caught in traps	Syringe pole	49	Gabor *et al.* (1997)
	Tiletamine-zolazepam	2.2				
United States	Xylazine	3.3	Free-ranging animals caught in traps	Blowpipe dart	144	Sweitzer *et al.* (1997)
	Tiletamine-zolazepam	1.7				
New Zealand	Xylazine	15.0***	Free-ranging animals caught in traps or with dogs	Hand injection	7	McIlroy (1989)
	Ketamine	15.0				
United States	Xylazine	4.9–9.8	Free-ranging animals caught in traps	Syringe pole	44	Baber and Coblentz (1982)
	Ketamine	4.9–9.8				
New Zealand	Unknown neuroleptics	Unknown	Free-ranging animals caught in traps	Unknown	21	Martin (1975)

*The reported dose was incorrect. When we calculated the actual dose that pigs received, it was much higher (3.6 mg/kg, see the Discussion).
**The reported dose is very likely to be incorrect. This was queried with the corresponding author and clarified to be actually 4.3 mg/kg (1.0 mL of 100 mg/mL tiletamine-zolazepam per kg).
***The reported dose is very likely to be incorrect. This would be an extraordinarily high dose to give to an animal.

dart rifle or blowpipe to administer TZX to the animals. These captures occurred in Victoria and Western Australia (WA). Program B used a pole syringe ('jab pole') for direct chemical immobilisation with TZ alone. These captures occurred in Queensland and New South Wales (NSW). Program C involved manual restraint without chemical immobilisation and was conducted in NSW (Fig. 1).

In WA, data were collected from four general regions during Program A studies: the southwest, northern wheatbelt, the Gascoyne, and the Kimberley. The southwest sites were primarily located in state-managed forests near Perth and Northcliffe (Hampton *et al.* 2004). Northern wheatbelt sites were situated in a landscape of agricultural land and native vegetation (see Twigg *et al.* 2007). The Gascoyne site was located on a semi-arid pastoral station, while the Kimberley site was on a tropical pastoral station. Program A sites in far-eastern Victoria were characterised by *Eucalyptus* woodlands and cypress pine (*Callitris glaucophylla*) forests within the national parks of the lower Snowy River Valley (Pulsford 1991). Program B and C sites occurred on private properties used for livestock production or conservation throughout NSW, typically characterised by mosaics of either *Eucalyptus* woodlands and grasslands or lignum (*Duma florulenta*) scrub and Acacia shrublands (Wilson et al. 2023*b*; Bengsen *et al.* 2025). Ambient temperatures measured on site at the time of collaring ranged from 6 to 30°C in Program A, from 6 to 43°C in Program B, and from 12 to 38°C in Program C.

Feral pigs were captured and collared for ecological and behavioural research studies conducted between April 2012 and February 2025 under AEC licences RW2694/14 (Murdoch University Animal Ethics Committee), 11/16 and 13/07 (Arthur Rylah Institute Animal Ethics Committee), 17-4-08 and 22-3-12 (WA DPIRD Animal Ethics Committee), AEC 16-115 and AEC 20-023 (University of New England Animal Ethics Committee), and OAEC-0702 and ORA 21/24/003 (NSW DPI Orange Animal Ethics Committee).

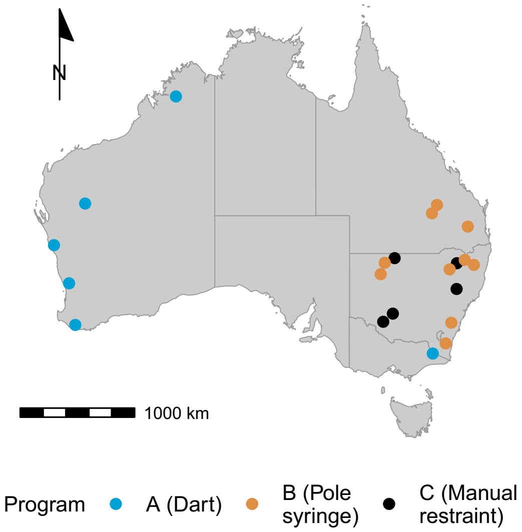

Fig. 1. Locations of study sites in which feral pigs were restrained for GPS collaring using chemical immobilisation delivered via dart (Program A), pole syringe (Program B), or with manual restraint only (Program C), between 2012 and 2025.

Trapping, chemical immobilisation, and anaesthesia

Pigs were captured in steel mesh traps typical of Australian studies (Pearson *et al.* 2014; Wilson *et al.* 2023*b*), consisting of a 'Figure 6' or panel trap (Waudby *et al.* 2022), a 'Matlock' trap (Smith 2018), or a Pig Brig® passive net trap (Field Engine Wildlife Research and Management LLC; Connecticut, USA) (Waudby *et al.* 2022).

In Program A, immobilisation chemicals were delivered via a dart rifle (DanInject JM Special, DanInject, Kolding, Denmark) or blowpipe (Teledart remote injection blowpipe KitB16, Teledart, Westheim, Germany). Trapped pigs were approached quietly on foot and darted from outside the trap (less than 10 m; Fig. 2*a*). For all animals, the intended dart administration site was the rump, and the intended injection route was intramuscular. The blowpipe fired 1.0-mL pressurised darts, fitted with 1.25-inch (3.8-cm) plain (non-barbed) needles. The dart rifle fired 2.5-mL pressurised darts, fitted with 1.25-inch (3.8-cm) barbed needles (all barbs were trimmed to a maximum length of 2–3 mm). The immobilising agents used were xylazine (100 mg/mL; Ilium Xylazil-100®; Troy Laboratories, NSW, Australia), combined with TZ (Zoletil® 500 mg freeze-dried powder; Virbac, Australia). Prior to darting, the body weight of each animal was visually estimated and all animals received an intended dose of approximately 2.0 mg/kg of each (Gabor *et al.* 1997). Once an animal had been darted, the operators moved away to reduce stress during induction while maintaining visual contact (Fig. 2*b*).

Once recumbent, feral pigs were approached quietly on foot. Animals were blindfolded with a blanket to reduce visual stimulation and to prevent potential injury to their eyes. Collars were fitted as quickly as possible while animals were maintained in lateral recumbency (Fig. 2*c*). Active cooling was achieved through cold water dousing (Fig. 2*c*), as recommended by past studies (Sawicka *et al.* 2015). Following completion of processing, the xylazine was antagonised via intramuscular injection of either yohimbine (mean 0.12 mg/kg per animal at 10 mg/mL; Reverzine®; Bayer Animal Health, NSW, Australia), or atipamezole (mean 0.17 mg/kg per animal at 5 mg/mL; Atipamezole®, Troy Laboratories). Where possible, anaesthetic monitoring of physiological parameters was performed immediately after lateral recumbency was achieved and then approximately every 10 min until the animal was standing. Heart rate was recorded by auscultation; respiratory rate by counting chest excursions; and body temperature by a thermometer placed 2–3 cm into the rectum.

Program B used a 10-mL pole syringe (Paxarms, Timaru, New Zealand; Fig. 3) to deliver an intramuscular injection

Fig. 2. Sequential steps followed for deployment of telemetry collars on Australian feral pigs (*Sus scrofa*) via darting with tiletamine-zolazepam and xylazine between 2012 and 2025: (*a*) darting method, (*b*) hindlimb darting site, (*c*) water dousing for active cooling and (*d*) anaesthetic recovery.

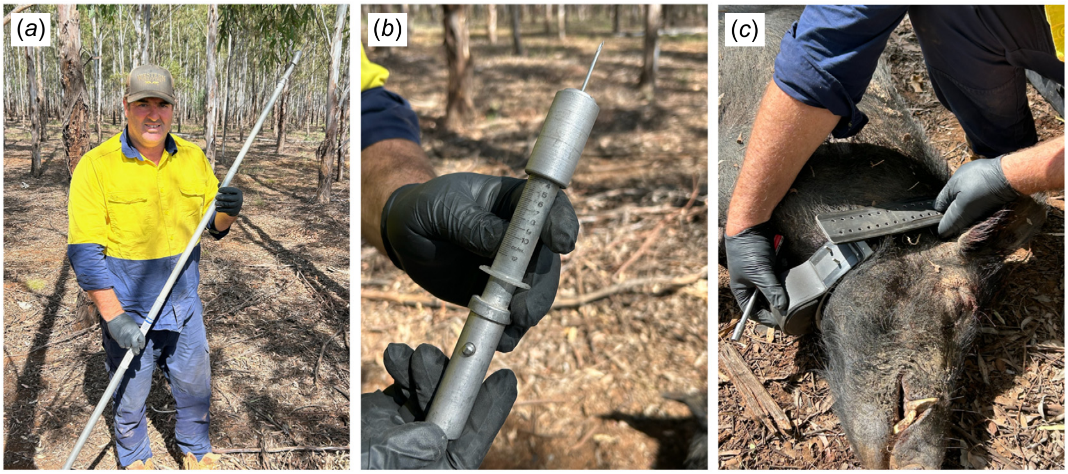

Fig. 3. Equipment used for deployment of telemetry collars on Australian feral pigs (*Sus scrofa*) via pole syringe injection of tiletamine-zolazepam between 2020 and 2024; (*a*) pole syringe, (*b*) detail of syringe mounted on pole, and (*c*) Lotek collar being fitted to an immobilised pig.

of TZ (Zoletil® 500 mg freeze-dried powder) at an intended dose of 4.0 mg/kg (erroneously reported as 1.0 mg/kg; Wilson *et al.* 2023*a*, 2023*b*; Kelly *et al.* 2025), based on visual estimation of each animal's body weight. All pigs were injected in the rump except for two that were injected in the neck.

