Report to WaterNSW on sarcoptic mange in wombats at Bendeela Recreation Area and proposed strategies for disease management

Scott Carver
Associate Professor of Wildlife Ecology
University of Tasmania
scott.carver@utas.edu.au

Introduction

Bare-nosed wombats (*Vombatus ursinus*, a.k.a. common wombats) are medium sized fossorial (burrowing) and nocturnal marsupial herbivores that primarily graze upon native and introduced grasses and grass roots (Triggs, 2009). Adult bare-nosed wombats weigh approximately 22kg, making them among the largest burrowing herbivores in the world (Johnson, 1998). In general, bare-nosed wombats spend up to 20 hours per day within their burrows and emerge around dusk to forage for approximately four hours per night. However, there is much individual variation, with some individuals emerging earlier or later, and foraging for shorter or longer periods (McIlroy, 1973). This species utilises burrows for a range of purposes (e.g., rest, thermal refuge, shelter from potential predators and fire) and switches the burrow that they sleep in every 1-9 days (Martin et al., 2019, Skerratt et al., 2004a). Bare-nosed wombats are solitary in nature, but are not territorial, having overlapping home ranges, and exhibiting tolerance of the presence of one another while foraging (Evans, 2008). The home range size of bare-nosed wombats is relatively small (150-400 meters in diameter) at elevations below 500 meters above sea level, and their densities are typically 0.1-0.5 individuals per hectare in suitable habitat (Green, 2005, Skerratt et al., 2004a). The main threatening processes faced by bare-nosed wombats are vehicle collisions, persecution by people, and disease (Martin et al., 2017).

The most significant health threat to bare-nosed wombats is sarcoptic mange, which is a disease caused by a parasitic mite, *Sarcoptes scabiei* (Martin et al., 2017). This parasite was introduced to Australia, likely multiple times, by European settlers and their domestic animals and has spilled over into wombats (Fraser et al., 2016). Called scabies in humans and sarcoptic mange in all other animals, *S. scabiei* is one of the most geographically widespread and burdensome of mammalian parasites, and has been documented to infect at least 150 mammal species (Escobar et al., 2022). This parasitic mite burrows into the skin of its host (including in wombats) causing a range of health impacts, with the most obvious being significant hair loss (alopecia), thickening and crusting of the skin (hyperkeratosis) and emaciation. The symptoms caused by *S. scabiei* infection are essentially a type of allergic response by the host to the parasite (Næsborg-Nielsen et al., 2022). Wombats appear to transmit *S. scabiei* among one another owing to their propensity to switch burrows, where a mange affected wombat may shed mites into the bedding chamber of a burrow, leading to transmission when it vacates the borrow and a healthy wombat colonises (Martin et al., 2018a). This is termed environmental transmission.

Available research suggests that once a bare-nosed wombat becomes infected with *S. scabiei*, the disease will progress over a period of approximately three months, ultimately resulting in death of the individual (Martin et al., 2018b, Skerratt et al., 2004b, Skerratt, 2003). Visible signs of disease start to become apparent 2-4 weeks after infection. The wombat will progressively lose fur, beginning around the abdomen and flanks and spreading from there. Hair loss may ultimately expand up to 80% of the body, but there is much

variation in extent among individuals (Skerratt et al., 1999). Mange affected wombats will also exhibit thickening and cracking of the skin, particularly along the flanks, upper limbs and neck, and broken skin can become fly-blown and infected with microorganisms, resulting in a significant odour at advanced stages of disease. Because of the metabolic demands of sarcoptic mange on bare-nosed wombats, individuals may emerge from burrows earlier and spend up to four times longer foraging each day, while still becoming emaciated (Martin et al., 2018b, Simpson et al., 2016). Clearly, bare-nosed wombats experience significant suffering as a consequence of sarcoptic mange. Outbreaks of sarcoptic mange occasionally occur and cause the decline of wombat populations, but more commonly sarcoptic mange occurs as an endemic infection in the population (Martin et al., 2018a, Beeton et al., 2019, Driessen et al., 2022). Thus, sarcoptic mange is primarily an animal welfare issue to bare-nosed wombats and occasionally a local conservation issue.

More positively, sarcoptic mange is a treatable disease in wombats. A range of treatment options exist, with the main ones being ivermectin, moxidectin (Cydectin), and fluralaner (Bravecto) (Mounsey et al., 2022, Bains et al., 2022, Takano et al., 2023). Treatments are typically delivered using a burrow flap or pole and scoop (Martin et al., 2017). More recently there have been advances toward using other treatment delivery methods, with one of these being a modified Jabstick (Dan Inject), which supports spot-on treatment delivery to free living wombats. Wombats are treated for sarcoptic mange by a wide group of people across southeast Australia, particularly wildlife carers and rehabilitators (Martin et al., 2017). Not all wombats that receive a treatment for sarcoptic mange may recover owing to individual variation in disease severity, secondary complicating factors, and the adequacy of drug dose received (Mounsey et al., 2022). Varying information exists on the safety, pharmacokinetics and efficacy of the major treatments for wombats (Mounsey et al., 2022, Bains et al., 2022, Wilkinson et al., 2021, Death et al., 2011, Skerratt et al., 2004b, Takano et al., 2023). The most modern treatment is Bravecto, which also has the most complete body of safety, pharmacokinetic and efficacy information (Wilkinson et al., 2021, Carver et al., 2022). The key advantages of Bravecto are the high degree of safety to wombats and longer duration of efficacy (Wilkinson et al., 2021). The key challenge of Bravecto has been spot-on drug delivery, but this challenge is largely overcome through use of the Jabstick.

