To catch a buffalo: field immobilisation of Asian swamp buffalo using etorphine and xylazine

CR MCMAHON and CJA BRADSHAW

Objective To demonstrate the efficacy of a mixture of etorphine and xylazine to safely immobilise wild buffalo (*Bubalus bubalis*) in the field.

Methods Body mass was estimated (to calculate mass-specific dosages) by deriving a predictive relationship between morphometric measurements (body length, height) and mass based on a dataset collected in Vietnam, because the study animals could not be weighed in the field.

Results Mass-specific dosages varied between 0.02 and 0.03 mg/kg for etorphine and between 0.14 and 0.22 mg/kg for xyalazine; induction times varied between 10 and 33 min, mean recumbency time was 68 min, and the mean time to standing was 10 min (range: 10–17 min).

Conclusions The mixture of ethorphine and xylazine was effective for immobilisation of this species and appeared to have a relatively large safety margin, based on the mass-specific dosages used. The allometric relationships described here should prove useful for those working with wild swamp buffalo.

Key words: allometry, *Bubalus bubalis*, epidemiology, etorphine, diprenorphine, global positioning system, collars, home range, disease spread

Aust Vet J 2008;86:235–241 doi: 10.1111/j.1751-0813.2008.00303.x

GPS	Global positioning system
TL	Total dorsal length from the bos to the base of the tail
TS	Total dorsal length from the shoulder to the base of the tail
TN	Head length from the bos to the tip of the snout
MH	Maximum height from the hoof to the shoulder
GN	Maximum height from the girth around the neck
THO	Curvilinear length of the outside horn
THI	Curvilinear length of the inside horn
BH	Circumference around the base of the horn
GLM	Generalised linear models
K-L	Kullback-Leibler
AIC_c	Akaike's information criterion corrected for small sample sizes

School for Environmental Research, Charles Darwin University, Casuarina Campus, Darwin, NT 0909; clive.mcmahon@cdu.edu.au

Natural environments and the biotas they support are under ever-increasing human pressures from habitat destruction and fragmentation, overexploitation, invasive species, and climate change.[1–4] To conserve and manage the plants and animals in these systems requires knowledge of their ecology and life history. However, measuring behaviour, demography and other aspects of wild animals can be dangerous and often requires chemical immobilisation prior to capture and manipulation,[5] especially for large ungulates such as Asian swamp buffalo (*Bubalus bubalis*).

Asian swamp buffalo were introduced from Timor to Fort Dundas on Melville Island as a source of meat and hides in 1826. Only 2 years later, buffalo were brought to mainland Australia at Cobourg Peninsula where some were eventually released or escaped into the wild. As a consequence, large populations are well-established in the wet tropics of the Northern Territory, Australia. Extremely high densities of buffalo (> 25/km^2)[6] can lead to extensive damage to waterways and landscapes through vegetation destruction, soil compaction and saltwater intrusion.[7–9]

Swamp buffalo are important throughout Asia because they contribute to the agricultural economy through the provision of milk, meat and draught power. In Australia, there is a small niche market for buffalo products; however, their economic importance is measured more by their past, actual and potential damage to established Australian agricultural industries. Perhaps the most important of these is the not negligible probability of spreading livestock diseases such as tuberculosis, brucellosis and foot-and-mouth disease,[10] thereby threatening Australia's lucrative livestock disease-free status. For example, foot-and-mouth disease in the United Kingdom was estimated to have cost billions of pounds to the agricultural economy, and there may be similar, if not more devastating, consequences in Australia should a disease like foot-and-mouth ever become established.[11]

By the mid-1980s, buffalo were widespread and numerous in Northern Australia and the population was estimated to exceed 300,000.[9] In a bid to secure freedom from brucellosis and tuberculosis in domestic cattle, a broad-scale density-reduction program known as the Brucellosis and Tuberculosis Eradication Campaign was initiated.[10] Buffalo densities were greatly reduced, but although the program was largely successful in eradicating buffalo mainly from pastoral lands, the present-day population of free-ranging swamp buffalo is again large (given the high sighting rate throughout much of the north of the Northern Territory and high annual removal rates [several thousand individuals per year] in certain regions), and appears to be increasing (although

population size and trends remain largely unquantified. Estimated buffalo densities have increased from approximately 1.26 buffalo/km^2 to 2.68 buffalo/km^2 in our study area.[6,12,13] Continued expansion of the population is now again raising concerns of disease proliferation, so basic biological, ecological and epidemiological studies have been initiated in an attempt to understand how a pathogen might spread through the population, and how management authorities might minimise negative effects.[10]

