Threatened Species Recovery Hub

National Environmental Science Programme

Guidelines for the treatment of Australian wildlife with sarcoptic mange

Part 2 - Literature review

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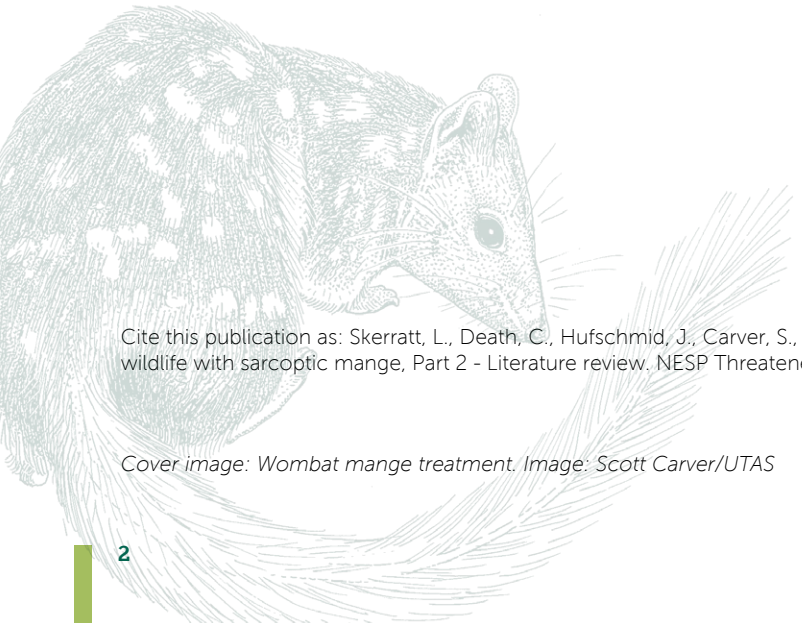

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Cover image: Wombat mange treatment. Image: Scott Carver/UTAS

Contents

Executive summary

Sarcoptic mange, caused by the mite *Sarcoptes scabiei*, is an emerging infectious disease that affects domestic and wild species globally. It was likely introduced to Australia via European settlement. In addition to affecting a number of our domestic species, it also affects multiple native Australian mammals. Mange has serious animal welfare impacts. It is chronically debilitating, causing significant morbidity and mortality, and is considered to be the most significant disease threat to wild wombats. Left untreated, mange can inflict immense suffering, frequently leading to death. Conservation impacts are poorly understood but mange is known to have caused the decline and possible local extinction of some bare-nosed wombat populations in southeastern Australia. Documented cases in other mammals include koalas and bandicoots, species already under multiple threats.

Significant time and resources are expended by wildlife veterinarians and volunteers in treating wildlife, particularly wombats, with sarcoptic mange. There is a compelling need and strong desire for guidance around treatment regimens and for research that would lead to improved treatment outcomes.

About this document

This document was developed as a sub-project of the National Environmental Science Program funded Threatened Species Recovery Hub (Project 1.4.4), carried out by the University of Melbourne in collaboration with the University of Tasmania in 2021.

This document consists of two separate sections **Part 1) Treatment guidelines** (separate sister document) including a summary mange treatment information sheet (Section 10, also published separately) and recommendations for future research around treatment (Section 9), underpinned by **Part 2) this Literature review** of current knowledge and treatment methods.

Each part targets different audiences. The treatment guidelines are for stakeholders who are directly involved in managing and delivering treatment (veterinarians; wildlife carers, treaters and rehabilitators; wildlife managers and policy makers). The recommendations are for those trying to coordinate the overall response to mange so that innovation and expenditure are directed to the right places. The literature review is for anyone seeking a snapshot of existing research-based and anecdotal knowledge.

The treatment guidelines should be viewed as a starting point for a second phase of research and stakeholder collaboration to progress the content and application of mange treatment guidelines in Australian wildlife.

About the project

Aims

- To collate all of the literature on mange infection and treatment in Australian wildlife into a single document in order to understand and share the current state of scientific knowledge.
- To draft national treatment guidelines in order to improve on-ground decision-making.
- To highlight knowledge gaps and recommend required research in order to improve treatment outcomes and future versions of the guidelines.
- To expand the dialogue among parties involved in wildlife mange treatment in Australia.

The literature review underpins the treatment guidelines. Our approach was to draft the guidelines based on the literature, and supplement them with targeted interviews with veterinary experts and anecdotal information from limited stakeholder feedback. **Further consultation is required.**

Context

The context for this work is the growing community expectation of appropriate treatment of mange-affected wildlife, due to the significant welfare implications and uncertainty about conservation impacts. The **risks of inaction are substantial**, including continued uncertainty about the conservation implications of sarcoptic mange in Australian wildlife and the ongoing animal welfare impacts, both of which fuel dissatisfaction among the community of people attempting to treat this condition.

Treatment of mange by volunteers has developed in an ad-hoc fashion, partly due to the long-term lack of research and communication, and partly due to the **absence of leadership to coordinate action** efficiently and effectively across multiple jurisdictions and stakeholder groups.

Application

The application of this research lies primarily in making all relevant mange treatment information available in one document, which will be of substantial benefit to those involved in treating wildlife affected by sarcoptic mange and to those attempting to take the next best steps to conduct research and respond to mange more effectively.

The treatment guidelines can be provided to veterinarians and wildlife volunteers by veterinary businesses, wildlife organisations and government agencies to improve knowledge of sarcoptic mange infection and treatment, thus helping to improve animal welfare and treatment outcomes.

Key findings

The key findings identified from our review of the published and unpublished literature, combined with stakeholder input, are as follows –

Treatment-specific findings based on the literature's limited evidence-base demonstrate that:

- Treatment of mange involves initial decision-making around disease severity and the likelihood of successful treatment, which relies on experienced personnel to assess animal welfare, and the availability of veterinarians and land managers.
- There is a need for consistent national mange severity assessment criteria.
- The complexities of treatment in free-ranging wildlife present significant ongoing challenges.
- Currently approved doses of various acaricides (e.g. moxidectin) have been shown to be effective if treatment courses are sufficiently long and animals are reliably treated, however this can be difficult to achieve in free-ranging wildlife.
- Where possible (i.e. captive or clinical environments), injectable acaricides should be used, especially in animals that have mange-affected skin.
- New treatments (e.g. fluralaner) are showing promising results in multiple species but require the direct supervision of a registered veterinarian until available under permit.
- Supportive treatment can greatly improve the welfare of the individual and the likelihood of successful treatment.
- Volunteer treatment of mange in free-ranging wildlife has developed in an ad-hoc fashion, partly due to the lack of research and clear communication, with significant differences in treatment practicalities and outcomes in captive versus free-ranging animals.
- There is considerable uncertainty as to what constitutes best-practice treatment in free-ranging wildlife. There remains a great deal of work to do before we will understand the best treatments for sarcoptic mange in Australian wildlife in different contexts.
- Knowledge gained through field treatment by wildlife volunteers is not captured. Some members of the wombat volunteer community identify as the custodians of a large body of information that requires investigation and validation to progress understanding of mange treatment in free-ranging wombats. There is dissatisfaction that field treatment experience is not endorsed as an evidence-base for using higher doses of moxidectin.

Other key findings that are integral to understanding the impacts of mange and determining how to target treatment effectively include:

- There is **minimal understanding of the prevalence and distribution of mange** across Australia, prompting the need for adequate monitoring.
- **There is no nationally coordinated approach to progressing research on this topic**. Most treatment-related university research is now one to two decades old, and prior recommendations for further work have not been actioned or funded. While research in a controlled setting has shown relatively predictable outcomes, effective treatment of wild populations is more complex and there is very little published information in this space.

Implications

The key findings have implications for policy-makers and funders. The knowledge gaps that have been highlighted, and the associated recommendations in the **Treatment Guidelines** can be used to direct funding and support towards essential research into treatment and the establishment of a national framework for responding to mange.