Wombats, sarcoptic mange and Bendeela Recreation Area

Bendeela Recreation Area (Figure 1) is home to a large population of bare-nosed wombats, and this forms a feature of the site that attracts campers and the general public. For the most part, wombat burrows are located in vegetation surrounding the camping areas. Typically, bare-nosed wombats begin emerging from burrows around dusk and forage on grass within the camping areas, and also surrounding vegetation. Within the camping area, the wombats are relatively habituated to humans, which presents a relatively rare opportunity for campers and the public to observe and photograph these iconic native marsupials. Many photos of wombats at Bendeela make it onto social media platforms further promoting the site and WaterNSW, but sometimes also attracting criticism and consequently presenting a public-relations issue. Reports of sarcoptic mange in bare-nosed wombats at Bendeela occur, and this presents a challenge for WaterNSW in their stewardship of the site and the welfare of wildlife therein, and also in managing public relations and expectations. Because of the profile of wombats at Bendeela, the occurrence of visibly sick individuals has garnered the interest of community groups, such as wildlife rescue and rehabilitation groups. Prior to the research presented in this report, the scale of the wombat mange issue at Bendeela was not

well understood (anecdotal reports ranged from 5-90% of wombats impacted), and practical and sustainable management options had yet to be considered. It is commendable that WaterNSW has been proactive in seeking to objectively understand the sarcoptic mange problem in wombats at Bendeela and seeks to identify a sustainable management program going forward.

Aims of this project

The aims of this project at Bendeela Recreation Area were to: (1) undertake surveys of bare-nosed wombats to gain an objective understanding of the extent of mange disease at the site; (2) utilising research advances in the control of sarcoptic mange in wombats and findings from surveys, develop a practical and sustainable management practice; (3) to undertake public consultation on what is happening and findings at Bendeela; and (4) to provide management recommendations and proposed strategies back to WaterNSW.