Manual restraint

Pigs that were not chemically immobilised (Program C) were secured inside the trap using a snout rope which was often attached to the pig using a hook on a pole. Once a pig was snout-roped, the rope was tied closely to the side of the trap, leaving little freedom of movement (Fig. 4*c*). Once all pigs selected for collaring were secured within the trap, any remaining pigs were allowed to leave through the trap gate or an opened panel. Pigs selected for collaring were then released from the trap one at a time by loosening the rope from the trap and allowing them to leave, whereupon one of their back legs was seized by an experienced feral pig handler

Fig. 4. Sequential steps followed for deployment of telemetry collars on Australian feral pigs (*Sus scrofa*) via manual restraint between 2021 and 2025:(*a*) capture inside the trap using a snout rope, (*b*) collar fitting, (*c*) a collared pig tied to the side of the trap prior to being safely released, and (*d*) cooling with water prior to release.

and the pig was tipped onto its side. A second handler sometimes assisted with tipping large pigs by grasping a front leg. Once recumbent, the pig was restrained by the handler with pressure on the upper shoulder and rump, being careful to avoid limiting the chest excursions (Fig. 4*b*). The head was then covered with a bag or cloth while the snout rope was removed, and a collar and ear tag were fitted by two other handlers. Body temperature was recorded using a digital thermometer inserted 2–3 cm rectally. Pigs were released as soon as possible once the collar was fitted. For large, aggressive males, the snout rope was often left in place during collaring so that the pig could be guided back into the trap and allowed to wander away once all handlers were at a safe distance (Fig. 4*c*).

Collar design and dimensions

Two collar types were used in Program A: a custom model provided by Telemetry Solutions (California, USA) and Lotek Iridiumtrack Heavy Duty 3D collars (Ontario, Canada). Collar straps were 50–80 cm in circumference. Collar straps were leather with foam padding, contoured with vertical elongation. Program B also used Lotek Iridiumtrack Heavy Duty 3D collars. Program C used Lotek Litetrack Iridium 750 PB+ collars (wild boar package), with foam-padded synthetic webbing straps ranging between 50 and 65 cm in circumference. Across all programs, all collars weighed ≤1.1 kg, representing <4.5% of the mass of the smallest pig collared (26 kg).

Duration parameters

We quantified induction time (IT), recumbent time (RT), and total time (TT) for each pig (Hampton *et al.* 2016). For manually restrained pigs in Program C, we also recorded latent time (LT), which was defined as the period between the trapping team arriving at the trap and the pig being restrained on the ground. For chemically immobilised pigs, we defined IT as the period between initial administration of the immobilising agent and the onset of effective immobilisation, and RT as the time from initial recumbency to the return to standing. There was no IT for manually restrained pigs as no drugs were administered. RT for manually restrained pigs was defined as the period between restraint on the ground and release, which equated to the time required to safely restrain the pig and complete all procedures. For all pigs, TT was defined as the cumulative total duration of all procedures: IT + RT (Ponjoan *et al.* 2008). For manually restrained pigs, we calculated a second TT that included the latent period (TT_L = LT + RT). Durations of IT, RT and TT were characterised for each program and capture method using Kaplan–Meier survival functions (Kaplan and Meier 1958), which were implemented using the survival package (v 3.7-0; Therneau 2024) for R (R Core Team 2024). To assess the extent to which warmer temperatures may have contributed to prolonged recovery in chemically immobilised pigs, we used linear regression to estimate the relationships between ambient temperature and RT for pigs in Programs A and C.

Mortality, hyperthermia and repeat darting

We quantified the frequency or proportion of several adverse events associated with darting (following Hampton *et al.* 2016). For each program we used logistic regression to estimate: (1) immediate mortality rate (the proportion of animals that died during capture); (2) post-procedural mortality rate (the proportion of animals that died from causes other than deliberate culling or vehicle collisions within 14 days of capture); and (3) hyperthermia rate (the proportion of animals with mean rectal body temperature >40.0°C; Ozeki *et al.* 2015). For Program A, we also quantified the proportion of feral pigs that required more than one dart for effective immobilisation (repeat darting rate; Hampton *et al.* 2016) and the frequency of darts missing target zones (rump and neck). Finally, we used linear regression to estimate the relationship between RT and body temperature for each method. We were unable to compare other potential adverse effects of handling, such as physical injuries or physiological stress, due to inconsistencies in data collection among the three independent programs. All regression models were fitted using JAGS (Plummer 2003) called via the runjags package (v2.2.2-1.1; Denwood 2016) in R (R Core Team 2024), using four chains of 15,000 draws, after discarding 5000 burn-in draws. Model convergence and adequacy were assessed by inspecting trace plots, density plots, effective sample sizes, and the Gelman–Rubin statistic (Brooks and Gelman 1998).

Post-release movements

The GPS collar settings varied among sites, with the frequency of location fixes ranging from 5 min to 1 h. To standardise the comparison of pig movement patterns after release, we thinned all location fix histories to hourly intervals. We removed any location with a dilution of precision >5, to eliminate potentially unreliable location data (Bjørneraas *et al.* 2010). GPS fixes recorded prior to the animal's release were discarded, and tracking data were restricted to the first 30 days post-release, beyond which capture effects were considered negligible. Only data from animals with at least 27 days of tracking and a location fix success rate above 70% were included in the analysis.

We fitted a continuous time movement model (ctmm) to each animal's tracking data (Calabrese *et al.* 2016) and used the fitted model to simulate trajectories for missing GPS fixes, creating regular hourly trajectories (Fleming *et al.* 2018). For each animal, we then calculated two metrics: the distance between successive hourly location fixes (step length, in m), and the distance from each location fix to the release site (defined as the first GPS fix in the tracking dataset, also in m).

For both movement metrics, we expected a non-linear trend over time with higher variability in the early days post release before animals eventually returned to normal activity patterns. We also expected the three treatments to influence the pigs' post-release movements. We therefore fitted negative binomial general additive mixed models (Wood 2017) for each metric (step length and distance to release site) with treatment-specific means and smooth term (cubic splines, $n = 3$) across the 30 days of tracking data. We included site as a random effect (mean and smooth term). We used the *gam.check* function to assess model convergence and goodness of fit (K-index close to 1; Wood 2017). All spatial data processing and model fitting was done in R v4.4.1 using the packages ctmm (v1.2.1, Calabrese *et al.* 2016), move (v4.2.6, Kranstauber *et al.* 2024) and mgcv (v1.9-1, Wood 2011).

Results

Collaring events were recorded for 114 feral pigs in Program A (TZX darting), 155 pigs in Program B (TZ pole syringe), and 91 pigs in Program C (manual restraint). LT for manually restrained pigs, prior to restraint, ranged from <1 to 64 min (median = 12.7 min). Median IT did not differ between pigs chemically restrained by darting in Program A (4 mins; 95% CI = 4, 5 min) or by pole syringe in Program B (4 min; 95% CI = 3, 4 min), although only pigs darted in Program A had an IT > 20 mins ($n = 7$, max IT = 53 min, Fig. 5). RT were shorter for manually restrained pigs in Program C (median = 4 min; 95% CI = 3, 5 min) than for chemically immobilised pigs in Programs A (median = 52 min; 95% CI = 48, 57 min) or B (median = 65 min, 95% CI = 63, 70 min). Most pigs (73%) in Program A were sufficiently recovered from immobilisation to leave the site within 1 h, but only 27% of pigs in Program B had recovered within 1 h. A similar pattern was apparent with total time: pigs in Program C had a much shorter TT (median = 4 min; 95% CI = 3, 5 min) than those in Program A (median = 60 min, 95% CI = 55, 63 min), which was shorter than those in Program B (median = 70 min, 95% CI = 66, 74 min). Total time for pigs in Program C remained much shorter than for chemically immobilised pigs when LT was included (median TT_L = 18 min, 95% CI = 16, 20 min).

Linear regression identified a slight positive relationship between ambient temperature and RT for pigs that were immobilised with TZ in Program B. Expected RT increased by 0.9 min (95% highest posterior density interval [HPDI] = 0.2, 1.5 min) with every 1°C increase in ambient temperature. No similar relationship was identified for TZX pigs in Program A (slope = 0.09, 95% HPDI = −1.1, 1.4).