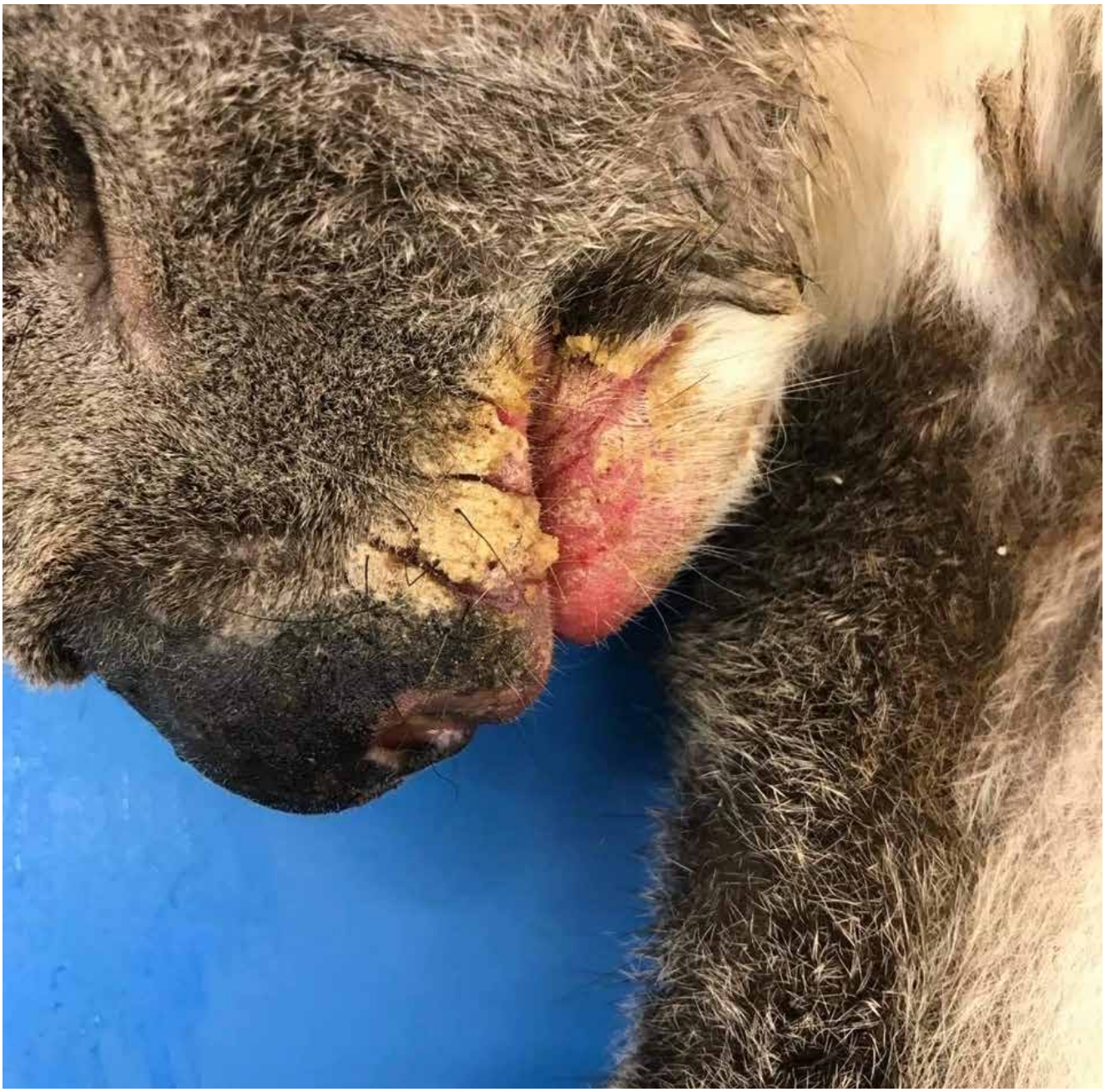
Next steps

The creation of a research plan for this important issue will be a vital next step in improving the health, welfare and conservation of Australian wildlife affected by sarcoptic mange. Building on the recommendations detailed in the **Treatment Guidelines**, the research plan should address the following key areas of work:

- Experimental pharmacokinetic research into optimal drug dose and delivery
- Resourcing mange treatment and decision-making in the field in various contexts
- Determining how treatment should best be managed at a national, state and local level
- Investigating how to best manage individuals and monitor success, using technology.

This research plan should seek ways to combine the knowledge gained through field treatment by wildlife volunteers with the more traditional research approach in order to reveal optimal treatment strategies and align treatment advice.

Our treatment-specific findings are embodied in the treatment guidelines and have implications for current and future treatment standards. The guidelines are an important first step in sharing information about mange. They will need to be updated to reflect best practice as knowledge expands through further research and through collaboration with volunteers who treat mange in the field. This will require someone to take ownership of the guidelines.



A koala with mange on its face. Image: Adelaide Koala and Wildlife Centre

Part 2 - Literature review: Sarcoptic mange in native Australian mammals

1.Introduction

The mange mite *Sarcoptes scabiei*, which causes intensely pruritic, alopecic and scaling dermatitis (Vogelnest, 2019), is known to affect almost all classes of mammals (Reiss, 2019, Escobar et al., 2021). The host range in Australian native mammals includes bandicoots, dingoes, koalas, possums, potoroos, wombats and wallabies.

Australian mammals are assumed to have little innate resistance because of a lack of evolutionary exposure (Reiss, 2019). There is little knowledge around mange transmission dynamics and reservoir species in the Australian context. It is difficult to eliminate mange from wildlife populations and infection is easily reintroduced in contiguous populations, and possibly from other host species where the population is isolated. Although they are obligate skin parasites, sarcoptid mites can survive in suitable environments (low temperature, high humidity) for up to 19 days in laboratory conditions (Arlian and Morgan, 2017). They have host preferences, but can cause at least transient disease in a range of host species (Vogelnest, 2019). Epidemiologic and phylogenetic evidence supports the theory that sarcoptic mange arrived in Australia with European settlers and their animals (Skerratt, 2005, Fraser et al., 2017), and then spilled over into native mammals (Reiss, 2019), with one example pathway being that foxes are known to utilise wombat burrows (Skerratt et al., 1998). Mange epizootics have been known to cause substantial population declines in fox (*Vulpes vulpes*) populations in Australia, Denmark, England, Italy, North America and Scandinavia (Soulsbury et al., 2007).

The pathology and clinical signs associated with mange in native Australian mammals are seen in other animals globally (Pence and Ueckermann, 2002, Fraser et al., 2016, Escobar et al., 2021). *Sarcoptes scabiei* burrows into the skin and ingests host cells and secretions, creating tunnels and depositing irritating and allergenic material (e.g., mite excretions, dead mites, moulted exoskeletons, and eggshells) (Pence and Ueckermann, 2002). The typical clinical signs in affected animals are dermatological and consist of early papules and self-trauma lesions, including alopecia and excoriations, which progress to prominent scaling (Vogelnest, 2019), crusting and hyperkeratosis (Hulst, 2019). Chronic infections present with marked parakeratotic scaling, forming dense sheets and focal fissuring (Vogelnest, 2019). The parakeratotic scale initially appears as confluent sheets of dandruff, which may build up over time into an adherent crust over 1 cm thick (WHA, 2021b). Fissures develop in the crust and underlying epidermis resulting in exposure of the dermis, haemorrhage, bacterial infection and sometimes flystrike (WHA, 2021b).

2. Species specific disease occurrence and effects

2.1 Wombats

Sarcoptic mange is the most frequently observed debilitating disease condition, which can be fatal (Reiss, 2019), in bare-nosed wombats (BNWs) and also impacts southern hairy-nosed wombats (SHNWs) (*Lasiorhinus latifrons*) (Vogelnest, 2019). It is present throughout the range of BNWs and occurs more sporadically in SHNWs (Martin et al., 1998), but there have been no reports of disease in the northern-hairy nosed wombat (*Lasiorhinus krefftii*) (Campbell-Ward, 2019).