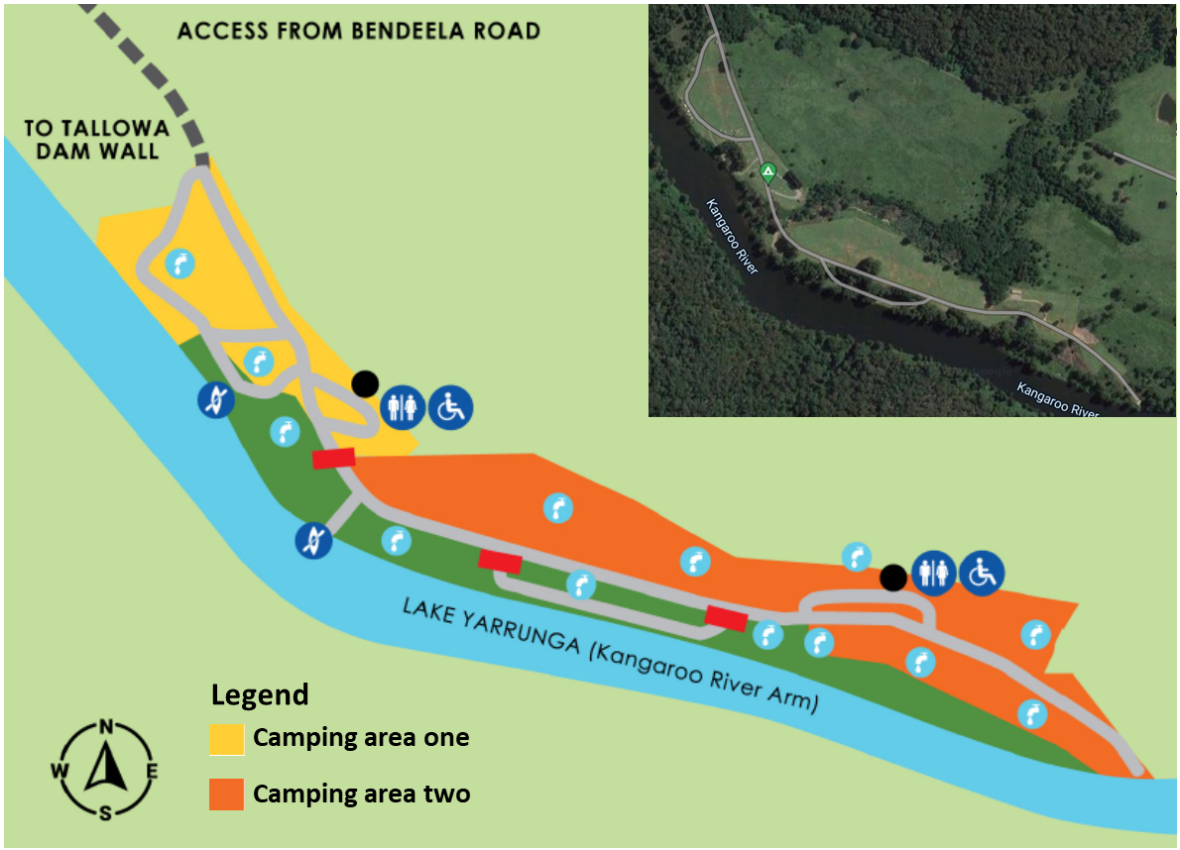


Figure 1. Map of Bendeela Recreation area with Google Earth map inset. This study focused on wombats occurring within Camping areas one and two. Map modified from https://www.waternsw.com.au/nsw-dams/greater-sydney-dams/bendeela-recreation-area

Methods, Results and Interpretations

Wombat and mange surveys

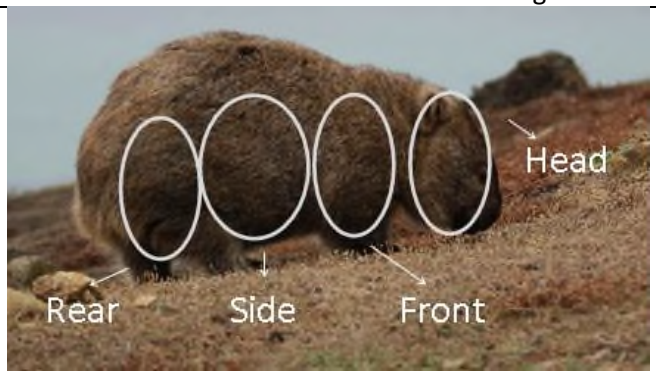
Five pre-treatment survey trips were undertaken between December 2020 and November 2021. Capacity to undertake pre-treatment transect surveys was impacted by COVID19 travel

restrictions for much of 2020 and 2021, influencing survey frequency (see Figure 3). Each survey trip involved walking transects across the length of both Camping areas one and two (Figure 1), and in some cases surrounding vegetation areas. On each occasion, transect surveys commenced in the hour before dusk and continued until an hour after dark. The length of the campground was covered twice on each survey occasion and attempts were made not to double count wombats, based on their location. Surveys were repeated for two nights each trip, although some of the early trips lasted three nights in order to investigate the feasibility of surveying extensive non-camping areas. We ultimately elected to focus exclusively on the camping area owing to reliability in surveying wombats in this area, and feasibility of a disease management program to be undertaken.

During transect surveys, wombats were sighted and scored for body condition and signs of mange disease using established visual scoring systems (Table 1). The life stage of each wombat was also recorded (juvenile, sub-adult, adult), but sex could not be consistently recorded. For sarcoptic mange, the scoring system considers body regions affected, the severity of visual signs of disease on each body section and confidence of the scorer in assigning those values. Binoculars were used to facilitate confidence in assigning scores to wombats, and also to enable surveying at a distance without disturbing the animal. When ambient light was low, a spotlight was also used. The relative location of the wombat within Bendeela was assigned to one of the following camping area categories to assist with tracking mange affected wombats over time (one-north, one-south, two-west, two-central, two-east, foreshore).

Table 1. Visual scoring system for wombat body condition and mange severity status at Bendeela Recreation Area. Image below illustrates the body sections that were each given a mange severity score for each side of the wombat.

Body condition		**Mange severity**		
Score	Definition	Score	Hair loss	Severity status
1	Poor, visibly thin, pelvis protruding	0	No signs of mange	Healthy
2	Moderate, pelvis may protrude	1	Ambiguous, possible hair thinning	Likely healthy
3	Good, normal, healthy	2	<10% affected by mange	Early mange
4	Very good, fat, glossy	3	10-40% affected by mange	Moderate mange
5	Very good, very fat, glossy	4	20-40% affected by mange	Severe mange
		5	>40% affected by mange	Extreme mange



A total of 341 wombat observations and health assessments were made during the pre-treatment surveys. Overall, the distribution of body condition scores indicates a generally healthy population (Figure 2). Across the site, most wombats were observed in the lower campground area (Table 2). The number of wombats that could be confidently assigned as showing signs of sarcoptic mange ranged from 0-6 individuals per survey (average 3.1). Healthy wombats exhibited higher average body condition scores, relative to wombats showing signs of sarcoptic mange (Figure 2, average 3.9 and 2.7 respectively). The average prevalence of mange in wombats observed in the campground areas was 3.2%, and manage affected wombat were only observed in camping area two during the pre-treatment period (Figure 3, Table 2). The prevalence of sarcoptic mange appeared to be relatively stable in bare-nosed wombats across the course of this study (Figure 3).