Etorphine has been used extensively as an immobilisation agent in ungulates and a wealth of information exists describing its use and effects in many different species.[14–22] However, there is little published information on the use of etorphine and xylazine in wild swamp buffalo, probably because most of the world's population is domesticated and there has been little incentive to study the species in the wild. Nonetheless, etorphine-based combinations have been used for the chemical restraint of wild buffalo in reserves and zoological gardens around the world. The lack of published descriptions is a major practical deficiency for a widespread and commercially and socially valuable animal. Although some information exists from other, closely related bovids (e.g. African buffalo, *Syncerus caffer*), there are enough subtle differences between species in their physiological and morphological traits to warrant the study of optimal species-specific doses (e.g. as for dose differences between elephant species[23]). Here we describe the efficacy of etorphine as the principal immobilising agent for the field capture of wild swamp buffalo in the tropical north of Australia. To this end we also quantify the relationship between various morphometric measurements and mass. Animal size and therefore mass is an integral life history trait used to assess drug effectiveness.

Materials and methods

We chemically immobilised four wild adult male Asian swamp buffalo in October 2006 during field work based in remote western Arnhem Land, northern Australia (12°51′S, 134°22′E) with the aim of using global positioning system (GPS) collars. The data collected by the collars will record movement patterns over a single year.

Individuals were immobilised by remote intramuscular injection with a combination of etorphine (M99®, Novartis, South Africa) and xylazine (Xylazil-100®); the latter was added because (1) it allows for a reduction in the concentration of both agents to safer therapeutic levels, (2) opioid sedation in general is unpredictable and hence often improved by adding a sedative, such as xylazine, and (3) it is an excellent muscle-relaxant.[24] We used this combination of drugs because both agents are easily reversible and have specific antagonists: diprenorphine (M5050 [Novartis]) for etorphine and yohimbine (Reverzine®) for xylazine. The drug combination was delivered in a 4-mL capacity dart with a 50-mm barbed needle shot from a hovering helicopter (Bell Jet Ranger) via a .22 calibre dart projector (Pneu-Dart, Williamsport, PA, USA). Etorphine was delivered at a nominal (based on a total body mass = 700 kg) dose of 15 µg/kg, xylazine at 0.11 mg/kg (1.2 mL of M99 at a concentration of 9.8 mg/mL) and 0.8 mL of Xylazil-100 at a concentration of 100 mg/mL) (Table 1). Antagonists were delivered IM at nominal rates of 0.021 mg/kg for diprenorphine (12 mg/mL) and 0.25 mg/kg for yohimbine (10 mg/mL) (Table 1).

A handheld water sprayer (20-L capacity) was used to mist the immobilised buffalo continually to prevent hyperthermia, as well as covering the head and back with wet hessian bags. Spraying commenced immediately the animal was immobilised and deemed safe to approach and was continued for the duration of the capture procedure. All animals were placed in sternal recumbency at the onset of immobilisation, an ophthalmic ointment was applied and the animal was blindfolded (Figure 1). To assist breathing and respiration through oxygen saturation of haemoglobin and further heat dissipation, we supplied pure oxygen intranasally at 1–2 L/min for the duration of the procedure (Figure 1).

For each capture we recorded the drug dose delivered, time to recumbency (defined as the time from when the drug was delivered

Table 1. Individual mass-specific dosages of etorphine and xylazine, and their specific antagonists (diprenorphine and yohimbine), and the responses of the four buffalo

Animal			Immobilising agent		Antagonists		Buffalo response variables			
No.	Total length (m)	$Mass_{est}$ (kg)	Etorphine (mg/kg)	Xylazine (mg/kg)	Diprenorphine (mg/kg)	Yohimbine (mg/kg)	Time to recumbency (min)	Level of chemical restraint	Recumbency time (min)	Standing time (min)
1	1.77	362	12.0 (0.033)	80.0 (0.22)	16.8 (0.046)	160 (0.44)	10	6	77	8
2	1.76	491	12.0 (0.024)	80.0 (0.16)	16.8 (0.034)	160 (0.33)	26	5	64	17
3	1.98	575	12.0 (0.021)	80.0 (0.14)	16.8 (0.029)	160 (0.28)	26	5	60	7
4	1.83	517	12.0 (0.023)	80.0 (0.15)	17.9 (0.035)	170 (0.33)	33	3	71	8
Mean	1.84	486	12.0 (0.025)	80.0 (0.16)	17.1 (0.035)	162.4 (0.33)	23.8	5	68.0	10.0