Sarcoptic mange in wombats is recognised as an emerging disease (Tompkins et al., 2015, Escobar et al., 2021), although it has been documented in wombats for a long time (Skerratt et al., 1998). It occurs widely, with mange existing under differing epidemiological conditions, including occasional outbreaks that can lead to local population declines (Martin et al., 2018a, Beeton et al., 2019, Carver et al., 2021, WHA, 2021b). In northern Tasmania a sarcoptic mange outbreak in the Narawntapu National Park reduced BNW population abundance by 94% between 2013–2016 (Martin et al., 2018a).

The first report of an outbreak of mange in free-ranging wombats was in BNWs in south-eastern New South Wales in 1937, but this was not confirmed by samples (Gray, 1937). Gray (1937) stated that areas of south-eastern New South Wales with previously large wombat populations were basically depopulated by mange. McIlroy (1973) indicated that three BNWs with mange were trapped between 1968–1970 near Bondo in southern NSW, but this diagnosis was not confirmed microscopically. Mange prevalence has been estimated to range from zero to more than 40%, depending on population and study, with prevalence of up to 100% reported in populations experiencing an epizootic (Martin et al., 2018a). The national survey published by Martin et al in 1998 indicated that mange had been observed in 93% of the 60 locations with respondents across the BNW range, with prevalence estimates at specific locations of up to 15% in NSW (based on estimates of wombat numbers) and 22% in VIC (based on small numbers of wombats).

This was higher than the previous estimates of 5% and 14% from two small studies in Victoria between 1982 and 1992 (Martin et al., 1998). Additional estimates of endemic prevalence ranging from 0-5% were reported for two populations at Warrigal and Buffalo River, Victoria in 1996 and 2000 (Skerratt et al 2004). From 1997 to 2000 there were several reports of localised epidemics of mange in BNWs in NSW, SA and VIC, however, prevalence was not estimated (Skerratt et al., 2004a). Speight et al (2017) stated that mange occurs endemically at 0–15% prevalence in common wombat populations throughout south-eastern Australia (Speight et al., 2017). Statewide monitoring in Tasmania since 2016 reports a mange prevalence ranging between 0–17.6% (average < 5%) (DPIPWE 2020). Stannard et al (2020) reported a prevalence range of 7–41% in BNWs across three sites in NSW, but it is not known whether these represent endemic or epidemic scenarios.

The earliest report of mange in SHNWs was that of Wells (1971), in which localities were not recorded, with subsequent isolated reports from the Nullarbor Plain, the Gawler Ranges, and the Murraylands in South Australia (the latter being in 1976 and the first case in which mites were formally identified) (Ruykys et al., 2009). Between 2003-2005, an outbreak occurred in the Murraylands (where mange prevalence was confirmed at 76% on one pastoral property) and a survey conducted at that time indicated that 43% of respondents had seen SHNWs with mange and that it had been present in the region since the 1970s, with anecdotal evidence similar to that from BNWs, i.e. of mange-induced population declines and an increase in mange during and following periods of drought (Ruykys et al., 2009). This relationship with drought was also made in the national survey of mange prevalence carried out in 1996 (Martin et al., 1998). Anecdotally, sarcoptic mange was rarely observed in SHNWs between 2011 and 2015 (Speight et al., 2017).

2.1.1 Epidemiology

The behavioural ecology of wombats likely predisposes them to infection (i.e. living in and sharing burrows). Burrows enhance the survival of mites when off the host by providing a stable temperate environment, which facilitates transmission (Skerratt 2005). The immune response to *S. scabiei* in wombats (Skerratt et al., 1998, Skerratt, 2003a) appears similar to that of other hosts that exhibit crusted mange symptoms, with mite survival and replication enhanced in thickly scaled areas (Vogelnest, 2019), promoting the development of parakeratotic mange (Skerratt, 2003a).

The likelihood of mange in BNWs may increase at higher population densities, especially in remnant riparian forests that adjoin agricultural grasslands, due to frequent burrow sharing and overlap of home ranges (Skerratt et al., 2004b). These factors and mite survival time in the environment may individually or in combination contribute to enhanced transmission and disease outbreaks, sometimes leading to local extirpations in fragmented populations (Borchard et al., 2012, Beeton et al., 2019, Campbell-Ward, 2019). The majority of published and unpublished studies about severely mange-affected BNW populations describe high population densities (e.g. Narawntapu), primarily in riparian habitat with nearby agricultural land (e.g., Bents Basin; Bendeelah; London Bridge; Shoalhaven (Borchard et al 2021); and Rocklily wombats (rocklilywombats.com). Although it is notable, the relationship between mange and wombat density will remain anecdotal until better information from long-term research is available and/or appropriate contrasts among populations are made. It has also been suggested that mange is more common in times of malnutrition, which is supported by studies on other mammals (Martin et al., 1998). Habitat disruption, host demographics such as recruitment of naïve animals (Fraser et al., 2016), occurrence and density of other mammalian hosts (e.g., foxes) (Schultz et al., 1996), mite survival, burrow switching and mite shedding rates (Martin et al., 2018a, Beeton et al., 2019), weather patterns and potentially even differing local flora (i.e. following reports by indigenous Australians of native plants that historically prevented and/or treated skin disease in wildlife (Waraburra Nura, 2021)) are also possible influencing factors.

It is likely that because wombats have a restricted energy budget, referring among other things to their low energy diet, their relatively low metabolic rate and feed intake compared with other herbivores, the energetic burden of mange can result in serious clinical effects such as emaciation (Campbell-Ward, 2019). In other words, when the energetic pressure of mange is too high, the host may not be able to compensate (Martin et al., 2018b). Martin et al. (2018b) showed that wombats are not able to meet the metabolic demands of mange infection through increased foraging.

2.1.2 Clinical signs

The severity of clinical signs of sarcoptic mange in free-living and experimentally infected BNWs has been shown to correlate with intensity of infection (i.e. mite numbers) (Skerratt et al., 1999, Skerratt et al., 2004b). Experimental infections showed that initial signs of mange were erythema followed by parakeratosis, alopecia, excoriation and fissuring of parakeratotic crust and skin (Skerratt, 2003b). The infestation can be present on the whole body; however, the most affected areas are usually the head, neck, shoulders and limbs (Skerratt et al., 1998). In free-ranging BNWs the clinical signs are also characterised by localized crusting progressing to hair loss, severe hyperkeratotic scale or crust, and erythema, with mostly symmetrical alopecia and degree of scaling or crusting (Hartley and English, 2005). Excoriation and fissuring of the crusts and skin can then result in haemorrhage, pyoderma and cutaneous myiasis (Hartley and English, 2005, Hulst, 2019).

Ruykys (1999) described similar lesions in SHNWs, with diseased animals (with no difference in prevalence between males and females) presenting with erythema, parakeratosis, alopecia, and reduced body condition. Skin lesions were most severe on the flanks and ears and least severe on the head, back and rump (Ruykys et al., 2009).

Mange-affected BNWs are generally in poorer body condition than mange-free individuals (Skerratt et al., 2004b, Hartley and English, 2005, Simpson et al., 2016) and Ruykys et al (2009) showed that diseased SHNWs also had lower median condition, less subcutaneous fat and higher bone prominence scores compared with healthy animals. Martin et al. (2018b) showed that the composition of sub-cutaneous fat also changed to reflect immune investment in combating mange disease.