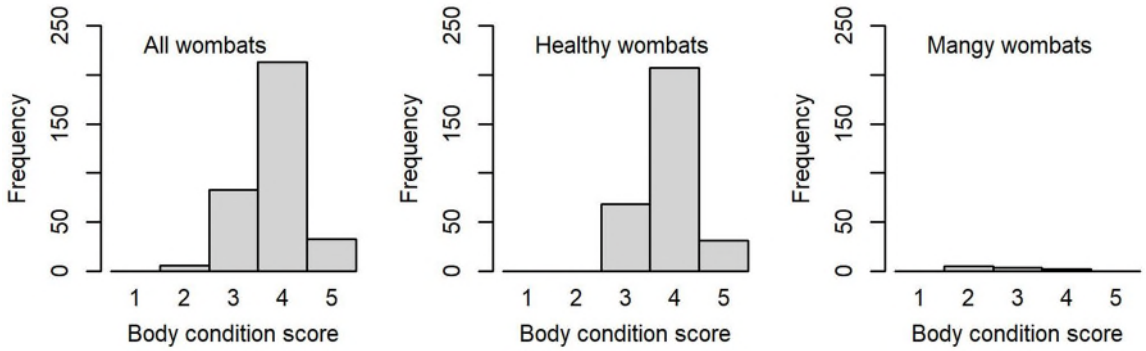


Figure 2. Distribution of body condition scores for bare-nosed wombats in pre-treatment surveys, including breakdown for healthy and mange affected wombats.

Table 2. Total counts of wombats during pre-treatment and treatment periods for each camping area at Bendeela Recreation Area, and counts of wombats showing signs of sarcoptic mange within these categories.

Survey period	**Camping Area**		
	One	Two	Total
Number of wombats			
Pre-treatment	74	267	341
Treatment	182	579	761
Total	256	846	1102
Number with signs of sarcoptic mange (%)			
Pre-treatment	0 (0.0)	11 (4.1)	11 (3.2)
Treatment	2 (1.1)	21 (3.6)	23 (3.0)
Total	2 (0.8)	32 (3.8)	34 (3.1)

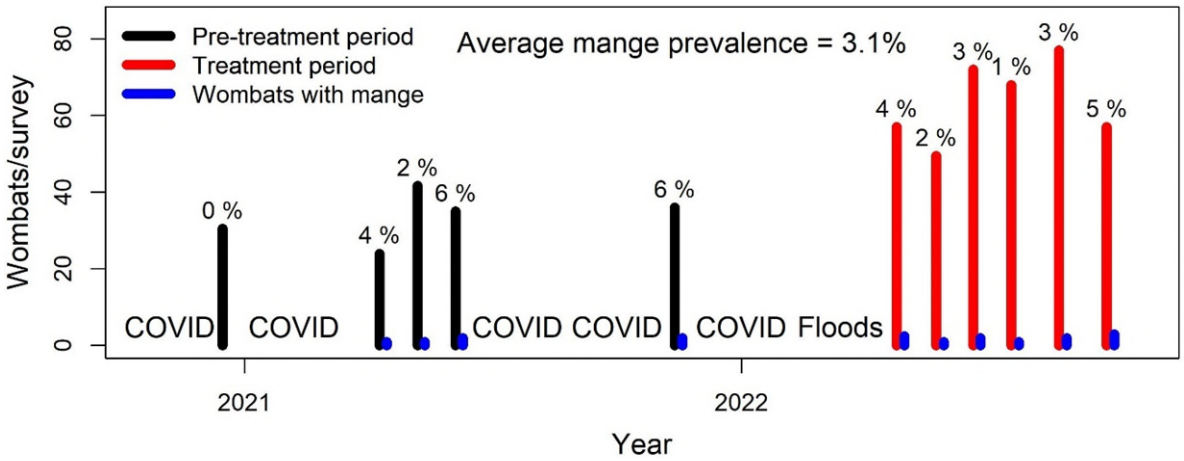


Figure 3. Results of surveys from pre-treatment (black bars) and treatment periods (red bars), showing the average number of wombats counted per survey and number with signs of sarcoptic mange (blue bars). Prevalence of mange per survey trip represented by numbers above bars, and the overall average mange prevalence is also given. Disruptions to survey activities by COVID19 and flooding also indicated.

It is important to note that these surveys were intended to gain a relative understanding of wombat abundance and mange prevalence at Bendeela (around the campground area specifically), but we were not attempting to estimate the total size of the wombat population at the site nor the absolute number of wombats with signs of mange.

Treatment program

COVID19 travel restriction extended into 2022 and were further compounded by flooding in the Kangaroo Valley area in early 2022 (Figure 3). The treatment period commenced in April 2022 and was able to be undertaken uninterrupted over a six-month period. We developed a treatment program based on the relative ease of surveying wombats within the camping area, the relatively low number of individuals showing signs of sarcoptic mange, and their habituation to people. During the treatment period, we continued the transect surveys as described above. When a wombat was scored as showing signs of sarcoptic mange, treatment was undertaken using Bravecto for Large Dogs or Bravecto for Extra-Large Dogs, administered as a spot-on dose to the flank of the wombat using a Jabstick (Dan Inject, Figure 4). In most cases treatment could be successfully administered to the wombat by a moderately experienced operator owing to relative habituation of wombats at Bendeela. Naturally, there were some occasions were treatment was not successfully administered, owing to a wombat fleeing or operator error. Bravecto was handled using gloves to avoid personal exposure to the drug.