The immediate mortality rate for pigs darted in Program A was 0.01 (95% HPDI = 0.00, 0.03). The one pig that died during capture was darted in the rump with a single dose of TZX and strongly resisted immobilisation before being collared and dying during recovery. No pigs in Programs B or C died during capture, but two pigs in Program B and one in Program C died within 24 h of being released (post-procedural mortality rate for each program = 0.01, 95% HPDI = 0.0, 0.03). Excluding those pigs that died as a result

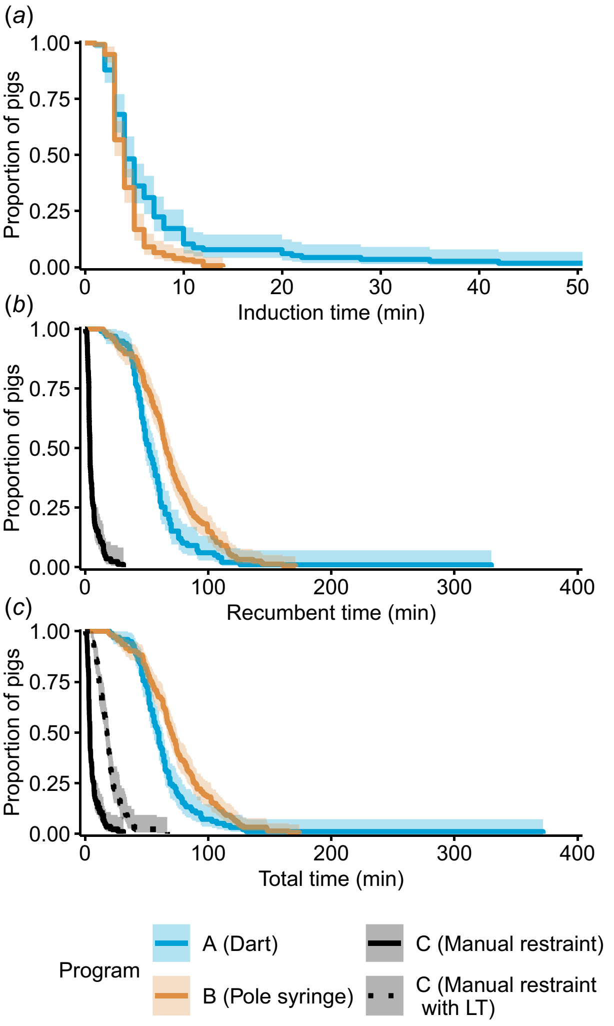

Fig. 5. Kaplan–Meier survival curves showing time-to-event data for processing of feral pigs for telemetry collar deployment using one of three restraint methods, between 2012 and 2025. Displayed are (*a*) induction time (IT), (*b*) recumbency time (RT), and (*c*) total time (TT). The dotted line in panel (*c*) indicates total time for Program C including a latent time (LT) before recumbency. Shaded ribbons represent 95% confidence intervals.

of vehicle collisions ($n = 1$ each in Programs A and C) or being shot during pest control works ($n = 2$ each in Programs A and C), no other pigs died within 14 days of release. Fifteen of the 114 pigs in Program A were darted twice (repeat darting rate = 0.13). Two of these pigs were initially darted in non-target areas: one in the abdomen, slightly forward of the rear leg, and one above the scrotum. There were no clear differences in hyperthermia rate among Programs A (0.18, 95% HPDI = 0.11, 0.25), B (0.19, 95% HPDI = 0.13, 0.26), or C (0.18, 95% HPDI = 0.10, 0.25), and mean body temperatures were very similar among programs (A 39.0°C, s.d. = 1.2; B 38.9°C, s.d. = 1.4; C 38.6°C, s.d. = 1.5). Body temperature was greater in pigs with longer RT in Program C, but not in Programs A or B (Table 2).

Table 2. Regression coefficients describing body temperature of feral pigs restrained using three different methods as a function of duration of recumbency (RT).

Program	n	α (95% HPDI)	β (95% HPDI)	RT range (min)
A (TZX dart)	99	39.7 (38.7, 40.6)	−0.01 (−0.02, 0.00)	13, 330
B (TZ pole syringe)	154	38.7 (38.1, 39.3)	0.00 (−0.01, 0.01)	15, 171
C (Manual restraint)	85	38.3 (37.8, 38.7)	0.07 (0.02, 0.13)	1, 31

Drug dosage and anaesthesia observations for all feral pigs are presented in Table 3. Realised drug doses were calculated retrospectively after estimation of body weight post-darting. Mean realised dosages of xylazine in Program A (2.5 mg/kg) were 25% higher than the intended dose of 2.0 mg/kg. Mean realised dosages of TZ were 30% higher than the intended 2.0 mg/kg in Program A (2.6 mg/kg), and 10% lower than the intended dosage of 4.0 mg/kg in Program B (3.6 mg/kg), see Table 1. Twenty-eight pigs in Program A did not receive

Table 3. Capture, handling and monitoring variables recorded during restraint of feral pigs, showing key inputs and measured outputs relevant to animal welfare outcomes.

Variable	Program A (TZX dart)	Program B (TZ pole syringe)	Program C (manual restraint)
Ambient temperature (°C)	19.2 ± 5.5	22.4 ± 8.1	19.2 ± 4.9
Animal mass (kg)	58.6 ± 19.1	61.5 ± 17.9	NR
Tiletamine-zolazepam dosage (mg/kg)	2.57 ± 0.86	3.59 ± 0.94	NA
Xylazine dosage (mg/kg)	2.50 ± 0.74	NA	NA
Yohimbine dosage (mg/kg)	0.11 ± 0.03	NA	NA
Atipamezole dosage (mg/kg)	0.18 ± 0.05	NA	NA
Heart rate (beats/min)	75.7 ± 24.1	NR	NR
Respiratory rate (respirations/min)	32.5 ± 15.0	NR	NR
Latent time (min)	NR	NR	13.4 ± 10.5
Induction time (min)	7.1 ± 8.5	4.3 ± 2.1	NA
Recumbent time (min)	58.1 ± 34.1	69.8 ± 29.2	6.0 ± 5.4
Total time (min)	64.9 ± 37.6	74.1 ± 29.3	19.3 ± 10.9
Injury score (scaled 0–4)	NR	NR	0.2 ± 0.4
Body temperature (°C)	39.0 ± 1.2	38.9 ± 1.4	38.6 ± 1.5
Hyperthermia proportion	0.18 ± 0.03	0.19 ± 0.03	0.18 ± 0.04
Repeat drug administration proportion	0.13 ± 0.03	0.00	NA
Immediate mortality proportion	0.01 ± 0.01	0.00	0.00
Post-procedural mortality proportion	0.00	0.01 ± 0.01	0.01 ± 0.01

Values are reported as means or proportions ± standard deviation. Total time for Program C includes latent time. Yohimbine was administered to 31 pigs and atipamezole to 54 different pigs.
NA, not applicable; NR, not recorded.

the intended antagonist (yohimbine or atipamezole) because they were deemed to be sufficiently recovered by the end of processing.

Tracking data were available for 210 pigs distributed across 17 sites. We discarded records from 35 of these pigs due to insufficient duration (<27 days, *n* = 23) or low location fix success rate (<70%, *n* = 12). The resulting movement dataset comprised 124,500 hourly GPS locations from 175 pigs (Program A = 70, Program B = 24, Program C = 81).

The mean distance between hourly GPS location fixes (step length) was similar among the three treatments during the 30-day post-release period (Program A = 164 m, 95% CI: 104, 224 m; Program B = 226 m, 95% CI: 152, 300 m; Program C = 161 m, 95% CI: 114, 209 m). The expected step length remained constant over time for all programs (Fig. 6*a*). Two chemically immobilised sows (one each in Programs A and B) showed high daily step lengths for the first 4 days after capture before settling to levels consistent with expected values. Two boars in Program B showed consistently higher than expected daily step lengths for the entire 30-day period.

The mean distance that pigs travelled from their release site (displacement) was lowest for the pigs subjected to manual restraint in Program C (1323 m, 95% CI: 778, 1868 m), followed by pigs immobilised by darting in Program A (1969 m, 95% CI: 897, 3040 m) or pole syringe in Program B (2271 m, 95% CI: 1262, 3280 m). The expected displacement increased over the first 4 days post-capture for pigs in all three programs (Fig. 7*b*). All manually restrained pigs showed consistent behaviour after release, with narrow confidence intervals around the expected displacement distances. The sow in Program B that showed a high expected daily step length for the first 4 days after capture also showed a higher-than-expected displacement during the 30 days after capture, resulting from a dispersal > 15 km. Pigs immobilised by darting in Program A showed the greatest variability in displacement (Fig. 7*b*). This was influenced by one highly mobile individual that was translocated approximately 12.5 km before being released and then dispersing approximately 25 km from its release site (Smith *et al*. 2025).

Discussion

This comparative assessment of three restraint methods for deploying telemetry devices on feral pigs demonstrates the value of integrating animal welfare metrics into wildlife handling protocols. By using standardised metrics, such as time-to-event data and the frequency of adverse events, we were able to compare outcomes across independent studies.