2.1.3 Clinical pathology

Blood parameters of mange-affected BNWs (Skerratt et al., 1999, Hartley and English, 2005) and SHNWs (Ruykys et al., 2013) are generally consistent with anaemia, inflammation and emaciation (Skerratt et al., 1999, WHA, 2021b). Results in these two species have been found to be broadly similar, including reduced serum creatinine, albumin, haematocrit and haemoglobin, and an increase in white blood cell and neutrophil counts (Campbell-Ward, 2019). Diseased SHNW have demonstrated elevated levels of alanine aminotransferase (ALT), indicating liver cell damage (Campbell-Ward, 2019), which is consistent with Skerratt's observations (2001) that mange or secondary infections can be associated with liver cirrhosis (chronic liver damage). Hartley and English (2005) noted that the low body weight, low body condition score, lack of subcutaneous fat and low concentration of albumin, creatinine and increased urea concentrations in blood suggests that there is increased protein catabolism of muscle mass in an attempt to compensate for the energy requirements of severe hyperkeratotic sarcoptic mange. Martin et al. (2018b) showed a 40% increase in metabolic rate associated with early-stage mange disease, relative to healthy wombats.

2.1.4 Behavioural effects

Wombats with severe parakeratotic sarcoptic mange are more active diurnally and readily approached, in contrast to the largely nocturnal habits of healthy animals (Skerratt et al., 2004b, Borchard et al., 2012, Martin et al., 2018b). These mange-infected individuals have higher metabolic rates, which are difficult to meet despite being outside of the burrow for longer to forage (Simpson et al., 2016), although foraging is less efficient (Martin et al., 2018b), presumably owing to discomfort associated with symptoms. Affected bare-nosed wombats have been observed to spend more time scratching and drinking, and less time walking, with a slower feeding rate than mange-free individuals (Simpson et al., 2016, Martin et al., 2018b). In SHNWs, diseased individuals were also often observed feeding during daylight hours, taking less heed of their surroundings and being caught more readily (Ruykys et al., 2009). Thermal images have shown that wombats with mange lose considerably more heat to the environment than healthy wombats due to a diminished insulation layer (Simpson et al., 2016, Martin et al., 2018b).

2.1.5 Comorbidities/concurrent disease

Fraser et al (2016) describe an increased incidence of secondary infections including pneumonia in mange-affected Australian wildlife. In mange-affected koalas, lymphadenomegaly of the nodes draining affected skin regions has been noted (Speight et al., 2017). In one wombat study, severe sarcoptic mange occurred in only 1/25 (4%) of road-killed or snare-trapped wombats, compared to 8/13 (62%) of sick wombats (found in the wild or presented to care; one of these had lymphosarcoma with pneumonia due to *Pneumocystis*.) (Skerratt et al., 1998), suggesting that mange is more likely in immunocompromised individuals or that it leads to immunocompromise. It has been hypothesised that new or reactivated herpesvirus infections in bare-nosed wombats could be associated with the debilitation caused by *S. scabiei* infections (Stalder et al 2015).

Mange appears to impact on the reproductive success of wombats. Skerratt et al (1999) found that the gonads of mature wombats with *S. scabiei* infection were not active or had minimal activity, suggesting that these animals were less likely to reproduce. Hartley and English (2005) performed a small study in the southern highlands of NSW in 2001-2002 where 36% (8/23) of wombats in the population were affected, with 78% of cases in females. Of the affected females, only 17% (1/6) showed evidence of reproductive activity, compared to 80% of unaffected females (Hartley and English, 2005). In their SHNW study, Ruykys et al (2009) also noted that both sexes with severe mange were in a non-reproductive state.

2.2 Koalas

The first report of mange in a koala was by Barker in 1974, in a hand-reared individual in Victoria that had contact with a pruritic wombat, and which was associated with pruritic lesions in human handlers. The koala was a juvenile, and displayed pruritic, hyperkeratotic, fissuring lesions of the footpads and interdigital spaces, and crusting and erythematous skin around the eyes, nostrils and chin (Barker, 1974). Severely thickened, dry, encrusted pads on both forepaws and the right hind foot, cracking hyperkeratotic lesions in the interdigital spaces, and scruffiness but little hair loss on the metacarpal and metatarsal areas and the face were noted (Barker, 1974). Skin around the eye and on the nose was thickened and encrusted and the lips, chin and nares were erythematous (Barker, 1974). The lesions were obviously irritating since the animal constantly licked and chewed the affected limbs and feet (Barker, 1974).

In 1982, Brown et al. described an outbreak of sarcoptic mange in a captive koala colony in Queensland, in which early cases showed small, dry lesions beneath the fur and severe cases showed generalised hyperkeratotic lesions, emaciation and had an offensive odour. The lesions started on the forearms, metacarpal and metatarsal regions, digits and thorax, then spread to the abdomen, head, face and ears (Brown et al., 1982). It is interesting to consider whether lesion location indicates transmission pathways. While some koalas died prior to treatment (hypothesised as being due to lack of feed intake), the authors reported successful treatment of all remaining cases. It was presumed that the outbreak occurred due to the introduction of an infected wild koala, and they stated that the condition was not pruritic in its mild form but that the infection appeared able to progress to extensive hyperkeratosis with fewer signs of inflammatory or degenerative changes in the skin than expected (Brown et al., 1982).

Obendorf (1982) described mange in 2/55 (4%) of koalas assessed in Victoria from 1975–1980. Severe disease was seen in these two juveniles (from Phillip Island), with thickened, dry, encrusted lesions on the footpads, digits, face, nose and lips, with some more minor lesions on the forelimbs, chest and abdomen (Obendorf, 1983). Alopecia was not a feature but the animals displayed pruritis, and the paper did not describe whether the animals were euthanised or treated (Obendorf, 1983).

More recently, Speight et al (2017) presented a case series of mange in free-ranging koalas from Victoria (n = 29) and South Australia (n = 29) from 2008–2015. Many of the koalas were found dead due to the severity of disease. Skin lesion location was broadly similar to that described above, and was most commonly over the distal limbs, particularly the interdigital regions, and the face (and sometimes the sternum, ventral thorax and abdomen) (Speight et al., 2017). Skin changes in koalas resemble those of wombats (Speight et al., 2017, WHA, 2021b). The pathology described was characterised by skin thickening, crusting and deep fissures into the dermis that oozed serosanguinous fluid (Speight et al., 2017). While the Victorian cases were found in several locations across the state, the South Australian cases all occurred in the Mount Lofty ranges near Adelaide (Speight et al., 2017). Seasonality of cases was demonstrated, with mange most commonly occurring in autumn, and in several locations there were credible links to mange-affected foxes. Male koalas were over-represented in outbreaks, which may be due to their roaming and fighting behaviour. In contrast to wombats, reporting of cases in koalas was lowest in winter, possibly due to more abundant food resources, and hence more robust host physiology, at that time (Speight et al., 2017).

2.3 Wallabies

There are two published reports of sarcoptic mange in wallabies, and one anecdotal report of probable mange in Tasmanian wallabies (Munday, 1988). In 2005, McLelland and Youl described a case series of five mange-affected agile wallabies (*Macropus agilis*) in the Northern Territory (three free-ranging and two in care). Of these cases, 3/5 were described as hyperkeratotic with skin crusting and fissures (affecting various parts of the body) and 2/5 displayed a pruritic dermatitis (McLelland and Youl, 2005). Two cases were severe enough that they lead to death or euthanasia, whereas the other three cases were described as being successfully treated, including one case with severe crusting (McLelland and Youl, 2005). A further two cases were subsequently reported to the authors by local veterinarians. Mites were genetically analysed and found to cluster with *S. scabiei* var *canis* collected from dog populations in Northern Australia (McLelland and Youl, 2005).

Holz et al (2011) reported a severe case of sarcoptic mange in a free-ranging swamp wallaby in Victoria (*Wallabia bicolor*) (Holz et al., 2011). The wallaby was euthanised due to marked hyperkeratosis and fissuring over the head and shoulders, and poor body condition. The authors speculated that transmission could have occurred from an infected wombat, due to mange being prevalent in the local population (Holz et al., 2011). Anecdotally, mange is periodically reported in swamp wallabies, but no systematic surveys of the frequency of occurrence have been undertaken.