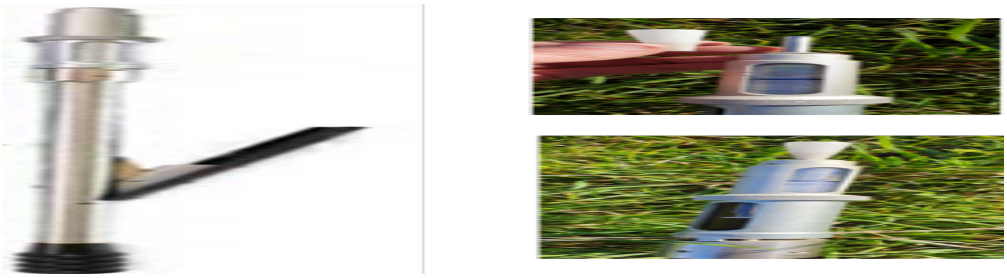


Figure 4. Dan Inject Jabstick with modification to the tip so as to support the spot-on delivery of Bravecto to wombats.

Characteristically, wombats that have been treated for sarcoptic mange will initially lose large patches of crusted-hyperkeratotic skin and fur from affected areas, leaving large patching of bare skin that is otherwise healthy. Hair regrows over a period of 3-4 months, assuming complete recovery from infection. During the treatment period, we recorded if individual wombats showed signs of recovery and also the extent of residual mange severity. Continuing to record mange severity is critical to assess if follow up doses of treatment are required. To evaluate success of the treatment program, we focussed on the average severity of mange among individuals showing signs of the disease or recovery from it (Figure 5). This provided an objective measure of treatment impact within the bare-nosed wombats occupying the camping area.

During the treatment period, a total of 761 wombat observations and health assessments were made (Table 2). The average severity of sarcoptic mange declined of the six-month period (Figure 5), indicating that the monthly treatment program was effective in reducing both the number of infected individuals and the severity of disease among infected individuals. By the end of the six-month treatment program, the average mange severity among wombats was sufficiently low, that signs of disease could only be detected by an experienced surveyor (Scott Carver).

Department of Biological Sciences
Private Bag 55
Hobart Tasmania
7001 Australia

T +61 3 6226 2603
F +61 3 6226 2698
www.utas.edu.au/plantsci
www.utas.edu.au/zoology
ABN 30 764 374 782 / CRICOS 00586B

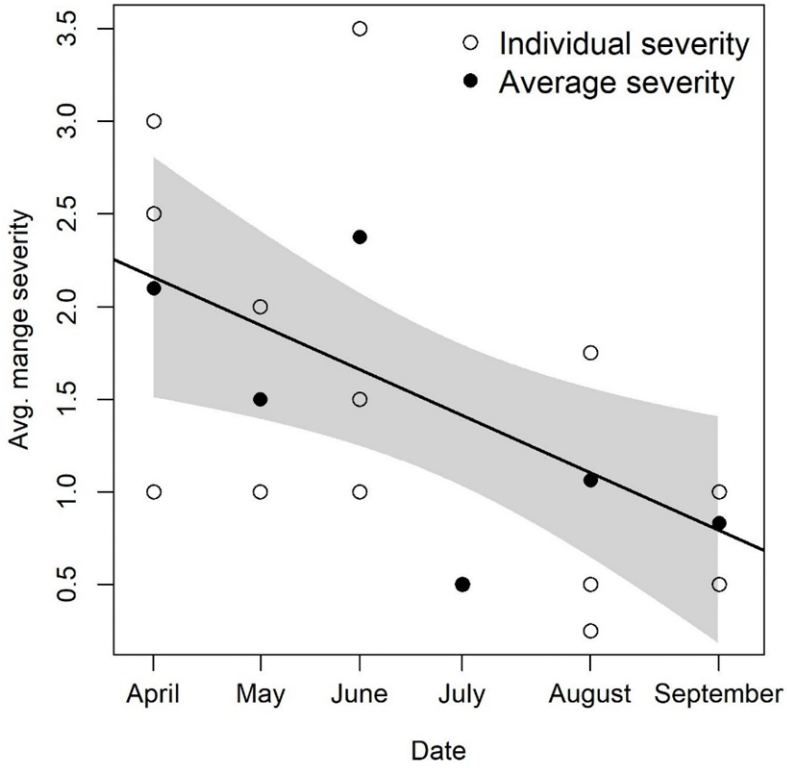


Figure 5. Decline in average mange severity of wombats surveyed at Bendeela during the treatment period. Individual wombats represented by open circles and average mange severity per survey trip indicated by closed circles. Fitted line and shaded 95% confidence intervals from linear regression analysis ($F_{1,21} = 7.99$, $P = 0.01$).