The concentrations of the drugs were: etorphine 9.8 mg/mL, xylazine 100 mg/mL, diprenorphine 12 mg/mL, yohimbine 10 mg/mL. Level of chemical restraint: 1 = light sedation, 2 = moderate sedation, 3 = heavy sedation, 4 = light immobilisation, 5 = heavy immobilisation, 6 = light anaesthesia.[27]

Figure 1. Immobilised male swamp buffalo (*Bubalus bubalis*) being fitted with a global positioning system collar. Note the intranasal tube supplying oxygen and the wet hessian bags used to keep the animal cool.

to the time that the animal lay down (lateral recumbency), level of chemical restraint[25,26] (using the following ordinal scale: level 1 = light sedation, level 2 = moderate sedation, level 3 = heavy sedation, level 4 = light immobilisation, level 5 = heavy immobilisation, level 6 = light anaesthesia), rectal temperature, recumbency time (time from when the animal lay down to when it stood up and walked away of its own accord after having received the antagonist M5050; dependent on the time taken to attach the GPS collar), and time to standing (time from injection of antagonists to when the animal stood up and walked away). Prior to administering the antagonists, we also injected each buffalo with 20 mL of long-acting penicillin (Benacillin®, IM) for parenteral treatment of infections, 20 mL of a selenium–vitamin E (tocopherol) mixture (Selvite E®) IM to counteract some of the adverse effects of capture myopathy,[27] and 20 mL of invermectin (Ivomec®, SC), an antiparasitic preparation that is effective against common internal and external parasites.[28] All drugs were stored and transported at below 25°C in the field.

We also took several morphometric measurements of the immobilised animals: total dorsal length from the bos to the base of the tail (TL), dorsal length from the shoulder to the base of the tail (TS), head length from the bos to the tip of the snout (TN), maximum height (MH) from the hoof to the shoulder (withers), girth around the neck (GN), curvilinear length of the outside horn (THO), curvilinear length of the inside horn (THI), and the circumference around the base of the horn (BH). We tagged each animal with two uniquely numbered plastic cattle ear tags (Allflex® Australia).

Analysis

To provide mass-specific dosages, we needed to estimate body mass based on our morphometric measurements. We obtained mass-measurement data (mass, TS and MH) for *B. bubalis* from northern Vietnam collected by the BIODIVA-Project for 33 individuals (19 males, 14 females) (unpublished data). We constructed five a priori linear models to derive an equation for predicting mass (Table 2). Models tested various hypotheses regarding the relationship between the additive effects of TS and MH to mass, as well as the expectation that the relationships differed between males and females. TS and MH were cubed to account for the cubic relationship between volume and length.[29] The relationships were constructed using generalised linear models (GLM) with a Gaussian error distribution and identity link function implemented in the *R* statistical package.[30]

An index of Kullback-Leibler (K-L) information loss was used to assign relative strengths of evidence to the different competing models,[31] and Akaike's information criterion (AIC_c) corrected for small sample sizes. This measure of model parsimony identifies those model(s) from a set of candidate models that minimise K-L information loss,[32] with the relative likelihoods of candidate models calculated using AIC_c weights.[33] Thus, the weight ($wAIC_c$) of any particular model varies from 0 (no support) to 1 (complete support) relative to the entire model set. Goodness-of-fit was assessed be calculating the per cent deviance explained for each model.

The saturated model (including all terms) had the highest information-theoretic model weight (see Results). The supported influence of the sex term required the construction of two separate relationships to predict mass (M_{est}):

$$M_{est} = \text{intercept} + TS^3 + MH^3$$

Using the male-specific equation (see Results) we calculated expected masses for the four captured buffalo for the estimation of mass-specific dosages. Single-term relationships between mass and the transformed variables were also assessed using information-theoretic evidence ratios ($ER = wAIC_c$ of the slope model ÷ $wAIC_c$ of the intercept [null] model).[31] We used the least-squares R^2 as a measure of the linear model's goodness-of-fit. All procedures and techniques used were reviewed and approved by the Animal Ethics Committee of Charles Darwin University.

Precautions

Etorphine is an extremely potent neuroleptanalgesic and, consequently, is highly toxic to humans.[22,33,34] Given this toxicity, up to 1000-fold the potency of morphine,[35] its use in Australia is restricted to licensed individuals. In humans, etorphine causes dizziness, nausea, respiratory depression, cyanosis, hypotension, loss of consciousness and death.[36] As a precaution against accidental injection or spillage/splashing when handling etorphine to load the darts, we wore (1) protective plastic full-face masks, (2) a double layer of latex surgical gloves, and (3) protective long-sleeved laboratory coats and closed shoes. In addition, we had 25 2-mL ampule doses of the pure opioid antagonist, naloxone, to treat accidental injection or contact with body tissues. The recommended procedure is to inject naloxone (0.4 mg/mL) in 1-mL doses IV or IM at intervals of 2–3 min until signs of

Figure 2. Australian swamp buffalo (*Bubalus bubalis*) mixing freely with a herd of domestic cattle in central Arnhem Land, northern Australia, demonstrates the great potential for spreading disease between wild and domesticated animals.

improvement of narcosis are observed. All the personnel handling etorphine were well-trained in cardiopulmonary resuscitation techniques.