2.4 Dingoes

Mange in dingoes was initially described in several case reports. McCarthy (1960a) described the anecdotal presence of periodic mange outbreaks in free-ranging dingoes in Queensland when populations were at high densities (McCarthy, 1960a). A subsequent contribution by McCarthy (1960b) described the successful experimental transmission of *S. scabiei* from an infected fox pelt to a pet dingo pup, which went on to infect the working dogs on the property (McCarthy, 1960b). Hoyte and Mason (1961) diagnosed and described severe sarcoptic mange in a wild female dingo and her two pups from Queensland (the mother was shot, one pup died, and the other was euthanised), which were sparsely haired with thickened, scaly skin, and reportedly had a foul odour (Hoyte and Mason, 1961).

Thomson (1992) studied dingoes in the Pilbara region of Western Australia between 1975 and 1984 and reported a mange incidence of 20% (60/300 captures), with males twice as likely to be affected compared with females. Twenty one percent of mange-affected adult dingoes were in poor condition, compared with only 5% of mange-free dingoes, but only one dingo was suspected to have died from mange (Thomson et al., 1992). Clinical signs ranged from frequent pruritis and small patches of thinly haired, scaly skin to one animal that was almost hairless, with thickened, crusty, haemorrhagic skin (Thomson et al., 1992). No treatment of mange in dingoes was discussed in any of these references but Thomson (1992) indicated recovery in one recaptured animal without treatment, which is consistent with other research on canids.

Corbett (1995) stated that mange is probably the most widespread parasitic disease in dingo populations in Australia (with an incidence ranging from 1% in central Australia, 2% in the southeast Highlands, 5% in northern Australia and 20% in Western Australia) but it is seldom debilitatin. Corbett (1995) also suggested that mange in dingoes co-occurs with other diseases, and is associated with prey species e.g., plagues of dusky rats.

More recent government reports have stated that sarcoptic mange is common among dingo and wild dog populations (Henderson, 2009), with relatively low mortality in wild dogs and dingoes (Fleming et al., 2001). Anecdotally, skin disease suggestive of mange is seen in almost all dingo populations, with a minority of individuals becoming disproportionately affected, sometimes with partial recovery (termed "leatherbacks", G. Ballard, 2021, pers.com). Dingo researchers from the wet tropics have not reported mange in dingoes (D. Morrant, 2021, pers. com.).

2.5 Bandicoots

One published case report outlines severe hyperkeratotic dermatitis in a wild-caught southern brown bandicoot (quenda, *Isoodon obesulus*) near Perth in Western Australia (Wicks et al., 2007). Lesions were located over the dorsal sacral area, tail base, flanks and caudal thighs, and consisted of alopecia and thick crusts with deep fissures; there is no description of whether the animal was euthanised or treated (Wicks et al., 2007). Clinically, the bandicoot was in moderate body condition but exhibited a systemic inflammatory response (similar to that described in wombats by Skerratt 2001) as evidenced by leucocytosis (due to a mature neutrophilia) and mild monocytosis and mild hyperfibrinogenaemia (Wicks et al., 2007).

Since 2019 there have been further cases (n > 70) in quenda seen by wildlife carers around Perth (S. Vitali, 2021, pers. com.; WHA, 2021a). It has been confirmed that these cases are being caused by *S. scabiei*.

2.6 Possums

Reports of mange have been made in the common ringtail (*Pseudocheirus peregrinus*) (Domrow, 1992) and common brushtail (*Trichosurus vulpecula*) (Munday, 1988) possum, however, scant (clinical or treatment) details were included in these references. The ringtail possum was a case report of a severe infestation that occurred near Melbourne, Victoria in 1986, which was associated with pruritic and erythematous skin lesions in a human (Domrow, 1992).

Since 2019 there have been further cases (n > 30) of sarcoptid mites causing mange in common brushtail (and rarely common ringtail) possums by wildlife care organisations in and around Adelaide, South Australia (T. May, 2021, pers. com.; WHA, 2021a). While the mite has been described as sarcoptid, further diagnostics are required to confirm whether *S. scabiei* is the cause.

2.7 Other species

One case in a long-nosed potoroo (*Potorous tridactylus tridactylus*) from Tasmania has been reported in Australia's electronic Wildlife Health Information System (WHA, 2021a). There have been anecdotal reports from wildlife volunteers of echidnas with mange; however, this has not been definitively diagnosed to date and skin lesions in this species could be a result of other conditions or parasites.

3. Treatment of sarcoptic mange in Australian wildlife

There is no accepted global standard treatment regime for mange in wildlife (WHA, 2021b). While treatment in a controlled setting has relatively predictable outcomes, effective treatment of wild populations requires an understanding of the epidemiology of the parasite in the population, including transmission pathways and persistent sources of infection (WHA, 2021b). The need for either multiple doses or a long-acting formulation has been demonstrated in most free-ranging wildlife species internationally where population level treatment has been attempted in animals with mange signs that are not mild. Some species have shown recovery after one injection of ivermectin alone, e.g., cheetahs (*Acinonyx jubatus*) (Gakuya et al., 2012), but not racoon dogs (*Nyctereutes procyonoides*) (Kido et al., 2014) or red foxes (*Vulpes vulpes*) (Newman et al., 2002) or chronically affected Spanish ibex (*Capra pyrenaica*; compared to success in mildly affected ibex) (León-Vizcaíno et al., 2001). Mildly affected kit foxes (*Vulpes macrotis*) recovered after one dose of selamectin (Cypher et al., 2017) but the more severe cases seemed to die with or without treatment. African buffalo (*Syncerus caffer*) (Munang'andu et al., 2010) needed multiple doses if the case was severe, but not if it was mild. For recent broader discussion of mange in wildlife globally see Astorga et al. (2018) and Escobar et al. (2021).

Concurrent administration of supportive therapy is a factor that has been positively associated with the success of treatment in various wildlife species being treated for mange (Rowe et al., 2019). In the study by Kido et al. (2014) captive raccoon dogs infested with *S. scabiei* developed sepsis, dehydration and malnutrition and those that received ivermectin, antibiotics and intravenous fluids had a significantly higher rate of recovery than raccoon dogs that received ivermectin alone (61.1 versus 42.6%, respectively) (Kido et al., 2014). In a treatment program for captive maras (*Dolichotis patagonum*) in a Korean zoo, weekly injections of prednisolone were given in addition to ivermectin (to reduce pruritis and inflammation) and while caution is often advised when using this class of potentially immunosuppressive drugs in conditions where a competent immune response is required for resolution of infection, in this case the colony recovered after four weeks of treatment (Kim et al., 2015). The recently updated veterinary textbook used by wildlife and zoo professionals in Australia, *Current Therapy in Medicine of Australian Mammals*, recommends repeated treatment with an avermectin (e.g., ivermectin or moxidectin; weekly until after clinical signs resolve (Bryant and Reiss, 2008)), removal of crusts, analgesia, fluid therapy, and antibiotics if secondary infections are present (Campbell-Ward, 2019). In addition to medical treatment, particular attention should be paid to the thermal environment and nutrition of mange-affected wombats in care (Campbell-Ward, 2019).

Whether to apply individual treatments to free-ranging populations should be considered very carefully, including: feasibility and efficacy, ecological impact, drug resistance, and cost (Moroni et al., 2020). A range of environmental, host and pathogen factors can influence disease dynamics between enzootic, epizootic and disease-free scenarios (Beeton et al., 2019). Balancing the relative merits of traditional ecological population-based management approaches to handle mange outbreaks (e.g. destruction of severely affected individuals), independent of drug-based treatments, may be warranted in many free-ranging wildlife contexts (Moroni et al., 2020). Models can inform practical solutions for controlling disease in the field, which may reduce the resources and field effort required to implement a successful regime (Martin et al., 2019).