It is important to note that sarcoptic mange will not be eradicated from Bendeela. Eradication is unlikely to be possible because Bendeela is essentially continuous habitat with the surrounding area and, thus, it is expected that wombats with sarcoptic mange will continue to occasionally occur at the camping area. The goals of the treatment program in this study is in regard to practical and feasible ongoing management, assuming relatively stable endemic disease conditions. Our research suggests that this epidemiology (stable disease dynamics) will likely continue at Bendeela. However, if a large sarcoptic mange outbreak were to occur, it should be expected that it would not be possible to control, and the wombat population would decline. There is no demonstrated effective population-level epidemic control approach for mange in wombats at this time.

Public consultation

Two rounds of online public consultation were undertaken with WaterNSW. The first was in October 2020, prior to commencement of the program, and the second in May 2022, early in the treatment phase. Both public consultations were largely attended by members of the wildlife rehabilitation sector. Public consultation involved PowerPoint presentations, followed by question and answer. In the latter presentation, results from the surveys were included.

Management recommendations and strategies for consideration

Important principles of any ongoing disease management program are: Practicality, Feasibility, Effectiveness, and measurable actions and outcomes (Surveillance)

- *Practicality* refers to the methods of disease management being achievable to perform by those undertaking the management program.
- *Feasibility* refers to the frequency of disease management being achievable on an ongoing basis.
- *Effectiveness* refers to the program achieving a level of disease management deemed satisfactory.
- *Surveillance* refers to documenting disease management actions and collecting information that allows Effectiveness to be assessed, and program changes to be considered.

Importantly, the exact nature of meeting these principles is expected to be specific to the organisation undertaking the program, and the development of a tailored approach is therefore warranted. Here I describe three strategies intended to illustrate differing approaches WaterNSW may consider in determining and adopting a disease management program that functions for their business and stakeholders. These strategies are not intended to be prescriptive, but rather a point from which to form decisions. Indeed, a different or mixture of strategies may warrant consideration.

Strategy 1 – A monthly survey and disease management program

This strategy would largely be a continuation of the existing disease management program implemented by Scott Carver for this study. Under this strategy transect surveys would be undertaken over two consecutive nights, once per month. All wombats observed would be counted and signs of mange documented. Any wombats that showed signs of mange disease would be treated. It is expected that surveys would take 2-3 hours per night. A database of the number of wombats observed, number showing signs of mange disease, and number of mangy wombats treated would be maintained for Surveillance purposes. Pros of this system would be a high level of Effectiveness and Surveillance, consistent with the present study at Bendeela, as well as a frequent presence creating a positive public image. A con of this strategy could particularly be in the area of Feasibility, as the time commitment of WaterNSW staff or associates might exceed what is reasonable to sustain. Additionally, the frequency of monthly disease management may mean that more personnel are required to maintain the program, coming at a cost to Practicality and also Surveillance, if record keeping and database management was not consistently managed.

Strategy 2 – A 2-4 monthly survey and disease management program

This strategy would replicate Strategy 1, but with the program undertaken less frequently. The pros of a less frequent strategy could be to enhance Practicality and Feasibility, particularly in meaning that fewer personnel would be needed for it to be performed, and greater consistency of the disease management program would support more consistent data collection for Surveillance. The cons could be that the Effectiveness of the program diminishes somewhat. The public image associated with this program may still be strong, particularly if communicated well, although probably not as strong as a monthly program.

Strategy 3 – ad hoc disease management without surveillance

This strategy is intended to represent a 'reactive' approach to disease management, whereby disease management in wombats is only ever undertaken when a diseased wombat is observed or reported by the public. The pro of this strategy is that it is high on Feasibility because the time commitments are only associated with individual treatment events. There are reasonable cons associated with this strategy. Practicality may diminish over time, as preparedness for when disease management is needed tends to decrease when it is ad hoc. Treatments may be effective for some individuals treated, but in the absence of Surveillance the Effectiveness of treatments will generally be unknown. Furthermore, under ad hoc strategies, the severity of sarcoptic mange usually has to be high before diseased wombats are opportunistically observed or reported. The public image associated with this strategy may still be moderate, as action will be seen when sick wombats are observed or reported, but criticism may also occur owing to perceptions of inaction or not being proactive about a recognised disease problem.