Results

Estimating mass

The most parsimonious model for estimating mass was the saturated model that included sex, length (TS) and withers (MH), accounting for 90% of the deviance in mass (Table 2, Figure 2). Thus, the sex-specific equations were:

$$m_{male} = 144.70 + 29.15 \cdot TS^3 + 148.97 \cdot MH^3$$

$$m_{female} = 67.98 + 16.61 \cdot TS^3 + 176.39 \cdot MH^3$$

where TS and MH are measured in metres. The male-specific equation predicted masses of 362, 491, 575 and 577 kg, respectively, for the four captured buffalo ($\bar{x}$ = 501.3 kg).

Table 2. *A priori* model set examining the hypothesised relationships among mass, sex, dorsal body length from shoulder to the pin bone (TS, in m) and vertical body height (MH, in m)

Model	*k*	*LL*	ΔAIC_c	$wAIC_c$	%DE
mass~sex+TS^3+MH^3	5	–151.8	0.0	0.999	89.8
mass~MH^3	3	–161. 7	14.4	7.4×10^{-4}	81.3
mass~TS^3+MH^3	4	–160.9	15.6	4.2×10^{-4}	82.2
mass~TS^3	3	–168.5	28.1	8.1×10^{-7}	71.9
mass~1	2	–189.4	67.5	2.2×10^{-15}	0

Models are ranked according to an information-theoretic measure of parsimony: Akaike's information criterion corrected for small sample sizes (AIC_c). Number of parameters (*k*), maximum log-likelihood (*LL*), the change in AIC_c between the top-ranked and subsequent models (ΔAIC_c), AIC_c weights ($wAIC_c$) and the per cent deviance explained (%DE) for each model.

Efficacy of the etorphine/xylazine mixture

Induction and recovery were uncomplicated, such that mucous membrane colour, capillary refill time and maintenance of body temperature were within generally accepted ranges (Table 3).[5] Mean induction time was 24 min (range: 10–33 min), mean recumbency time was 68 min (range: 60–77 min), and mean time to standing was 10 min (range: 7–17 min). The mean level of chemical restraint was 5, which is characterised by some muscle tone and a faint palpebral response. However, one animal (buffalo 4 in Table 1) was only immobilised to level 3 (moderately sedated), which was just sufficient to allow a GPS collar to be attached. This relatively lower level of immobilisation (compared with the other three buffalo) may have been the result of the longer chase time required (from spotting the animal to when the dart was fired; data not recorded). Another explanation may be that not all of the drug was delivered, because of inadequate muscle penetration, although this seems unlikely given that the length of the needle was 50 mm (i.e. long enough to have gained access to the underlying muscle through the hide [mean hide thickness = 16.5 mm, SD = 4.7 mm, n = 32 – these data were collected as part of the broader ecological epidemiological study]). None of the needles when removed were bent and all were well embedded in the muscle. One week post-capture, all four animals were seen alive and roaming freely with their collars attached and at that time we did not observe any overt signs of capture myopathy, such as muscle stiffness or lack of coordination.

Discussion

In the present study, the combination of etorphine and xylazine delivered remotely by a dart travelling at high velocity from a hovering helicopter was effective for immobilising wild swamp buffalo. Appropriate concentrations of both of these drugs can be delivered in a small volume of liquid and both agents have the added advantage of being reversible with specific antagonists. The level of immobilisation and lack of complications permitted safe, rapid and effective manipulation of the animals for measurement and GPS collar deployment. The depth of immobilisation, which was acceptable given that all of the buffalo recovered