3.1 Peer reviewed literature

3.1.1 Wombats

Treatment of mange in wombats is discussed below in chronological order. An historic account of *Sarcoptes* treatment in captive southern hairy-nosed wombats reported success with a mixture of lard, sulphur, sulfiram/'Tetmosol' and an organochlorine chemical (gammexane/'Lindane') (Wells, 1971). Munday (1988) noted that amitraz and abamectin ('Avomec') were effective treatments and also indicated that malathion effectively suppressed but did not necessarily eliminate mange in wombats, while cautioning that young wombats sometimes exhibited signs of toxicity if treated repeatedly with organophosphates.

Treatment with three subcutaneous (SC) injections of ivermectin at 0.3 mg/kg, and one initial injection of long acting penicillin (procaine penicillin 15 mg/kg IM, benzaine penicillin 11 mg/kg IM), given 10 days apart led to complete resolution of clinical signs in eight BNWs (Skerratt, 2003a). However, not all mites were eliminated and there was a recrudescence of sarcoptic mange in three wombats after two months; mites were successfully eliminated after a second treatment regimen of three ivermectin injections at 0.3 mg/kg SC (Skerratt, 2003a).

Skerratt et al. (2004) described the successful treatment and release of five wombats that had been experimentally infected with sarcoptic mange. All wombats were treated with 0.4 mg/kg of SC ivermectin at 100 days post infection (Skerratt et al., 2004b). The three wombats with mild mange showed no mites on skin scrapings four weeks later and were considered cured, however, the two wombats with severe mange still had mites detected and were given another 0.8 mg/kg ivermectin SC plus topical amitraz (250 µg/ml) (Skerratt et al., 2004b). This second treatment was then repeated twice at 10-day intervals in the most severely affected wombat (Skerratt et al., 2004b). Subsequently, Skerratt (2005) stated that the most effective method to reduce the intensity of infection and eliminate mites is to treat affected wombats in captivity with two acaricides, one systemic and one topical.

A community survey carried out by Ruykys et al (2009) received feedback that malathion had been used to successfully treat mange in SHNWs. Ruykys et al (2013) reported successful treatment of two mild, but not one severe, free-ranging cases with one dose of ivermectin at 0.2 mg/kg SC. In contrast, one dose of ivermectin at 0.2 mg/kg SC was effective in two severe cases in captive SHNWs, which was hypothesised as being due to supportive care and lack of reinfection pressure (Ruykys et al., 2013).

A 12-week trial treatment of administering topical moxidectin (5 g/L) at 4 ml/wombat via burrow flaps was undertaken on 40 burrows in a wild population of BNWs in the Wolgan Valley Conservation Reserve, Newnes, NSW (Old et al., 2018). The follow-up spotlighting surveys revealed no change in the mange level in the affected wombats, so the treatment regime was not considered successful in this context (Old et al., 2018).

Wilkinson et al (2021) recently described the pharmacokinetics, safety and efficacy of the isoxazoline class drug fluralaner ('Bravecto® spot-on solution for dogs') topically at 25 mg/kg (n = 5; same as domestic dog dose) or 85 mg/kg (n = 2), with an elimination half-life of 40 and 166 days respectively (Wilkinson et al., 2021). Clinical resolution of sarcoptic mange was observed in three affected study animals (2 moderate, 1 mild, captive during treatment trial) within 3–4 weeks of treatment, all wombats remained ectoparasite-free for 15 weeks, and no negative health impacts were noted (as assessed by haematology, biochemistry and behaviour) (Wilkinson et al., 2021). Use of Bravecto® (fluralaner), based on this research has been detailed in a factsheet produced by Wilkinson and Carver (2021) that is hosted on the University of Tasmania website (Wilkinson and Carver, 2021).

Within Australia, there has been increasing interest by the public and focus groups in options for treatment of mange in free-living wombats (WHA, 2021b). Treatment of mange in free-living wombats is carried out primarily by volunteer wildlife groups and carers (O'Sullivan 2018). In most cases, carers provide individual treatment to wombats, but where a large number of wombats in one area display symptoms, efforts to treat the population may occur. This involves attempting to treat and monitor all wombats/burrows within a given area, which is labour-intensive, time-consuming and costly (O'Sullivan 2018). While treatment with acaricides is usually effective in captive wombats, they may prove less effective in the wild due to the difficulty of retreating all wombats (Old et al., 2018).

Several attempts to treat wombats at the population scale have been undertaken with only one currently published (Martin et al., 2019). Martin et al (2019b) treated a population in Tasmania experiencing a mange epizootic in 2016–2017 using topical moxidectin (5 g/L) at 1 ml/kg, by placing 5 ml in burrow flaps (average < 200) of all active, recently active, and activated burrows, weekly for 12 weeks. Population level monitoring was undertaken, and 10 individually identifiable wombats were also followed closely (Martin et al., 2019). Recovery was observed at both the population and individual levels during and in the months immediately after the intensive treatment campaign, but the disease eventually resurged over the ensuing 12 months leading to continued population decline (see also Martin et al. 2018a). Subsequent modelling explored a range of scenarios to improve disease control in this circumstance, showing improved treatment delivery success and a longer lasting treatment to be important steps to enhance capacity (Martin et al. 2019b).

The use of burrow flaps to treat wild populations has limitations in large populations because it is difficult to know if individual wombats are being treated consistently, and those that are treated may not be infested with the mite (Old et al., 2018). In one attempt in NSW which used burrow flaps over 14 weeks, it was recognized retrospectively that the ratio of burrows with treatment flaps to the number of active burrows in the population was very small, and due to the very large population of wombats in the study area, without intensive observations, it was difficult to determine which wombats resided in which burrows (Old et al., 2018). Some wombats required up to five days getting accustomed to the presence of the treatment flaps at the entrance of their burrows, and others damaged the treatment flaps, resulting in replacement of 20% of those installed (Old et al., 2018).

3.1.2 Koalas

The earliest description of mange treatment was in a severely affected koala using 0.2% malathion baths (three times at 10 day intervals), with a complete clinical recovery reported (Barker, 1974). In treating a mange-affected koala colony (of unknown size), Brown et al. (1982) used two 0.025% amitraz baths, 10 days apart (which included soaking to enable softening and removal of crusts). Both the clinically affected and the unaffected koalas were treated the same way. One koala required two further (four total) amitraz baths to clear the mange infection, and the authors reported that all koalas that responded more slowly to treatment were concurrently infected with *Microsporum* sp. (ringworm) (Brown et al., 1982).

Speight et al (2017) described an attempt to treat a mange-affected koala with 0.2 mg/kg SC ivermectin and daily antibiotics (enrofloxacin 10 mg/kg), however, the animal died after three days of treatment.

3.1.3 Wallabies

The only published report of sarcoptic mange treatment in wallabies describes successful treatment (with release to the wild and no further follow up) of three agile wallabies: two with topical selamectin (three doses of 45 mg at 3-weekly intervals) and one with injectable ivermectin (two doses of 300 µg/kg SC, two weeks apart) (McLelland and Youl, 2005). This paper also refers to an unsuccessful treatment attempt (in one of the individuals subsequently treated with selamectin) using injectable ivermectin and long acting corticosteroids (McLelland and Youl, 2005)

3.2 Anecdotal/grey literature

3.2.1 Wombats

Veterinarians treating wombats with mange across Australia report successful eradication of infection in juvenile wombats with mild clinical signs, using the same doses of injectable ivermectin or moxidectin recommended in companion animals and livestock (generally 0.2–0.4 mg/kg, weekly for 1–4 months) (A. Kreiss, C. Steventon, J. Weller and M. Campbell-Ward, 2021, pers. com.). Some veterinarians also report success in adult wombats with the 2020 APVMA permit topical moxidectin dose of 0.8 mL/kg up to a maximum of 20 mL/wombat (A. Lowe, J. Weller, 2021, pers. com.). Some clinics have also started to use fluralaner spot-on at dog doses (25 mg/kg) to treat mild to moderate mange in juvenile wombats, and report successful resolution of infection with this regimen. All interviewed veterinarians reported that by the time they were presented for assessment at a veterinary clinic, all severe mange cases in adult wombats required euthanasia on humane grounds, due to the significant systemic effects of the disease (e.g., poor body condition and severe skin infection). In general, only wombats that are severely compromised by mange can be handled and presented to a veterinarian.