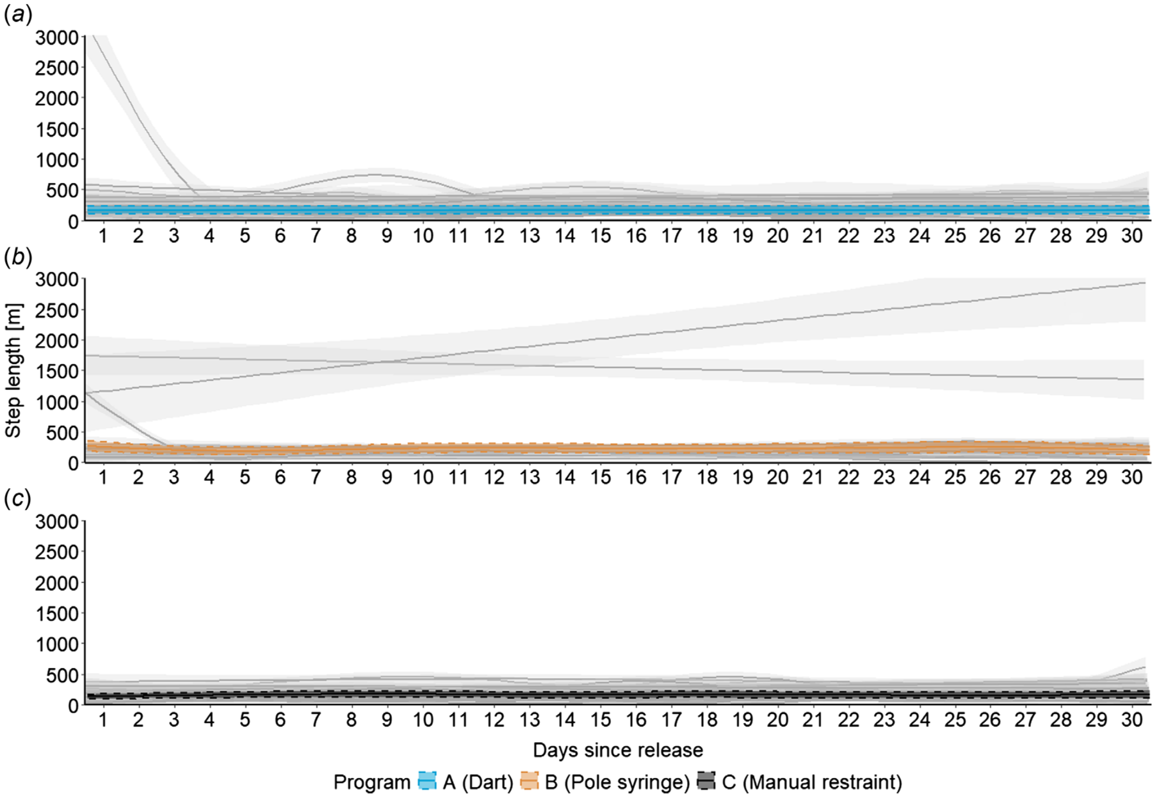

Fig. 6. Expected daily step length of 175 feral pigs captured in one of three research programs using different methods for immobilising and handling animals. Coloured trend lines and ribbons represent expected values and their 95% confidence intervals for each capture program, and grey lines represent expected values for each pig within the program.

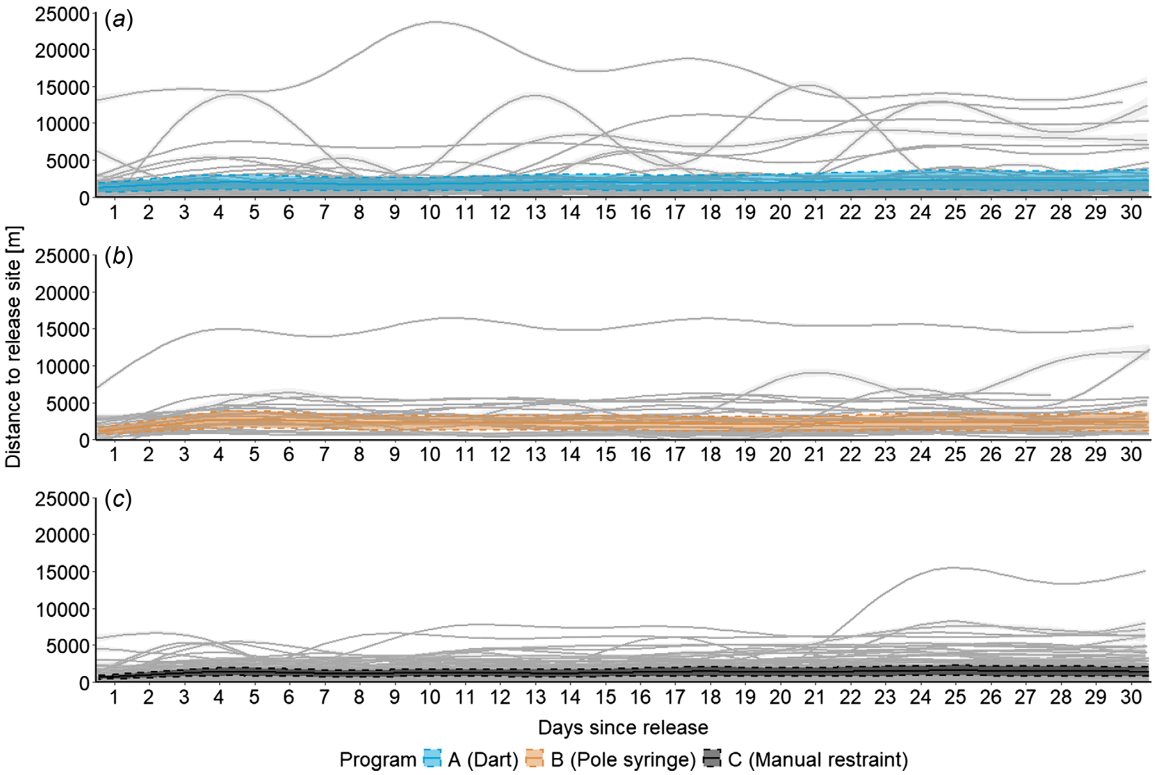

Fig. 7. Expected daily displacement from the point of release for 175 feral pigs captured in one of three research programs using different methods for immobilising and handling animals. Coloured trend lines and ribbons represent expected values and their 95% confidence intervals for each capture program, and grey lines represent expected values for each pig within the program.

This provided two distinct benefits over previous studies: (1) greater inferential power arising from larger sample sizes than have previously been available, and (2) stronger support for broader inference because outcomes were replicated across independent studies conducted by different teams under different environmental and operational conditions. The resulting data can help to refine existing practices or develop alternative approaches. This, in turn, should assist with the optimisation of future operations for animal welfare, while improving the reliability and utility of tracking data for ecological research and management.

Acute stress durations

In this study, we found that the total time from drug administration to release was shorter for pigs immobilised with TZX via darting (Program A) compared to those given TZ alone via pole syringe (Program B). Expected IT were generally similar between the two treatments and were comparable with previous studies using similar drugs and capture methods (Gabor *et al.* 1997; Ellis *et al.* 2019). However, seven TZX darted pigs experienced prolonged inductions (>20 min).

Darted pigs also showed a wider range of recumbency durations than those immobilised using a pole syringe, including the pig initially darted in the abdomen, which took 5.5 h to recover sufficiently to move away from the site, despite the administration of yohimbine. Nonetheless, the shorter expected (median) RT observed in pigs darted with TZX demonstrates the value of reversable immobilisation agents that allow a lower dose of TZ, thereby expediting recovery and reducing unnecessary physiological stress (Ellis *et al.* 2019). The shorter expected recumbency duration for TZX darted pigs, relative to pigs immobilised using TZ delivered via pole syringe, resulted in a lower expected total time, despite the slightly longer expected induction duration. However, the wide range of durations experienced by darted pigs shows the importance of examining and reporting the full range of conditions experienced by individual animals subjected to different regimes, rather than just reducing durations to average values.

The slight positive relationship between ambient temperature and RT for pigs that were administered TZ via pole syringe in Program B suggests that high ambient temperatures may have compromised recovery in these pigs, which received higher TZ doses and were exposed to a greater range of high temperatures than pigs that received TZX. However, the effect size was very small. Other factors that we were unable to directly compare in this study, such as physiological stress responses, may have had a much greater impact on RT.

Pigs that were manually restrained had much shorter recumbent and total times than chemically immobilised pigs. Most manually restrained pigs (85%) were collared and released within 15 min of restraint. Exceptions occurred when pigs were held while time was taken to modify collars that did not match the neck size of the pig. The shorter recumbent and total times for processing manually restrained pigs were driven by two main factors: (1) the absence of induction and recovery times, and (2) a greater level of urgency imposed by the inability to process several pigs simultaneously, unlike chemically immobilised pigs in Programs A and B. The short recumbent periods obtainable through manual restraint may sometimes be desirable for minimising the duration of exposure to stressors. However, the focus on expediency and limited range of interventions that can be performed on manually restrained pigs does limit the wider utility of this technique. Moreover, safe manual restraint requires experienced and physically capable pig handlers, working in a well-coordinated team with clear roles and effective communication throughout the handling process.

Long latent periods (>30 min) between arrival at a trap and restraint of a pig sometimes occurred in Program C when three or more pigs were collared from the same trap, as animals were handled sequentially, rather than simultaneously. The duration of the latent period between a handling team arriving at a trap and restraining a captured animal was not recorded for Programs A or B and has not generally been reported in previous studies, although in many cases much of this period will be captured in the IT. The latent period represents a potentially important window during which animals are subjected to stress prior to handling. Prolonged exposure to stressors such as the presence of the handling team can induce heightened physiological stress responses in wild pigs (Lavelle *et al.* 2019). Stress-induced activation of the sympathetic nervous system can cause a surge in catecholamine levels, which can interfere with the efficacy of α-2 agonists like xylazine (Kreeger *et al.* 2023).

The wide variation in RT, especially among darted pigs, is consistent with previous studies and likely reflects individual differences in stress levels at the time of immobilisation (Barasona *et al.* 2013; Brogi *et al.* 2019; Lavelle *et al.* 2019). In addition to the latent period proposed above, several other factors have been identified as likely contributors to the intensity of stress responses and consequent resistance to immobilisation. These include the type and size of trap used, the number of animals captured together, and the duration of confinement prior to immobilisation. Larger traps and greater numbers of pigs per trap may lead to heightened stress, as animals have more space to move and can become agitated by the behaviour of others in the trap (Fenati *et al.* 2008; Barasona *et al.* 2013; Brogi *et al.* 2019; Lavelle *et al.* 2019). Given the high variability in immobilisation responses and the uncertainty surrounding contributing factors, it is important that captured animals are closely monitored throughout all stages of capture and handling. Handling teams must be prepared to administer additional doses or antagonists as needed.