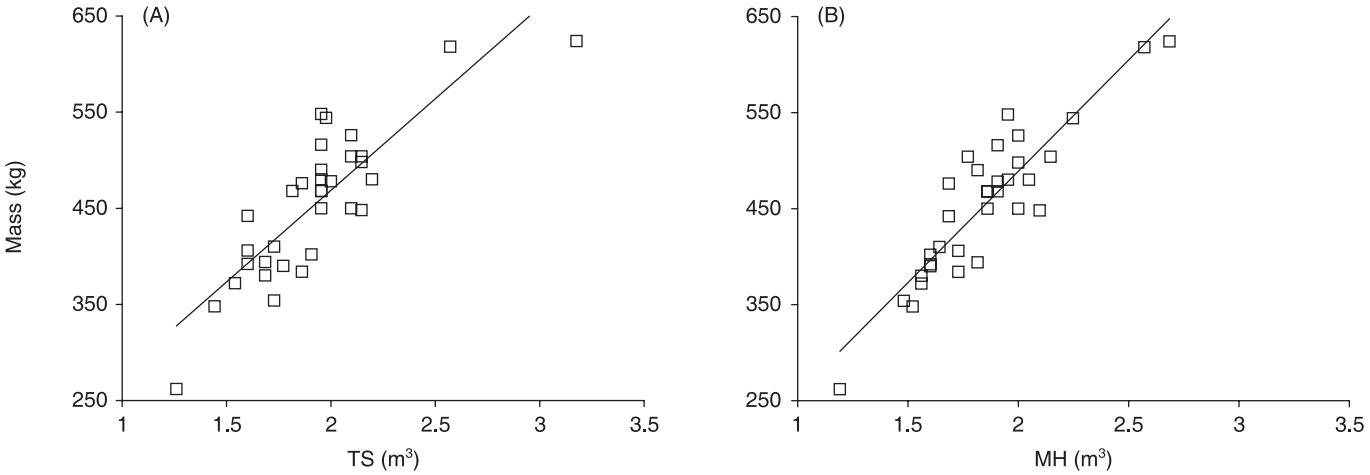

Figure 3. Relationships of mass (kg) and (A) dorsal body length from shoulder to the pin bone (TS, in m) and (B) vertical body height (MH, in m). The univariate relationships were strongly supported (information-theoretic evidence ratios [*ER*] and R^2 goodness-of-fit): (A) $ER = 3 \times 10^8$, $R^2 = 0.71$); (B) $ER = 3 \times 10^{11}$, $R^2 = 0.81$).

Table 3. Body temperature of the four Asian swamp buffalo

	1	2	3	4
Start time (t)	Temperature (°C)			
	08:10	15:00	08:20	11:00
t (min)	39.0	40.1	36.6	40.6
t + 5	39.1	40.2	36.6	40.5
t + 10	39.1	40.1	36.6	40.2
t + 15	39.1	40.1	36.6	40.0
t + 20	39.0	39.9	36.6	40.0
t + 25	39.0	39.9	36.6	39.9
t + 30	38.9	39.8	36.6	39.9
t + 35	38.8	39.7	36.6	39.9
t + 40	38.8	39.6	36.6	39.9
t + 45	38.8	39.6	36.6	39.9
t + 50	38.8		36.6	39.9
t + 55	38.8			39.9
t + 60	38.7			
t + 65	38.7			
t + 70	38.7			

Sustained high body temperature is the most common capture-related problem, so temperature monitoring is a valuable tool for avoiding hyperthermia-related complications.[5]

without recorded incident, and immediate placement of animals in sternal recumbency, effectively reduced the likelihood of bloat, regurgitation, aspiration and severe hypoxia.[37]

The induction times were relatively long, and our experience suggests that animals that are pursued for longer periods are less likely to display a typical response to immobilising agents. Our anecdotal observations of a prolonged recovery or lack of response to the immobilising agents, especially alpha-2 agonists such as xylazine, in excited or agitated animals are supported by published reports.[38–40] Another explanation is that swamp buffalo have unique physiological traits that make them less susceptible to etorphine immobilisation, which would warrant further investigation. However, it is more likely that incomplete drug delivery or excitation of the animal before and after darting and prior to recumbency contributed to the outcome. In the present study, the length and type of needles used in the darts, and their complete penetration of the hide, appear to rule out incomplete drug delivery as the cause of the long induction times, which suggests that that there were profound physiological effects of excitation on the drugs' absorption and action.

This study is an important precursor to the goal of collecting comprehensive behavioural, ecological and epidemiological information about swamp buffalo in northern Australia. Buffalo are potentially a major vector for several debilitating livestock (and possibly human) diseases (Figure 3), so continued collection of basic data for both the construction of eco-epidemiological models predicting their impact and for efficient control is essential. Our results are the first reported doses for the only known drug combination that effectively immobilises the wild swamp buffalo. A previous study of non-native banteng (*Bos javanicus*) in Australia determined that a relatively high volume (5–7 mL) of a combination of detomidine (Dormosedan®, Novartis Animal Health Australasia Pty Ltd) and tiletamine–zolazepam (Zoletil-100®, Virbac Australia Pty Ltd) was required for sufficient immobilisation,[38] but that drug combination is likely to be ineffective in wild swamp buffalo, given their generally larger size and higher levels of aggression[42] and the necessity for aerial delivery systems (i.e. the darts would not hold the volume required).