Additional considerations/recommendations

1. It is recommended that prior to implementing an agreed upon disease management program that individuals who will be responsible for the program receive training support from Scott Carver in both the identification of sarcoptic mange, treatment and Surveillance. This may involve one training session or multiple, depending on the needs of WaterNSW.
2. It is recommended that at least two people are trained in disease management of wombats, so that there is some redundancy against changes in personnel, and that existing personnel can train new personnel over time.
3. It is recommended that a budget be allocated to resource the chosen disease management program.
4. It is recommended that equipment for disease management and Surveillance be stored in an appropriate location. Maintenance of treatment equipment is critical, so instructions with clear procedures would be valuable. Having trigger-points for stocking and replacement of equipment and consumables is recommended.
5. It is recommended that a system of database management be put in place to support Surveillance. This may be a simple as a sharable Excel file held on a cloud storage platform.
6. It is recommended that WaterNSW make summaries of their Surveillance and disease management actions publicly available at least annually, either through their website or embedded in reporting for the site.
7. It is recommended that public engagement about wombats, sarcoptic mange, and disease management be increased at Bendeela. Some signage already exists at Bendeela about wombats and mange disease, and this is both read and valued by visitors to the camping area. Newer and more detailed information should be considered, particularly around the entrance to Bendeela, as well as at existing information points. Renewed signage would be an opportunity for WaterNSW to promote a more positive and proactive position with regard to caring for the welfare of wombats at the campground. New signage could also include an outlet for the public to communicate if a mange affected wombat is observed (i.e., a when and where observed internet link, with option to attach photo), providing a sense of involvement and that reporting may lead to tangible actionable outcomes.
8. Owing to the profile of sarcoptic mange in wombats at Bendeela and that some wildlife rehabilitation groups can be quite vocal with regard to this, it is recommended that WaterNSW consider adopting a clear position. For example, it could be chosen that

WaterNSW may manage the issue entirely in-house, or work with wildlife rehabilitation groups to implement disease management. If WaterNSW elects to work directly with any wildlife rehabilitation groups, it is recommended they select a single preferred group (e.g., WIRES, Wildlife South Coast, etc.), as relationships among wildlife rehabilitation groups are often complex. The NSW Parks and Wildlife Service may be able to provide helpful advice also.

Permissions for this work

Permissions for this project was granted by the University of Tasmania Animal Ethics Committee (20370) and through a scientific licence from the NSW National Parks and Wildlife Service (SL102612).

Acknowledgements

Strong working relationships are critical to any partnership with industry, and in this regard, I would like to particularly acknowledge Mary Knowles, Craig MacDonald and Alec Davie from WaterNSW, and Coral Reynolds from Comcon. Capacity for this study to take place smoothly was significantly facilitated by these individuals. Laura Pulscher, Shannon Taylor, Diana Escalante, David Phalen, Mary Knowles, Christina Naesborg-Nielsen, Ryan McCluskey, Aditi Sriram and Reuben Rosario all provided assistance with undertaking surveys and treatments of wombats. I am grateful to MSD Animal Health, particularly Karen Lipworth, for providing the Bravecto using in this study. Aditi Sriram, Ronald Weering and Andrea Kubin from NSW NPWS also provided valuable support across the life of this project.

References

BAINS, J., CARVER, S. & HUA, S. 2022. Pathophysiological and pharmaceutical considerations for enhancing the control of *Sarcoptes scabiei* in wombats through improved transdermal drug delivery. *Frontiers in Veterinary Science,* 9**,** 944578.

BEETON, N. J., CARVER, S. & FORBES, L. K. 2019. A model for the treatment of environmentally transmitted sarcoptic mange in bare-nosed wombats (*Vombatus ursinus*). *Journal of Theoretical Biology,* 462**,** 466-474.

CARVER, S., PETERS, A. & RICHARDS, S. A. 2022. Model Integrated Disease Management to facilitate effective translatable solutions for wildlife disease issues. *Journal of Applied Ecology,* 59**,** 2902-2910.

DEATH, C. E., TAGGART, D. A., WILLIAMS, D. B., MILNE, R., SCHULTZ, D. J., HOLYOAKE, C. & WARREN, K. S. 2011. Pharmacokinetics of Moxidectin in the southern hairy-nosed wombat (*Lasiorhinus latifrons*). *Journal of Wildlife Diseases,* 47**,** 643-649.

DRIESSEN, M. M., DEWAR, E., CARVER, S. & GALES, R. 2022. Conservation status of common wombats in Tasmania I: incidence of mange and its significance. *Pacific Conservation Biology,* 28**,** 103-114.

ESCOBAR, L. E., CARVER, S., CROSS, P. C., ROSSI, L., ALMBERG, E. S., YABSLEY, M. J., NIEDRINGHAUS, K. D., VAN WICK, P., DOMINGUEZ-VILLEGAS, E., GAKUYA, F., XIE, Y., ANGELONE, S., GORTÁZAR, C. & ASTORGA, F. 2022.

Sarcoptic mange: An emerging panzootic in wildlife. *Transboundary and Emerging Diseases,* 69**,** 927-942.

EVANS, M. C. 2008. Home range, burrow-use and activity patterns in common wombats (*Vombatus ursinus*). *Wildlife Research,* 35**,** 455-462.

FRASER, T. A., CHARLESTON, M., MARTIN, A., POLKINGHORNE, A. & CARVER, S. 2016. The emergence of sarcoptic mange in Australian wildlife: an unresolved debate. *Parasites & Vectors,* 9**,** 316.