Hyperthermia

Prolonged immobilisation or recumbency can increase the risk of physiological complications in wild animals, including feral pigs (Ellis *et al.* 2019). Extended periods of immobilisation can exacerbate thermoregulatory stress, particularly under warm ambient conditions, due to pigs' limited capacity for heat dissipation. This risk may be increased by the peripheral vasoconstriction that can occur with α-2 agonists, which has been reported in pigs (Lee *et al.* 2010) and other ungulates (e.g. Roug *et al.* 2024), and which can reduce peripheral heat loss and thereby interfere with thermal regulation. However, there was no clear difference in the frequency of hyperthermia across the three restraint programs. The slight positive relationship between body temperature and recumbency duration in manually restrained pigs was offset by the short recumbency duration for these pigs. Nonetheless, the combination of prolonged immobilisation, warm to hot ambient temperatures (up to 43°C), and impaired thermoregulation as a side effect of immobilising agents, likely contributed to the elevated body temperatures observed in some individuals. Pigs were often actively cooled by dousing with water during and after handling (Figs 2 and 4), but the effectiveness of this intervention may be reduced when immobilisation or recumbency is extended (Leiberich *et al.* 2023). To minimise the risk of hyperthermia, handling teams should implement appropriate cooling strategies, particularly under hot environmental conditions. Pre-emptive water cooling, including wetting down of the inside of the trap, is recommended for chemically immobilised pigs. However, for manually restrained pigs, water is often best applied immediately prior to release to avoid handling difficulties and compromised safety associated with wet and muddy animals.

Mortality

Previous studies have proposed that two separate mortality rates should be reported for studies involving chemical immobilisation of wildlife: mortality at the time of capture to account for acute trauma, and mortality within 14 days post-capture to account for chronic metabolic diseases (e.g. capture myopathy; DelGiudice *et al.* 2005; Hampton *et al.* 2016). The 1% immediate mortality rate for TZX darted pigs in the present study was similar to previous studies in which pigs died or were euthanised during handling due to hyperthermia or trap-related injuries (0.02–10.6% mortality; Fournier *et al.* 1995; Fenati *et al.* 2008; Barasona *et al.* 2013; Ellis *et al.* 2019; Morelli *et al.* 2021).

The absence of mortality during capture and handling among the 246 pigs immobilised using pole syringing or manual restraint demonstrates that significant mortality is not an inevitable outcome of capture and handling. However, all three post-procedural deaths occurred within 24 h of release of pole syringed or manually restrained pigs, suggesting that acute physiological stress, rather than chronic metabolic conditions, may have been the underlying cause. Notably, the pig that died following manual restraint was captured from a population experiencing food and water scarcity (Site YB, Bengsen *et al.* 2025), which may have reduced its capacity to cope with additional stressors. Post-mortem investigations were not possible for this animal as it had been almost completely cannibalised within 24 h.

Repeated darting

Across all darted pigs, the repeat darting rate of 13% was within the wide range of repeated or supplemental drug administration rates reported in the literature (0.02–0.31; Fenati *et al.* 2008; Barasona *et al.* 2013; Morelli *et al.* 2021). The average of 1.1 darts per pig in the present study compares favourably to a study comparing different trap designs, which reported that an average of 1.7 darts were required per pig, due to poor dart placement (Lavelle *et al.* 2019). Unlike darts, pole syringes are not greatly affected by wind or animal movement, potentially making them more reliable for delivering the intended dose to the target muscle group, which should produce more consistent induction. Pole syringes are also considered less likely to cause traumatic injuries than darts, which can be fired at relatively high velocities from dart guns (Cracknell 2013). However, they are impractical for use in large corral or net traps in which pigs have substantial freedom of movement and can easily avoid the syringe.

Post-release behaviour

Many studies have reported a period of subdued activity in ungulates, including wild pigs (Brogi *et al.* 2019), lasting several days after collaring (Stiegler *et al.* 2024). The absence of any change in expected daily step length in the three programs examined in the present study suggests that none of the capture and handling protocols inhibited the motility, or capacity for movement, of captured feral pigs. However, the slight increase in displacement from the point of release observed in all programs over the first 4 days suggests that capture and handling did have an intermittent effect on pigs' mobility, or range of movement. The duration of reduced mobility in the present study (4 days) was substantially less than the 10-day period over which both motility and mobility were depressed in wild pigs immobilised using TZ or TZX in a European study (Brogi *et al.* 2019). A recent review found that 63% of ungulate studies with suitable data reported similar results, with displacement tending to increase over the first 4–7 days after release (Stiegler *et al.* 2024). It is commonly supposed that the intensity of behavioural disruption is related to the duration of chemical immobilisation (e.g. Brogi *et al.* 2019; Stiegler *et al.* 2024). However, the consistency of reduced mobility across all programs in the present study, and the presence of behavioural disturbances in other ungulates handled without chemical immobilisation (Morellet *et al.* 2009; Bengsen *et al.* 2021), suggests that it is not solely a response to exposure to neurologically active chemicals. These findings reinforce the need to anticipate short-term bias in tracking collar data immediately following deployment, regardless of the capture or handling method used (Morellet *et al.* 2009; Stiegler *et al.* 2024).

Study limitations

This study drew on *post hoc* data collected from three independent research programs, each employing different capture, restraint and data collection methods. While this approach allowed for broad comparisons and increased inferential power, it also introduced several limitations related to data consistency and completeness. First, drug combinations were confounded with administration method. This made it impossible to clearly separate differences in outcomes that might have been due to the use of TZ or TZX from those due to the use of remote darting or pole syringing. Second, latent periods were only recorded for manually restrained pigs in Program C. Exposure to the trapping team in the period between the team's arrival and immobilisation or restraint could be an important stressor for trapped animals, but absence of these data from Programs A and B precludes a full comparison of peritraumatic stress across methods. Third, the number of other pigs present in the trap was only recorded for Program C. Group size and social dynamics within traps are expected to influence stress responses and chemical immobilisation efficacy, but the lack of these data for Programs A and B limits our ability to assess its role in observed outcomes. Fourth, trap-related injuries were not consistently recorded or scored across programs. While one program scored injuries consistently, and field notes confirmed that minor injuries occurred in all programs, the absence of systematic injury data prevented robust comparisons of physical trauma across restraint methods.

Recommendations

The limitations of this study reveal the need for more standardised data collection and reporting protocols in future telemetry studies involving feral pigs or similar species. Consistent recording of latent periods, group sizes, the nature and frequency of injuries, and confinement duration would enhance the reliability of welfare assessments and improve the comparability of results across studies. Injuries could be scored using simple scales (Webb *et al.* 2008), as occurred in Program C and for some pigs in Program B, or using more detailed criteria as provided by international standards (e.g. ISO 1999). In addition to physical injuries, the systematic recording and reporting of other adverse events (e.g. regurgitation, respiratory depression, prolonged induction, and extended recovery) would provide a greater evidence base for refining immobilisation and handling protocols. These data would enable more powerful *post hoc* comparisons and support the development of best-practice approaches optimised for animal welfare outcomes. Where feasible, study designs (or minimum datasets) should also aim to disentangle the effects of drug protocol from those of delivery method (e.g. darting vs pole syringe), so that welfare outcomes can be more confidently attributed to specific components of the restraint approach.

To our knowledge, this study is the first to directly compare manual restraint with chemical immobilisation for handling feral pigs. While previous studies have asserted that chemical immobilisation is necessary to reduce physiological stress and improve study outcomes (e.g. Brogi *et al.* 2019; Ellis *et al.* 2019), our findings did not support this assumption. Manually restrained pigs experienced significantly shorter durations of stress (even when LT was added to these pigs only), avoided the neurological and physiological effects of immobilising agents, and showed no difference in the frequency of adverse outcomes. Their post-release spatial behaviour was comparable to that of chemically immobilised pigs for at least 14 days. Manual restraint does require experienced handlers and also limits the scope and duration of interventions that can be performed. However, mechanical aids can facilitate longer or more complex procedures (e.g. Lavelle *et al.* 2021). Manual restraint should be considered a viable option for studies where extended or painful interventions are not required.

When chemical immobilisation is desirable, drug combinations that include reversible agents (e.g. xylazine with yohimbine or atipamezole) offer clear advantages (Caulkett and Arnemo 2024). These combinations allow for more controlled immobilisation and faster recovery, reducing the duration of physiological stress and improving animal welfare outcomes (Cattet *et al.* 1999). However, reversible drug regimes sometimes necessitate the use of immobilising agents that are less widely available, or more expensive. Their use must also be balanced against potential complications such as respiratory depression and hypoxaemia. Notably, none of the methods described here used intra-nasal oxygen supplementation, which is routinely used for species known to be more susceptible to hypoxaemia, hyperthermia and capture myopathy, e.g. chital/axis deer (*Axis axis;* Hampton *et al.* 2021). Supplemental oxygen should be provided whenever feasible, to mitigate hypoxaemia and improve overall safety during immobilisation (Ellis *et al.* 2019). Hypoxaemia appears to be common in wild suids and may not be reliably identified in the field using pulse oximetry alone (Ellis *et al.* 2019; Morelli *et al.* 2021). However, mild hypoxaemia may resolve without intervention, and oxygen supplementation during feral pig immobilisation has not yet been widely adopted in practice. Controlled studies evaluating the benefits (and practical feasibility) of supplemental oxygen in chemically immobilised feral pigs in the field would provide valuable clarity.

The method of drug administration is also likely to play an important role in the consistency and safety of immobilisation. Pole syringes generally offer more reliable delivery to target muscle groups and are less prone to complications arising from poor dart placement or environmental factors such as wind. They are also less likely to cause traumatic injuries. However, pole syringes are impractical in larger traps where pigs have substantial freedom of movement. Handler experience and training are also important considerations (Cracknell 2013), and optimal outcomes are most likely when handlers are well-trained in, and familiar with, the equipment they use.