Conclusion

In the present study of the immobilisation of wild swamp buffalo, the induction times were, in our opinion, too long (mean = 24 min),

which can result in long chase sequences that exhaust the target animal, thus increasing the risk of traumatic injury, induce hyperthermia, and may cause capture myopathy that kills the animal even weeks post-capture.[27] Although we were able to minimise the risk of these complications, a reduction in the induction time is still desirable. There are three options: (1) administer higher doses, (2) deliver the principal immobilising drugs in a medium that facilitates uptake of the agent, and (3) add sedative drugs, such as acepromazine, to etorphine (e.g. Large Animal Immobilon®). Administration of higher doses, especially if specific antagonists are available to reverse the immobilisation, may be effective. The second and third options are attractive because uptake-facilitating agents such as hyaluronidase have been used to reduce induction times in other bovids, and immobilising agents such as Large Animal Immobilon® are available commercially. Hyaluronidase is stable for up to 48 hours when mixed with immobilising agents, and facilitates absorption by increasing tissue permeability and absorptive tissue area by as much as 40%.[42]

Nonetheless, the combination of etorphine and xylazine alone is effective for safe and efficient immobilisation of wild swamp buffalo, and is potentially a much safer drug combination than detomidine and tiletamine:zolazepam for use with other large ungulates introduced to Australia (e.g. banteng, horses and donkeys). Given that both agents (etorphine and xylazine) can be antagonised (diprenorphine and yohimbine, respectively), this combination has an advantage over many others in which only one (or none) of the agents can be reversed (e.g. tiletamine in Zoletil®). The provision of species-specific doses will facilitate studies of large wild ungulates that require chemical immobilisation prior to manipulation.

Acknowledgments

We thank P Carmody (NT Parks and Wildlife Service), J Rostron, M Rostron, V Rostron and M Ryan (Djelk Rangers), I Gurry (Parap Veterinary Surgery), C Crossing, K Mines (Charles Darwin University), M Haupt (University of Pretoria), F Holzträger and R Upton (Novartis South Africa), A Teesman (Jayro Helicopters) and H Stone (Poisons Branch, NT Government). We extend special thanks to C Berthouly and M Pedrono (BIODIVA-Project) for allowing us to use their morphometric data. This project was funded by an Australian Research Council Linkage Project grant (LP0669303) to both authors.