Skerratt (2001) outlines an attempt to reduce the effects of mange in BNWs near Buckety in New South Wales, utilising repeated treatments of mild to moderate mange with acaricides and euthanasia and disposal of severely affected wombats. The success of the treatment program on the population was not discussed.

The BNW population at Cape Portland, Tasmania, underwent a treatment attempt by a community group that was reported by the Department of Primary Industries, Parks, Water and Environment (DPIPWE) (Driessen et al., 2018). The prevalence of mange did not differ between 2017 and 2018 despite concerted efforts by volunteers to treat mange, using burrow flaps (on 90 burrows) dosed with moxidectin (dose not specified) (Driessen et al., 2018). The mange severity was apparently less in 2018 compared with 2017, however, and the total population size did not change (Driessen et al., 2018).

A BNW population at Bents Basin in NSW reported successful eradication of mange from the treatment area for 20 months after a treatment and monitoring program was conducted from 2014–2019, coordinated by NSW Parks and Wildlife with input from the University of Sydney Veterinary School (D. Phalen and T. Leary, 2021, pers. com.). Approximately 60 wombats were treated weekly with Cydectin® (5 g/L) at 4 ml/wombat using between 112 and 256 burrow flaps for 13 treatments over six months (weekly for eight weeks, fortnightly for two treatments, then monthly for three treatments).

Great care was taken to have treatment burrow flaps at every burrow at the site, active or inactive (treatment began on 112 burrows but as new burrows were identified they were also treated), and remote cameras were able to confirm secondary to application of dye by the burrow flaps that there was successful application to 70–90% of the wombats with each treatment (publication in preparation). A single severely affected wombat was recorded at 20 months post completion of the treatment and at 42 months post-treatment there was clear evidence that mange had returned to the population.

Another mange-affected, high-density BNW population in NSW, at London Bridge near Googong, was successfully treated in 2018–2019 in a collaboration between veterinarians within the ACT Government and the 'Wombat Rescue' organisation (A. Lowe and Y. Vermaak, 2021, pers. com.), with a dose derived following informal communication with Virbac, the producer of Cydectin®. This dose is the same as the current APVMA approved permit dose. Approximately 100 wombats across 160 burrows had 20 ml of pour-on (5 g/L) applied weekly by burrow flap for 18 treatments over 12 months (weekly for eight weeks, then fortnightly for 16 weeks, with repeat treatments up to 12 months). This treatment program employed remote cameras and dye to enable knowledge of treatment success. Treatment ceased 18 months ago and no re-infection to date has been detected, although the project is still in monitoring phase (Y. Vermaak, 2021, pers. com.). This project will soon be published in the peer-reviewed literature.

Both of the above studies demonstrated that successful population-level treatment of sarcoptic mange in wombats is possible using the 2020 APVMA approved Cydectin® dosage regimens, if all burrows and wombats are reliably treated and monitored.

Old et al (2021) interviewed 18 wildlife carers (contacted via the network of the Wombat Protection Society of Australia) from New South Wales, Tasmania and Victoria about their BNW mange treatment regimes in free-ranging wombats. They described treatment and follow up for 33 "successful" cases, where the dose of topical Cydectin® delivered varied from 4–200 ml per wombat, using various combinations of 'pole-and scoop' and 'burrow flap' application. There was acknowledged confirmation bias, in that it is more likely that successes will be reported over failures, with the added complication that the majority of treated free-ranging wombats will have unknown outcomes. Most of the initial and subsequent doses described as "successful" were multiple times higher than the current maximum APVMA permit approved dose of 20 ml per wombat (Old et al., 2021). There was acknowledgement that part of the Cydectin® dose can be lost during application (e.g., if the wombat shakes, the burrow flap is blown by the wind, or the wombat is excessively wet or dirty prior to application) which makes it hard to know the actual volume applied to, and absorbed by, the wombat (Old et al., 2021). In the 20 "recovered" moderate and severe cases, treatment had occurred at weekly intervals (on average), over an average duration of approximately three months (range ≈ 1–7 months) (Old et al., 2021). The 10 "unsuccessful" cases described from the survey included some individuals treated with the previously (2017) approved APVMA dose (4 ml/10 kg weekly) that did not improve, some individuals treated with doses similar to "recovered" cases that either died or did not improve, through to some individuals treated with higher doses (e.g., 100–200 ml) that died or disappeared (Old et al., 2021). The consensus from this survey appeared to be that the APVMA recommended length of treatment (4 months) is difficult to achieve in free-ranging wombats. Wildlife carers may be opting to treat wombats with larger initial doses in the event the wombat is unable to be located again for retreatment or because they feel that higher doses are more effective, or both (Old et al., 2021). There is uncertainty about what dose is optimal, despite anecdotal evidence from wildlife volunteers, due to a lack of formal research into the toxicity of the active and carrier ingredients at higher and more frequent doses.

The Old et al (2021) Cydectin® review highlights the time commitment that wildlife carers make when they embark upon attempting to treat a free-ranging wombat with mange and demonstrates the extent of experience and passion in the community. There was no discussion of supportive treatment being offered in parallel to acaricide application, but some of the images indicated that supplementary feeding was occurring (e.g., wombats photographed eating from food bowls) (Old et al., 2021). One observation from this work was that there might not be "one-regimen-fits-all" and that perhaps the treatment process should be assessed for each wombat (Old et al., 2021).

While the Old et al (2021) survey covers Cydectin® use, anecdotally wombat carers also use other products to treat mange, including commercially available domestic animal and livestock products such as ivermectin, Revolution® (selamectin), Advocate® (imidalcloprid and moxidectin) and Bravecto® (fluralaner), in addition to older regimes using sulphur & oil (with unknown success or animal health and welfare implications) and investigation of a new "natural" product ("CritterKleen", Tasmania) (O'Sullivan, 2018). Anecdotally, there have been reports of wombats being treated with a combination of medications, for example Cydectin® and Bravecto®, with unknown animal health and welfare implications.

Anecdotally, several free-ranging cases of mange in Tasmania are responding well to a single dose of Bravecto® (S. Carver, 2020, pers. com.). Some wildlife volunteers that have used Bravecto® to date have commented that it does not seem to cure mange even with multiple doses. Others have indicated that it seems to clear infection but can take > 6 weeks, and also that it has not worked if the wombats were wet at the time of treatment or got wet within 24 hours, presumably due to a lack of initial absorption of the product (a sentiment mirrored by Stannard et al (2020)). Monthly administrations of Bravecto up to three months have been suggested as safe if needed (Wilkinson and Carver, 2021). Further research is required to determine the safety, efficacy and environmental effects of Bravecto® in various contexts to reassure users it is an appropriate alternative to Cydectin®.

Various treatment regimes are currently advocated by carer organisations, with some recommending the 2020 WPSA and Mange Management APVMA approved protocols of 0.8 ml per kg weekly for 15 weeks (Mange Management 2021, https://mangemanagement.org.au/) and others advising higher doses over shorter treatment periods, in line with the 2021 WPSA APVMA permit (WPSA 2021, www.wombatprotection.org.au/mange-disease). There is potential for new products and new delivery methods using emerging technology to greatly improve treatment success in this space.