Finally, it is important for researchers to take a proactive role in documenting and publishing animal welfare outcomes arising from their interventions. Transparent reporting not only strengthens the scientific foundation of wildlife management practices but also fosters informed, evidence-based dialogue about acceptable research methods. Publishing animal welfare data helps to dispel misconceptions, counter emotionally driven critiques, and refine techniques based on empirical evidence rather than assumptions (McMahon *et al.* 2012). By embedding welfare assessments into study design and reporting, researchers contribute to a culture of accountability and continuous improvement.

Conclusion

We used a standardised animal welfare assessment framework to quantify and compare durations of procedures and exposure to stressors, frequencies of adverse events, and post-release movement patterns across methods. Our findings show that manual restraint, when performed by experienced handlers, can offer a safe and efficient alternative to chemical immobilisation. When chemical immobilisation is appropriate, drug combinations that include reversible agents, such as xylazine with yohimbine or atipamezole, can reduce recovery times and physiological stress. The method of drug delivery also matters: pole syringes can provide more consistent IT and fewer complications than darting.

Ultimately, the choice of restraint method must be guided by the specific goals and constraints of each study. Animal welfare considerations should always be prominent in both planning and reporting. We encourage researchers to use standardised data collection protocols and to publish detailed welfare outcomes to support evidence-based refinement of wildlife handling practices. Doing so will not only improve the ethical foundation of telemetry studies but also enhance the quality and reliability of the data they produce.

References

Anderson DP, Latham MC, McClelland P, Latham ADM (2022) Analysis of spatiotemporal patterns of home range use and habitat selection to inform management of feral pigs on Auckland Island. *New Zealand Journal of Ecology* **46**(3), 3489. doi:10.20417/nzjecol.46.3489

Arnemo J (2004) Chemical immobilization and anaesthesia of wild boars. In 'DDA News' 1, p. 4. Orion Pharma Animal Health, Turku, Finland.

Baber DW, Coblentz BE (1982) Immobilization of feral pigs with a combination of ketamine and xylazine. *The Journal of Wildlife Management* **46**(2), 557–559. doi:10.2307/3808682

Barasona JA, López-Olvera JR, Beltrán-Beck B, Gortázar C, Vicente J (2013) Trap-effectiveness and response to tiletamine-zolazepam and medetomidine anaesthesia in Eurasian wild boar captured with cage and corral traps. *BMC Veterinary Research* **9**(1), 107. doi:10.1186/1746-6148-9-107

Barrios-Garcia MN, Ballari SA (2012) Impact of wild boar (*Sus scrofa*) in its introduced and native range: a review. *Biological Invasions* **14**(11), 2283–2300. doi:10.1007/s10530-012-0229-6

Bengsen AJ, West P, Krull CR (2017) Feral pigs in Australia and New Zealand: range, trend, management and impacts of an invasive species. In 'Ecology, Evolution and Management of Wild Pigs and Peccaries. Implications for Conservation'. (Eds M Melletti, E Meijaard) pp. 325–338. (Cambridge University Press: Cambridge)

Bengsen AJ, Hampton JO, Comte S, Freney S, Forsyth DM (2021) Evaluation of helicopter net-gunning to capture wild fallow deer (*Dama dama*). *Wildlife Research* **48**(8), 722–729. doi:10.1071/WR21007

Bengsen AJ, Comte S, Crittle T, Holbery S, Marshall D, Marshall L, Parker L, Forsyth DM (2025) Aerial shooting is unlikely to cause dispersal or consistent changes in the movements of feral pigs (*Sus scrofa*). *Wildlife Research* **52**(6), WR25024. doi:10.1071/WR25024

Bjørneraas K, Van Moorter B, Rolandsen CM, Herfindal I (2010) Screening global positioning system location data for errors using animal movement characteristics. *The Journal of Wildlife Management* **74**(6), 1361–1366. doi:10.1111/j.1937-2817.2010.tb01258.x

Brogi R, Brivio F, Bertolucci C, Benazzi M, Luccarini S, Cappai N, Bottero E, Pedrazzoli C, Columbano N, Apollonio M (2019) Capture effects in wild boar: a multifaceted behavioural investigation. *Wildlife Biology* **2019**, 1–10. doi:10.2981/wlb.00497

Brooks SP, Gelman A (1998) General methods for monitoring convergence of iterative simulations. *Journal of Computational and Graphical Statistics* **7**(4), 434–455. doi:10.1080/10618600.1998.10474787

Calabrese JM, Fleming CH, Gurarie E (2016) ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology and Evolution* **7**(9), 1124–1132. doi:10.1111/2041-210X.12559

Campbell TA, Long DB, Lavelle MJ, Leland BR, Blankenship TL, VerCauteren KC (2012) Impact of baiting on feral swine behavior in the presence of culling activities. *Preventive Veterinary Medicine* **104**(3), 249–257. doi:10.1016/j.prevetmed.2012.01.001

Cattet MR, Caulkett NA, Polischuk SC, Ramsay MA (1999) Anesthesia of polar bears (*Ursus maritimus*) with zolazepam-tiletamine, medetomidine-ketamine, and medetomidine-zolazepam-tiletamine. *Journal of Zoo and Wildlife Medicine* **30**(3), 354–360. https://www.jstor.org/stable/20095878

Cattet M, Boulanger J, Stenhouse G, Powell RA, Reynolds-Hogland MJ (2008) An evaluation of long-term capture effects in ursids: implications for wildlife welfare and research. *Journal of Mammalogy* **89**(4), 973–990. doi:10.1644/08-MAMM-A-095.1

Caulkett N, Arnemo JM (2024) Comparative immobilization and anesthesia – free-ranging terrestrial mammals. In 'Veterinary Anesthesia and Analgesia: The Sixth Edition of Lumb and Jones'. (Eds L Lamont, K Grimm, S Robertson, L Love, C Schroeder) pp. 1077–1090. (John Wiley and Sons: Hoboken, USA)

Cracknell J (2013) Remote chemical injection: darting in practice. *In Practice* **35**(1), 17–23. doi:10.1136/inp.f12

DelGiudice GD, Sampson BA, Kuehn DW, Powell MC, Fieberg J (2005) Understanding margins of safe capture, chemical immobilization, and handling of free-ranging white-tailed deer. *Wildlife Society Bulletin* **33**(2), 677–687. doi:10.2193/0091-7648(2005)33[677:UMOSCC]2.0.CO;2

Denwood MJ (2016) runjags: an R package providing interface utilities, model templates, parallel computing methods and additional distributions for MCMC models in JAGS. *Journal of Statistical Software* **71**, 1–25. doi:10.18637/jss.v071.i09

Einwaller J, Meyer LCR, Auer U, Raekallio M, Nowack J, Haw A, Vetter S, Painer J, Stalder G (2022) Cardiovascular effects of intravenous vatinoxan in wild boars (*Sus scrofa*) anaesthetised with intramuscular medetomidine-tiletamine-zolazepam. *Veterinary Record* **190**, e835. doi:10.1002/vetr.835.

Ellis CK, Wehtje ME, Wolfe LL, Wolff PL, Hilton CD, Fisher MC, Green S, Glow MP, Halseth JM, Lavelle MJ (2019) Comparison of the efficacy of four drug combinations for immobilization of wild pigs. *European Journal of Wildlife Research* **65**, 78. doi:10.1007/s10344-019-1317-z

Fenati M, Monaco A, Guberti V (2008) Efficiency and safety of xylazine and tiletamine/zolazepam to immobilize captured wild boars (*Sus scrofa* L. 1758): analysis of field results. *European Journal of Wildlife Research* **54**(2), 269–274. doi:10.1007/s10344-007-0140-0

Fischer JW, McMurtry D, Blass CR, Walter WD, Beringer J, VerCauteren KC (2016) Effects of simulated removal activities on movements and space use of feral swine. *European Journal of Wildlife Research* **62**(3), 285–292. doi:10.1007/s10344-016-1000-6

Fleming C, Sheldon D, Fagan W, Leimgruber P, Mueller T, Nandintsetseg D, Noonan M, Olson K, Setyawan E, Sianipar A (2018) Correcting for missing and irregular data in home-range estimation. *Ecological Applications* **28**(4), 1003–1010. doi:10.1002/eap.1704

Fournier P, Fournier-Chambrillon C, Maillard D, Klein F (1995) Zoletil immobilization of wild boar (*Sus scrofa* L.). *Ibex Journal of Mountain Ecology* **3**, 134–136.

Gabor TM, Hellgren EC, Silvy NJ (1997) Immobilization of collared peccaries (*Tayassu tajacu*) and feral hogs (*Sus scrofa*) with Telazol® and xylazine. *Journal of Wildlife Diseases* **33**(1), 161–164. doi:10.7589/0090-3558-33.1.161

Gaston W, Armstrong JB, Arjo W, Stribling HL (2008) Home range and habitat use of feral hogs (*Sus scrofa*) on Lowndes County WMA, Alabama. In 'Proceedings of National Conference on Feral Hogs', April 13-15, 2008. Hosted by the Missouri Department of Conservation, St. Louis, MO.