GREEN, K. 2005. Winter home range and foraging of common wombats (*Vombatus ursinus*) in patchily burnt subalpine areas of the Snowy Mountains, Australia. *Wildlife Research,* 32**,** 525-529.

JOHNSON, C. N. 1998. The evolutionary ecology of wombats. *In:* WELLS, R. T. & PRIDMORE, P. A. (eds.) *Wombats.* New South Wales: Surrey Beatty and Sons.

MARTIN, A., SKERRATT, L. & CARVER, S. 2017. Sarcoptic mange in Australian wildlife. Fact Sheet for Wildlife Health Australia. https://wildlifehealthaustralia.com.au/FactSheets.aspx. Available: https://wildlifehealthaustralia.com.au/FactSheets.aspx.

MARTIN, A. M., BURRIDGE, C. P., INGRAM, J., FRASER, T. A. & CARVER, S. 2018a. Invasive pathogen drives host population collapse: Effects of a travelling wave of sarcoptic mange on bare-nosed wombats. *Journal of Applied Ecology,* 55**,** 331-341.

MARTIN, A. M., FRASER, T. A., LESKU, J. A., SIMPSON, K., ROBERTS, G. L., GARVEY, J., POLKINGHORNE, A., BURRIDGE, C. P. & CARVER, S. 2018b. The cascading pathogenic consequences of *Sarcoptes scabiei* infection that manifest in host disease. *Royal Society Open Science,* 5**,** 180018.

MARTIN, A. M., RICHARDS, S. A., FRASER, T. A., POLKINGHORNE, A., BURRIDGE, C. P. & CARVER, S. 2019. Population-scale treatment informs solutions for control of environmentally transmitted wildlife disease. *Journal of Applied Ecology,* 56**,** 2363-2375.

MCILROY, J. C. 1973. *Aspects of the ecology of the common wombat, Vombatus ursinus (Shaw, 1800).* PhD, Australian National University.

MOUNSEY, K., HARVEY, R. J., WILKINSON, V., TAKANO, K., OLD, J., STANNARD, H., WICKER, L., PHALEN, D. & CARVER, S. 2022. Drug dose and animal welfare: important considerations in the treatment of wildlife. *Parasitology Research,* 121**,** 1065-1071.

NÆSBORG-NIELSEN, C., WILKINSON, V., MEJIA-PACHECO, N. & CARVER, S. 2022. Evidence underscoring immunological and clinical pathological changes associated with *Sarcoptes scabiei* infection: synthesis and meta-analysis. *BMC Infectious Diseases,* 22**,** 658.

SIMPSON, K., JOHNSON, C. N. & CARVER, S. 2016. *Sarcoptes scabiei*: the mange mite with mighty effects on the common wombat (*Vombatus ursinus*). *PLoS ONE,* 11**,** e0149749.

SKERRATT, L. F. 2003. Clinical response of captive common wombats (*Vombatus ursinus*) infected with *Sarcoptes scabiei var. wombati*. *Journal of Wildlife Diseases,* 39**,** 179-192.

SKERRATT, L. F., MIDDLETON, D. & BEVERIDGE, L. 1999. Distribution of life cycle stages of *Sarcoptes scabiei var wombati* and effects of severe mange on common wombats in Victoria. *Journal of Wildlife Diseases,* 35**,** 633-646.

SKERRATT, L. F., SKERRATT, J. H. L., BANKS, S., MARTIN, R. & HANDASYDE, K. 2004a. Aspects of the ecology of common wombats (*Vombatus ursinus*) at high density on pastoral land in Victoria. *Australian Journal of Zoology,* 52**,** 303-330.

SKERRATT, L. F., SKERRATT, J. H. L., MARTIN, R. & HANDASYDE, K. 2004b. The effects of sarcoptic mange on the behaviour of wild common wombats (*Vombatus ursinus*). *Australian Journal of Zoology,* 52**,** 331-339.

TAKANO, K., HARVEY, R. J., DE HAYR, L., CARVER, S. & MOUNSEY, K. 2023. Pharmacokinetic and pharmacodynamic considerations for treating sarcoptic mange with cross-relevance to Australian wildlife. *International Journal for Parasitology: Drugs and Drug Resistance***,** In press.

TRIGGS, B. 2009. *Wombats,* Australia, CSIRO Publishing.

WILKINSON, V., TOKANO, K., NICHOLS, D., MARTIN, A., HOLME, R., PHALEN, D., MOUNSEY, K., CHARLESTON, M., KREISS, A., PYE, R., BROWNE, E., NÆSBORG-NIELSEN, C., RICHARDS, S. A. & CARVER, S. 2021. Fluralaner as a novel treatment for sarcoptic mange in the bare-nosed wombat (*Vombatus ursinus*): safety, pharmacokinetics, efficacy and practicable use. *Parasites & Vectors,* 14**,** 18.

Department of Biological Sciences
Private Bag 55
Hobart Tasmania
7001 Australia

T +61 3 6226 2603
F +61 3 6226 2698
www.utas.edu.au/plantsci
www.utas.edu.au/zoology
ABN 30 764 374 782 / CRICOS 00586B