3.2.1 Koalas

Veterinarians with experience treating koalas with sarcoptic mange reported a general lack of success when attempting to treat mildly to moderately affected koalas (with, for example, ivermectin at 0.3 mg/kg weekly, combined with topical bathing in medicated shampoo under anaesthetic), and felt that there was often comorbidity/concurrent disease (e.g., chlamydia, kidney failure) or immunosuppression in these koalas, which was assumed to contribute to their lack of response to treatment (N. May and A. Gillett, 2021, pers. com.). In general, by the time koalas were impacted enough by the disease to be presented for veterinary assessment, they required euthanasia on humane grounds due to severe pruritis and self-trauma to the face, hands and genitals (N. May, 2021, pers. com.).

3.2.1 Possums

Female brushtail possums treated for mild to moderate sarcoptic mange in Adelaide have shown good response to fluralaner spot-on at 25 mg/kg as a one-off treatment (N. May, 2021, pers. com.). More severe cases that are self-traumatising their face and genitals are euthanised on humane grounds, and males are not treated as they need to be housed for four weeks and cannot be reintroduced into their territory. Photographs are taken every week to enable objective comparison of improvement to be made. Additional supportive care such as injectable antibiotics, extra feed (including possum milk) and probiotics are provided to these cases (N. May, 2021, pers. com.).

4. Knowledge gaps

Aligning with the gaps identified in this review, Wildlife Health Australia (2021) summarised that monitoring of the distribution of mange and prevalence in affected species, along with ongoing work on practical, ethical and effective treatments, are vital. They indicated that further research is required in the following areas:

- Modes and degree of transmission between and within species (including vectors, and how transmission varies with host population density and dynamics)
- Evolutionary history of mange mite in Australia
- Physical and behavioural impacts of mange on hosts and why this differs across species
- Understanding dynamics of impacts of mange at the population level
- Understanding the environmental factors that exacerbate impacts of mange on host populations (e.g. soil type, local flora and fauna including pest and domestic species, weather patterns, climate)
- Understanding of the host immunological response to mange, and other factors that determine the range of host species
- Distribution and monitoring of mange presence and prevalence within Australian mammal populations
- Clinical pathology associated with mange in the host, and co-morbidities
- Best treatment regimens for mange at an individual and population scale (WHA, 2021b).

Many of these research gaps/recommendations have previously been raised in reports and peer-reviewed publications (e.g. Death et al 2011 and Rowe et al 2016). Wildlife carers have emphasised the importance of framing research questions to be useful for field application.

In addition, or more specifically, this review has highlighted the need to investigate:

- Acaricide pharmacokinetics, safety and efficacy using various administration routes and doses, comparing oral, injectable, topical, short-acting and long-acting formulations of various drugs in animals of various species and ages, including consideration of whether prior mite exposure and treatment of the population has occurred.
- Understanding empirical epidemiological factors (environmental, host, pathogen etc.) that influence prevalence/severity/population impacts of mange in different wildlife populations and regions, and guidelines about how to investigate these factors.
- Methods to eliminate sarcoptic mange (including consideration of new, alternative treatments and delivery methods) and mitigate reintroduction into populations, especially isolated ones.
- Understanding of mite resistance to treatment
- Research into cross-species transmission
- The environmental toxicological implications of mange programs in the field, particularly under differing dose regimes of moxidectin, including impacts on waterways.
- Whether existing data kept by wildlife carers, veterinarians, sanctuaries and others may be of any value in understanding prevalence and distribution of mange (especially in the absence of national monitoring for mange), and any drug reactions or toxicity.
- The potential for a database to enable central recording and monitoring of mange in populations.
- Data required to inform and improve statistical and mathematical models of sarcoptic mange in wombat populations, to enable new hypotheses to be generated and tested, including prediction of high-risk populations that require more intensive monitoring.
- A better understanding of the distribution and impact of sarcoptic mange in the wombat population. Tasmania is the only jurisdiction that has undertaken government funded surveys of mange distribution and prevalence (O'Sullivan, 2018), so there is a lack of baseline information to enable assessment of the size and impact of the problem in mainland Australia. Martin et al. (1998), the only study that has investigated sarcoptic mange distribution, was conducted over two decades ago.
- Which environmental variables result in population stress and subsequent outbreaks. Long-term population studies have recently been published for Tasmania (Carver et al. 2021), and broader mange prevalence and distribution information for the State is impending for 2021/22.
- Ongoing involvement by state/territory and national governments to develop nationally consistent policies and support funding applications, and to build baseline understanding of the distribution, impact and surveillance options. DPIPWE in Tasmania have contributed significant funding and resources to support treatment trials and other research (R. Gales, 2021, pers. com). There is increasing involvement and interest in this space, for example NSW Parks and Wildlife are updating their Codes of Practice for wombats in care (A. Sriram, 2021, pers. com.), the ACT government is developing a wombat management program (A. Lowe, 2021, pers. com.), and Mange Management Inc. in Victoria received a government grant in 2020 for wombat mange treatment.

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7. Appendix: Literature Search Strategy

Medline/Web of Science

TS=((wildlife OR fauna OR native OR koala OR wombat OR macropod OR marsupial) AND (mange OR sarcopt*) AND (treat* OR therap* OR medicat* OR pharm* OR drug) AND Australia)) *AND* ***SPECIES***: (Animals)
Indexes=MEDLINE Timespan=All years

PubMed

(((wildlife[All fields] OR fauna[All fields] OR native[All fields] OR koala[All fields] OR wombat[All fields] OR macropod[All fields] OR wallaby[All fields] OR marsupial[All fields]) AND (mange[All fields] OR sarcopt*[All fields])) AND (treat*[All fields] OR therap*[All fields] OR medicat*[All fields] OR pharm*[All fields] OR drug[All fields])) AND (Australia[All fields] OR Oceania[All fields]) AND other animals

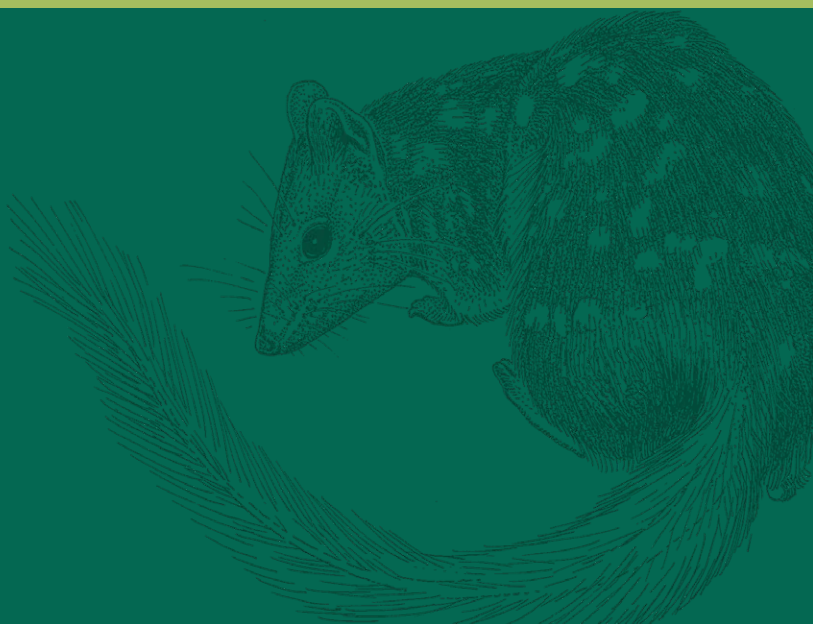
Google

(((wildlife OR fauna OR native OR koala OR wombat OR macropod OR wallaby OR marsupial) AND (mange OR ***sarcoptic****)) AND (treat* OR therap* OR medicat* OR pharm* OR drug)) AND (Australia OR Oceania)

-> All prior and subsequent relevant material was sourced by checking bibliographies of the above sources and relevant text books.

Wombat mange treatment. Image: Scott Carver

Further information:
http://www.nespthreatenedspecies.edu.au



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Threatened Species Recovery Hub

National Environmental Science Programme