Ghai RR, Wallace RM, Kile JC, Shoemaker TR, Vieira AR, Negron ME, Shadomy SV, Sinclair JR, Goryoka GW, Salyer SJ, Barton Behravesh C (2022) A generalizable one health framework for the control of zoonotic diseases. *Scientific Reports* **12**, 8588. doi:10.1038/s41598-022-12619-1

Hampton JO, Spencer PB, Alpers DL, Twigg LE, Woolnough AP, Doust J, Higgs T, Pluske J (2004) Molecular techniques, wildlife management and the importance of genetic population structure and dispersal: a case study with feral pigs. *Journal of Applied Ecology* **41**(4), 735–743. doi:10.1111/j.0021-8901.2004.00936.x

Hampton JO, Robertson H, Adams PJ, Hyndman TH, Collins T (2016) An animal welfare assessment framework for helicopter darting: a case study with a newly developed method for feral horses. *Wildlife Research* **43**, 429–437. doi:10.1071/WR15230

Hampton JO, Amos M, Pople T, Brennan M, Forsyth DM (2021) Minimising mortalities in capturing wildlife: refinement of helicopter darting of chital deer (*Axis axis*) in Australia. *Wildlife Research* **48**(4), 304–313. doi:10.1071/WR20106

ISO (1999) ISO 10990-5:1999 Animal (mammal) traps — Part 5: Methods for testing restraining traps. International Organization for Standardization, Geneva, Switzerland.

Kaplan EL, Meier P (1958) Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association* **53**(282), 457–481.

Kästner SB (2006) A2-agonists in sheep: a review. *Veterinary Anaesthesia and Analgesia* **33**(2), 79–96. doi:10.1111/j.1467-2995.2005.00243.x

Kelly C, Marshall D, Sydenham A, Marshall L, Proboste T, Harriott L, Gentle M (2025) Variable response to aerial culling demonstrates adaptability of feral pigs. *Applied Animal Behaviour Science* **292**, 106815. doi:10.1016/j.applanim.2025.106815

Kranstauber B, Smolla M, Scharf AK (2024) Move: visualizing and analyzing animal track data. Available at https://CRAN.R-project.org/package=move

Kreeger T, Arnemo JM, Caulkett NA, Hampton JO, Meyer LC (2023) 'Handbook of wildlife chemical immobilization.' 6th edn. (Terry Kreeger: Bovey, Minnesota)

Kunnasranta M, Miettinen E, Melin M, Meller A, Väänänen V-M, Huitu O, Holmala K (2024) The performance of alternative GPS tracking devices: a case report on wild boars (*Sus scrofa*). *Animal Biotelemetry* **12**(1), 27. doi:10.1186/s40317-024-00382-1

Lavelle MJ, Snow NP, Ellis CK, Halseth JM, Glow MP, VanNatta EH, Sanders HN, VerCauteren KC (2019) When pigs fly: Reducing injury and flight response when capturing wild pigs. *Applied Animal Behaviour Science* **215**, 21–25. doi:10.1016/j.applanim.2019.03.014

Lavelle MJ, Snow NP, Ellis CK, Halseth JM, Fischer JW, Glow MP, Vannatta EH, Friesenhahn BA, Vercauteren KC (2021) Improved strategies for handling entire sounders of wild pigs. *Wildlife Society Bulletin* **45**(1), 170–175. doi:10.1002/wsb.1160

Lee JY, Jee HC, Jeong SM, Park CS, Kim MC (2010) Comparison of anaesthetic and cardiorespiratory effects of xylazine or medetomidine in combination with tiletamine/zolazepam in pigs. *Veterinary Record* **167**, 245–249. doi:10.1136/vr.c3611.

Leiberich M, Fitte A, Burroughs R, Steyl J, Goddard A, Haw A, Boesch JM, Kohn TA, Meyer LC (2023) Cooling by dousing with cold water does not alter the pathophysiological biochemical changes induced by capture in blesbok (*Damaliscus pygargus phillipsi*). *The Journal of Wildlife Diseases* **59**(2), 288–298. doi:10.7589/JWD-D-22-00059.

Martin JT (1975) Movement of feral pigs in North Canterbury, New Zealand. *Journal of Mammalogy* **56**(4), 914–915.

Matthews A, Ruykys L, Ellis B, FitzGibbon S, Lunney D, Crowther MS, Glen AS, Purcell B, Moseby K, Stott J, Fletcher D, Wimpenny C, Allen BL, Van Bommel L, Roberts M, Davies N, Green K, Newsome T, Ballard G, Fleming P, Dickman CR, Eberhardt A, Troy S, McMahon C, Wiggins N (2013) The success of GPS collar deployments on mammals in Australia. *Australian Mammalogy* **35**(1), 65–83. doi:10.1071/AM12021

Mayberry C, Bencini R, Mawson P, Maloney S (2014) Sedation of western grey kangaroos (*Macropus fuliginosus ocydromus*) with tiletamine-zolazepam. *Animal Welfare* **23**(2), 141–144. doi:10.7120/09627286.23.2.141

McGregor HW, Hampton JO, Lisle D, Legge S (2016) Live-capture of feral cats using tracking dogs and darting, with comparisons to leg-hold trapping. *Wildlife Research* **43**(4), 313–322. doi:10.1071/WR15134

McIlroy J (1989) Aspects of the ecology of feral pigs (*Sus scrofa*) in the Murchison area, New Zealand. *New Zealand Journal of Ecology* **12**, 11–22. https://www.jstor.org/stable/24053176

McIlroy J, Gifford E (1997) The 'Judas' pig technique: a method that could enhance control programmes against feral pigs, *Sus scrofa*. *Wildlife Research* **24**(4), 483–491. doi:10.1071/WR96109

McIlroy JC, Saillard RJ (1989) The effect of hunting with dogs on the numbers and movements of feral pigs, Sus scrofa, and the subsequent success of poisoning exercises in Namadgi National Park, ACT. *Australian Wildlife Research* **16**, 353–363. doi:10.1071/WR9890353

McMahon C, Collier N, Northfield J, Glen F (2011) Taking the time to assess the effects of remote sensing and tracking devices on animals. *Animal Welfare* **20**(4), 515–521. doi:10.1017/S0962728600003158

McMahon CR, Hindell MA, Harcourt RG (2012) Publish or perish: why it's important to publicise how, and if, research activities affect animals. *Wildlife Research* **39**(5), 375–377. doi:10.1071/WR12014

Miettinen E, Melin M, Holmala K, Meller A, Väänänen V-M, Huitu O, Kunnasranta M (2023) Home ranges and movement patterns of wild boars (*Sus scrofa*) at the northern edge of the species' distribution range. *Mammal Research* **68**(4), 611–623. doi:10.1007/s13364-023-00710-5

Mitchell J, Dorney W, Mayer R, McIlroy J (2009) Migration of feral pigs (*Sus scrofa*) in rainforests of north Queensland: fact or fiction? *Wildlife Research* **36**, 110–116. doi:10.1071/WR06066

Morellet N, Verheyden H, Angibault JM, Cargnelutti B, Lourtet B, Hewison MA (2009) The effect of capture on ranging behaviour and activity of the European roe deer *Capreolus capreolus*. *Wildlife Biology* **15**(3), 278–287. doi:10.2981/08-084

Morelli J, Rossi S, Fuchs B, Richard E, Braz Barros DS, Küker S, Arnemo JM, Evans AL (2021) Evaluation of three medetomidine-based anesthetic protocols in free-ranging wild boars (*Sus scrofa*). *Frontiers in Veterinary Science* **8**, 277. doi:10.3389/fvets.2021.655345

Ozeki LM, Caulkett N, Stenhouse G, Arnemo JM, Fahlman Å (2015) Effect of active cooling and α-2 adrenoceptor antagonism on core temperature in anesthetized brown bears (U*rsus arctos*). *Journal of Zoo and Wildlife Medicine* **46**(2), 279–285. doi:10.1638/2014-0052R.1

Pearson HE, Toribio JA, Hernandez-Jover M, Marshall D, Lapidge SJ (2014) Pathogen presence in feral pigs and their movement around two commercial piggeries in Queensland, Australia. *Veterinary Record* **174**(13), 325–325. doi:10.1136/vr.102019

Plummer M (2003) JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. In 'Proceedings of the 3rd International Workshop on Distributed Statistical Computing', March 20-22, 2003. (Eds K Hornik, F Leisch, A Zeileis) pp. 1–8. (Technische Universität Wien: Vienna, Austria)

Ponjoan A, Bota G, Morena ELG, Morales MB, Wolff A, Marco I, Mañosa S (2008) Adverse effects of capture and handling little bustard. *The Journal of Wildlife Management* **72**(1), 315–319. doi:10.2193/2006-443

Proboste T, Turnlund A, Bengsen A, Gentle M, Wilson C, Harriott L, Fuller RA, Marshall D, Soares-Magalhaes RJ (2025) Quantifying feral pig interactions to inform disease transmission networks. *eLife* **13**, RP102643. doi:10.7554/eLife.102643.3

Pulsford IF (1991) History of disturbances in the white cypress pine (*Callitris glaucophylla*) forests of the lower Snowy River Valley, Kosciusko National Park. Master of Science, Australian National University, Canberra, Australia.