References

1. Balmford A, Green RE, Jenkins M. Measuring the changing state of nature. *Trends Ecol Evol* 2003;18:326–330.
2. Clavero M, García-Berthou E. Invasive species are a leading cause of animal extinctions. *Trends Ecol Evol* 2005;20:110–110.
3. Laurance WF. Reflections on the tropical deforestation crisis. *Biol Conserv* 1999;91:109–117.
4. Sodhi NS, Brook BW, Bradshaw CJA. *Tropical conservation biology*. Blackwell Publishing, Oxford, 2007.
5. Osofsky SA, Hirsch KJ. Chemical restraint of endangered mammals for conservation purposes: a practical primer. *Oryx* 2000;34:27–33.
6. Bayliss P, Yeomans KM. Distribution and abundance of feral livestock in the Top End of the Northern Territory (1985–86), and their relation to population control. *Aust Wildlife Res* 1989;16:651–676.
7. Knighton AD, Mills K, Woodroffe CD. Tidal creek extension and saltwater intrusion in Northern Australia. *Geology* 1991;19:831–834.
8. Mulrennan ME, Woodroffe CD. Saltwater intrusion into the coastal plainsof the lower Mary River, Northern Territory, Australia. *J Environ Manag* 1998;54:169–188.
9. Skeat AJ, East TJ, Corbett LK. Impact of feral water buffalo. In: Finlayson CM, Oertzen IV, editors. *Landscape and vegetation ecology of the Kakadu region, Northern Australia*. Kluwer Academic Publishers, The Netherlands, 1996:155–177.
10. Radunz B. Surveillance and risk management during the latter stages of eradication: experiences from Australia. *Vet Microbiol* 2006;112:283–290.
11. Department of Environment and Heritage. *Review of progress on invasive species*. Natural Resource Management Policy Branch, Canberra, 2005.
12. Koenig J, Griffiths AD, Godjuwa C, Camion O. Aerial survey of vertebrates in the Mann river district, central Arnhem Land. *Northern Territory Naturalist* 2003;17:7–19.
13. Yibarbuk D, Whitehead PJ, Russell-Smith J et al. Fire ecology and Aboriginal land management in central Arnhem Land, northern Australia: a tradition of ecosystem management. *J Biogeogr* 2001;28:325–343.
14. Ancrenaz M, Ostrowski S, Anagariyah S, Delhomme A. Long-duration anesthesia in Arabian oryx (*Oryx leucoryx*) using a medetomidine-etorphine combination. *J Zoo Wildl Med* 1996;27:209–216.
15. Gatesman T, Wiesner H. Immobilization of polar (*Thalarctos maritimus*) and brown (*Ursus arctos*) bears using etorphine and xylazine. *J Zoo Animal Med* 1982;13:11–18.
16. Griffiths D, Wiig O, Gjertz I. Immobilization of walrus with etorphine hydrochloride and Zoletil®. *Marine Mammal Sci* 1993;9:250–257.
17. Kock MD, Lagrange M, Dutoit R. Chemical immobilization of free-ranging black rhinoceros (*Diceros bicornis*) using combinations of etorphine (M99), fentanyl, and xylazine. *J Zoo Wildlife Med* 1990;21:155–165.
18. Kock MD, Martin RB, Kock N. Chemical immobilization of free-ranging African elephants (*Loxodonta africana*) in Zimbabwe, using etorphine (M99) mixed with hyaluronidase, and evaluation of biological data collected soon after immobilization. *J Zoo Wildlife Med* 1993;24:1–10.
19. Kock MD, Morkel P, Atkinson M, Foggin C. Chemical immobilization of free-ranging white rhinoceros (*Ceratotherium simum simum*) in Hwange and Matobo National Parks, Zimbabwe, using combinations of etorphine (M99), fentanyl, xylazine, and detomidine. *J Zoo Wildlife Med* 1995;26:207–219.
20. Koubek P, Mrlik V. Immobilization of the stags of red deer (*Cervus elaphus* L) by etorphine. *Vet Med* 1988;33:375–380.
21. Ramdohr S, Bornemann H, Plotz J, Bester MN. Immobilization of free-ranging adult male southern elephant seals with Immobilon (TM) (etorphine/acepromacine) and ketamine. *S Afr J Wildlife Res* 2001;31:135–140.
22. Haigh JC. Opioids in zoological medicine. *J Zoo Wildlife Med* 1990;21:391–413.
23. Gray CW, Nettasinghe APW. A preliminary study of immobilization of the Asiatic elephant (*Elephas maximus*) utilizing etorphine (M-99). *Zoologica* 1970;55:51–53.
24. Khan ZP, Ferguson CN, Jones RM. Alpha-2 and imidazoline receptor agonists: their pharmacology and therapeutic role. *Anaesthesia* 1999;54:146–165.
25. McMahon CR, Burton HR, McLean S, Slip D, Bester MN. Field immobilisation of southern elephant seals with intravenous tiletamine and zolazepam. *Vet Rec* 2000;146:251–254.
26. Woods R, McLean S, Nichol S, Burton HR. A comparison of some cyclohexamine based drug combinations for chemical restraint of southern elephant seals (*Mirounga leonina*). *Marine Mammal Sci* 1994;10:412–429.
27. Chalmers GA, Barrett MW. Capture myopathy. In: Hoff GL, Davis JW, editors. *Noninfectious diseases of wildlife*. Iowa State University Press, Ames, 1982:84–94.
28. Fox LM. Ivermectin: uses and impact 20 years on. *Curr Opin Inf Dis* 2006;19:588–593.
29. Tierney M, Hindell MA, Lea M-A, Tollit D. A comparison of techniques used to determine body condition of southern elephant seals, *Mirounga leonina*. *Wildlife Res* 2001;28:581–588.
30. R Development Core Team. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria, 2004.
31. Burnham KP, Anderson DR. *Model selection and multimodal inference: a practical information-theoretic approach*. Springer-Verlag, New York, 2002.
32. Burnham KP, Anderson DR. Multimodel inference: understanding AIC and BIC in model selection. *Sociol Methods Res* 2004;33:261–304.