R Core Team (2024) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Roug A, Nol P, Mama K (2024) Efficacy of tolazoline and vatinoxan in reducing adverse effects of butorphanol-azaperone-medetomidine immobilization in Rocky Mountain elk (*Cervus canadensis*). *Journal of Zoo and Wildlife Medicine* **55**, 136–142. doi:10.1638/2023-0049

Sawicka J, Fuller A, Fick LG, Hetem RS, Meyer LC (2015) Efficacy of different cooling methods for capture-induced hyperthermia in antelope. *African Journal of Wildlife Research* **45**(1), 100–110. doi:10.3957/056.045.0111

Shapiro L, Eason C, Bunt C, Hix S, Aylett P, MacMorran D (2016) Efficacy of encapsulated sodium nitrite as a new tool for feral pig management. *Journal of Pest Science* **89**, 489–495. doi:10.1007/s10340-015-0706-7

Sharp T (2012) Standard Operating Procedure PIG004: Use of Judas pigs. Invasive Animals CRC, Canberra, Australia. Available at http://www.pestsmart.org.au/wp-content/uploads/2012/12/PIG004_Judas-pigs_web.pdf

Smith A (2018) Trapper's methods adapted to technology. In 'Farm Weekly', 27 September 2018. Farm Weekly, South Perth, Australia. Available at https://www.farmweekly.com.au/story/5671647/trappers-methods-adapted-to-technology/

Smith D, Bradhurst R, Adams P, Dawson S, Davies H, Fleming PJ, Meek PD (2025) Atypical movement behaviour of a translocated feral pig (*Sus scrofa*). *Austral Ecology* **50**(10), e70134. doi:10.1111/aec.70134

Stiegler J, Gallagher CA, Hering R, Müller T, Tucker M, Apollonio M, Arnold J, Barker NA, Barthel L, Bassano B, van Beest FM, Belant JL, Berger A, Beyer DE Jr, Bidner LR, Blake S, Börner K, Brivio F, Brogi R, Buuveibaatar B, Cagnacci F, Dekker J, Dentinger J, Duľa M, Duquette JF, Eccard JA, Evans MN, Ferguson AW, Fichtel C, Ford AT, Fowler NL, Gehr B, Getz WM, Goheen JR, Goossens B, Grignolio S, Haugaard L, Hauptfleisch M, Heim M, Heurich M, Hewison MAJ, Isbell LA, Janssen R, Jarnemo A, Jeltsch F, Miloš J, Kaczensky P, Kamiński T, Kappeler P, Kasper K, Kautz TM, Kimmig S, Kjellander P, Kowalczyk R, Kramer-Schadt S, Kröschel M, Krop-Benesch A, Linderoth P, Lobas C, Lokeny P, Lührs M-L, Matsushima SS, McDonough MM, Melzheimer J, Morellet N, Ngatia DK, Obermair L, Olson KA, Patanant KC, Payne JC, Petroelje TR, Pina M, Piqué J, Premier J, Pufelski J, Pyritz L, Ramanzin M, Roeleke M, Rolandsen CM, Saïd S, Sandfort R, Schmidt K, Schmidt NM, Scholz C, Schubert N, Selva N, Sergiel A, Serieys LEK, Silovský V, Slotow R, Sönnichsen L, Solberg EJ, Stelvig M, Street GM, Sunde P, Svoboda NJ, Thaker M, Tomowski M, Ullmann W, Vanak AT, Wachter B, Webb SL, Wilmers CC, Zieba F, Zwijacz-Kozica T, Blaum N (2024) Mammals show faster recovery from capture and tagging in human-disturbed landscapes. *Nature Communications* **15**(1), 8079. doi:10.1038/s41467-024-52381-8

Sweitzer RA, Ghneim GS, Gardner IA, Vuren DV, Gonzales BJ, Boyce WM (1997) Immobilization and physiological parameters associated with chemical restraint of wild pigs with Telazol$^{®}$ and xylazine hydrochloride. *Journal of Wildlife Diseases* **33**(2), 198–205. doi:10.7589/0090-3558-33.2.198

Taylor D, Katahira L (1988) Radio telemetry as an aid in eradicating remnant feral goats. *Wildlife Society Bulletin* **16**(3), 297–299. https://www.jstor.org/stable/3782103

Therapeutic Goods Administration (2024) Scheduling basics. Vol. 2024. Australian Goverment, Department of Health, Canberra, Australia. Available at https://www.tga.gov.au/scheduling-basics-medicines-and-chemicals-australia

Therneau T (2024) A package for survival analysis in R. R package version 3.7-0. Available at https://CRAN.R-project.org/package=survival

Theuerkauf J, Barrière P, Cadin K, Gula R (2022) A trial of satellite GPS telemetry on feral pigs in tropical mountain rainforest. *Australian Mammalogy* **45**(1), 121–124. doi:10.1071/AM22015

Twigg LE, Lowe T, Martin G (2007) Bait consumption by, and 1080-based control of, feral pigs in the Mediterranean climatic region of south-western Australia. *Wildlife Research* **34**(2), 125–139. doi:10.1071/WR06084

USDA APHIS (2021) The Use of Dogs and Other Animals in Wildlife Damage Management. United States Department of Agriculture - Animal and Plant Health Inspection Service, Riverdale, USA.

VerCauteren KC, Pepin KM, Cook SM, McKee S, Pagels A, Kohen KJ, Messer IA, Glow MP, Snow NP (2024) What is known, unknown, and needed to be known about damage caused by wild pigs. *Biological Invasions* **26**(5), 1313–1325. doi:10.1007/s10530-024-03263-z

Waudby HP, Turner JM, Coulson G, Taggart D, Watson D, Bengsen AJ, Meek PD, Bower DS, Thompson S, Lumsden LF, Hampton JO, Death C, Thompson G, Finlayson G, Hamilton DG, Petit S, Dunlop J, Bentley J, Vanderduys E, Ballard GA, Morrant DS (2022) Wildlife capture methods. In 'Wildlife research in Australia: practical and applied methods'. (Eds BP Smith, HP Waudby, CA Alberthsen, JO Hampton) pp. 108–149. (CSIRO: Melbourne, Australia)

Webb SL, Lewis JS, Hewitt DG, Hellickson MW, Bryant FC (2008) Assessing the helicopter and net gun as a capture technique for white-tailed deer. *The Journal of Wildlife Management* **72**(1), 310–314. doi:10.2193/2007-101

Wilson C, Gentle M, Marshall D (2023*a*) Feral pig (*Sus scrofa*) activity and landscape feature revisitation across four sites in eastern Australia. *Australian Mammalogy* **45**(3), 305–316. doi:10.1071/AM22034

Wilson C, Marshall D, Gentle M (2023*b*) Factors influencing the activity ranges of feral pigs (*Sus scrofa*) across four sites in eastern Australia. *Wildlife Research* **50**(11), 876–889. doi:10.1071/WR22095

Wilson C, Gentle M, Marshall D (2024) Enhancing strategic deployment of baiting transects for invasive species control – a case study for feral pig baiting in north-eastern Australia. *Wildlife Research* **51**(4), WR23115. doi:10.1071/WR23115

Wood SN (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society Series B: Statistical Methodology* **73**(1), 3–36. doi:10.1111/j.1467-9868.2010.00749.x

Wood SN (2017) 'Generalized additive models: an introduction with R.' (CRC Press: Boca Raton, USA)

Zabek MA, Wright J, Berman DM, Hampton JO, Collins CW (2015) Assessing the efficacy of medetomidine and tiletamine-zolazepam for remote immobilisation of feral horses (*Equus caballus*). *Wildlife Research* **41**(7), 615–622. doi:10.1071/WR14108

Data availability. Data relating to capture, handling and spatial behaviour are available on Zenodo (https://doi.org/10.5281/zenodo.20115803). Fieldwork for this study was conducted on private properties. The raw geographic data that support this study cannot be publicly shared because of ethical or privacy reasons and may be shared upon reasonable request to the corresponding author if appropriate.

Conflicts of interest. Jordan Hampton is an Associate Editor for *Wildlife Research* but was not involved in the peer review or decision-making process for this paper.

Declaration of funding. Funding for the field studies examined in this work was provided by Parks Victoria, Western Australia Department of Primary Industries and Regional Development, New South Wales Department of Primary Industries and Regional Development, and Riverina Local Land Services. No specific funding was provided for the preparation of this paper.

Acknowledgements. The authors wish to thank the WA Department of Biodiversity, Conservation and Attractions, Northern Biosecurity Group, Lake Muir Denbarker Community Feral Pig Eradication Group, Chittering Valley Land Conservation District Committee, Murdoch University, Department of Environment, Land, Water and Planning, Riverina Local Land Services, Bush Heritage Australia and Parks Victoria for facilitating this study. We thank Dave Forsyth and Chris Anderson for funding and managing Victorian fieldwork. We thank Jim Miller, Tracey Kreplins, Wayne Heal, Marieke Jensen, Jill Shephard, Darryl Crowley, Kevin Machen, Andy Lockey, Corissa Miller, Andrew Perry, Rob Atkinson, Mark Lamb, Chris Brausch, Suzie Holbery, and Pip Taylor for help with fieldwork.

Author affiliations

[A]NSW Department of Primary Industries and Regional Development, Vertebrate Pest Research Unit, 4 Marsden Park Road, Calala, NSW 2340, Australia.

[B]Harry Butler Institute, Murdoch University, 90 South Street, Murdoch, WA 6150, Australia.

[C]Department of Primary Industries and Regional Development, 1 Nash Street, Perth, WA 6000, Australia.

[D]NSW Department of Primary Industries and Regional Development, Vertebrate Pest Research Unit, 1447 Forest Road, Orange, NSW 2800, Australia.

[E]Evolution and Ecology Research Centre, The University of New South Wales, Sydney, NSW 2006, Australia.

[F]Centre for Invasive Species Solutions, PO Box 5005, University of Canberra, Canberra, ACT 2617, Australia.

[G]NSW Department of Primary Industries and Regional Development, Vertebrate Pests Biosecurity, 4 Marsden Park Road, Calala, NSW 2340, Australia.

[H]School of Veterinary Medicine, Murdoch University, 90 South Street, Murdoch, WA 6150, Australia.

[I]Faculty of Science, University of Melbourne, Parkville, Vic 3010, Australia.