33. Blane GF, Boura ALA, Fitzgerald AE, Lister RE. Actions of etorphine hydrochloride (M99): a potent morphine like agent. *Br J Pharmacol Chemother* 1967;30:11–22.
34. Blane GF. Trial of etorphine hydrochloride (M99-Reckitt) in carcinoma pain: preliminary report. *Br J Pharmacol* 1970;39:252P–253P.
35. Dobbs HE. Effect of cyprenorphine (m285), a morphine antagonist, on the distribution and excretion of etorphine (m99), a potent morphine-like drug. *J Pharmacol Exp Ther* 1968;160:407–414.
36. Sterken J, Troubleyn J, Gasthuys F et al. Intentional overdose of large animal immobilon. *Eur J Emerg Med* 2004;11:298–301.
37. Bradshaw CJA, Traill LW, Wertz KL, White WH, Gurry IM. Chemical immobilisation of wild banteng (*Bos javanicus*) in northern Australia using detomidine, tiletamine and zolazepam. *Aust Vet J* 2005;83:616–617.
38. DeKock M, Meert TF. Alpha(2)-adrenoceptor agonists and stress-induced analgesia in rats: Influence of stressors and methods of analysis. *Pharmacol Biochem Behav* 1997;58:109–117.
39. Greene SA, Thurmon JC. Xylazine: a review of its pharmacology and use in veterinary-medicine. *J Vet Pharmacol Ther* 1988;11:295–313.
40. Walter WD, Leslie DM, Herner-Thogmartin JH, Smith KG, Cartwright ME. Efficacy of immobilizing free-ranging elk with Telazol (R) and xylazine hydrochloride using transmitter-equipped darts. *J Wildlife Dis* 2005;41:395–400.
41. Tulloch DG. Water buffalo, *Bubalus bubalis*, in Australia: reproductive and parent-offspring behavior. *Aust Wildlife Res* 1979;6:265–287.
42. Booth NH, McDonald LE. *Veterinary pharmacology and therapeutics*. 6th edn. Iowa State University Press, Ames, 1988.

(Accepted for publication 6 November 2007)

Graham Irving Alexander, AO

1928 – 2007

Queensland has lost a giant contributor to agricultural productivity, rural research and community service with the death of Dr Graham Alexander

Queensland Country Life

Graham Alexander had a distinguished career as a veterinarian, public servant and catalyst for international development. He grew up in North Queensland and maintained a strong affinity with the bush. Graham rose from a cadetship awarded by the then Queensland Department of Agriculture and Stock (QDPI) to become its Director General in 1980. As was customary at the time, he completed final years at Sydney University. Initial postings were to Brisbane and Rockhampton, and a Doctorate at Oregon State University researching animal genetics exposed him to the American system. He promoted the training and development of his staff by course work inside and outside the Department.

Graham became Cattle Husbandry Branch Director in 1964. He had already initiated the early work that led to widespread acceptance of Brahman cattle. Graham then took up the challenge to reverse the 'league table' in Australian milk production per cow. In 1968 Queensland's production per cow was only half that of Victoria, but when Graham developed an innovative research and extension program with a dedicated team who worked closely with the Queensland dairy industry, per cow production steadily increased, and by the 1980s exceeded that of Victoria.

After leaving QDPI, Graham's existing international career expanded dramatically in the 1990s. His unique background across primary industries led to significant knowledge transfer and industry developments in livestock and horticulture in the ASEAN countries. He led a highly successful Australian group in closing gaps in the world's knowledge of bluetongue, and was involved in the development and management of the Australian Animal Health Laboratory. Graham's involvement in animal disease control began as an undergraduate with his 1947 brucellosis study and was maintained throughout his career with BTEC (Brucellosis and Tuberculosis Eradication Campaign). He chaired the 1995 national review of BTEC and the Tuberculosis Freedom Assurance Program review in 2001. Graham was keen to see the AVA take a stronger role in eradicating feral animals, following the successful eradication of tuberculosis and brucellosis.

The Australian Veterinary Association was an early interest and he moved through Queensland President (1968) to Australian President in 1977–78. Graham was closely involved in establishing the Australian Association of Cattle Veterinarians (President 1974–76), and the formation of the Australian College of Veterinary Scientists (Presidential Award 1988) of which he was President twice. In 1985 he was awarded the Kendall Oration and Medal; and the Gilruth Prize in 1999. He was President of the Australian Society of Animal Production 1968–70 and held four fellowships of agricultural societies, various life memberships and was Queensland Professional of the Year 2000. He tirelessly supported the Queensland University Veterinary Faculty and the university at large, as a member of the University Senate for 18 years and Deputy Chancellor of the University 1993–95.

Graham's veterinary and rural community interests were varied and he nominated almost 40 people for honours and awards. He was a lateral thinker, a veterinarian and a proud and effective Australian.

T St George, G Murphy and M Alexander

doi: 10.1111/j.1751-0813.2008.00309.x