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Treatment of Sarcoptic Mange in Wombats With Topical Moxidectin

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ABSTRACT

Sarcoptic mange is a debilitating disease affecting free-living/wild bare-nosed wombats (*Vombatus ursinus*). The disease causes thickening of the skin, pruritus, alopecia and deep fissures in the skin of infected animals, and ultimately death if left untreated. In Australia, there are approvals from the Australian Pesticides and Veterinary Medicines Authority to use moxidectin for treating sarcoptic mange in bare-nosed wombats; however, few published literatures document the success of treatment regimens. Two adult male bare-nosed wombats presented with dermatitis, erythema and crusting of the skin. Evaluation of skin scrapings confirmed the presence of live *Sarcoptes scabiei*. Both wombats were treated with three 100-mL doses of moxidectin topically poured on to the dorsal backline approximately 7 days apart. Both animals showed improvement, with skin becoming clear of crusting and dermatitis, and no *S. scabiei* mites were present on either animal after 2 weeks. Here, we presented two clinical scenarios of sarcoptic mange in wombats that were successfully treated with three 100-mL doses of moxidectin applied topically. We recommend this treatment be used where wombats can be identified and monitored throughout their recovery.

1 | Introduction

Sarcoptic mange is a disease that can infect more than 140 species of mammals worldwide (Pence and Ueckermann 2002). It is caused by a mite, *Sarcoptes scabiei*, which burrows into the epidermis and causes a hypersensitivity reaction (Pence and Ueckermann 2002). Signs of sarcoptic mange are primarily seen on the skin in the form of alopecia, hyperkeratosis, erythema and fissures (Pence and Ueckermann 2002). In Australia, sarcoptic mange affects a number of native species, including koalas (*Phascolarctos cinereus*), swamp wallabies (*Wallabia bicolor*), quenda (*Isoodon fusciventer*), southern hairy-nosed wombats (*Lasiorhinus latifrons*) and bare-nosed wombats (*Vombatus ursinus*) (Botten, Ash, and Jackson 2022; Brown, Seawright, and Wilkinson 1981; Holz, Orbell, and Beveridge 2011; Ruykys et al. 2009; Skerratt, Martin, and Handasyde 1998). Sarcoptic mange infections in bare-nosed wombats have been shown to infect up to 41% of a local population (Stannard et al. 2021); however, this varies across each local population (Driessen et al. 2022; Hartley and English 2005; Martin, Handasyde, and Skerratt 1998; Skerratt, Martin, and Handasyde 1998).

Current treatment regimens of sarcoptic mange for wombats approved by the Australian Pesticides and Veterinary Medicines Authority (APVMA) include moxidectin with two dose rate permits approved, and more recently, fluralaner. The first moxidectin

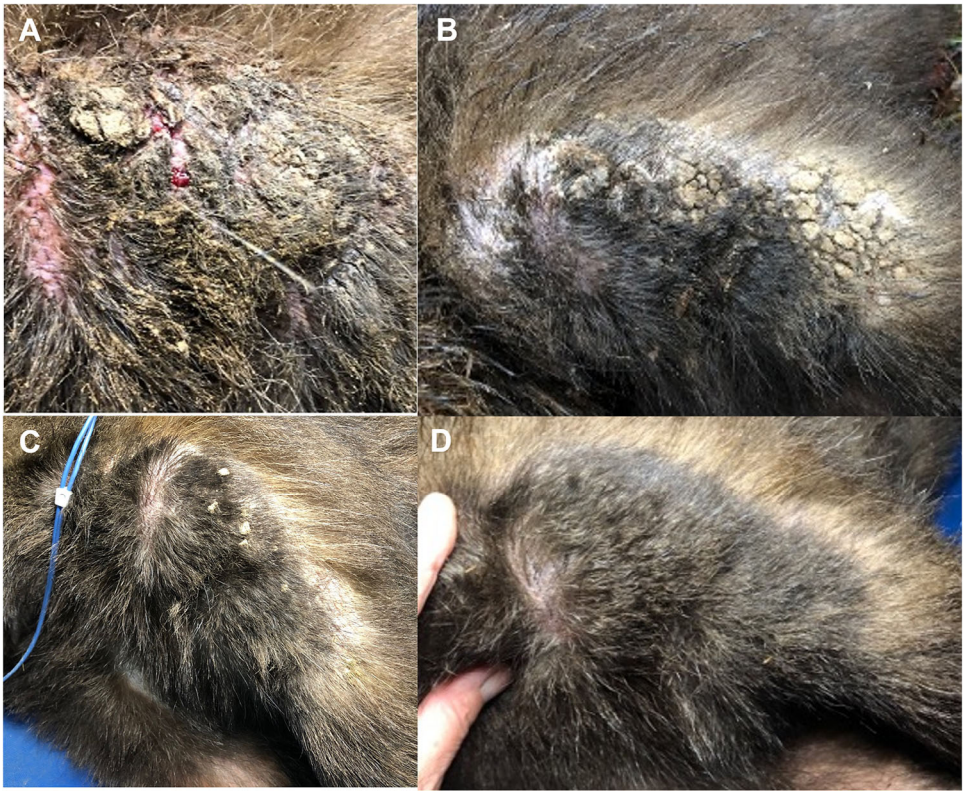

FIGURE 1 | Hyperkeratosis and scabbing of the skin on wombat 1, (A) day 0 and (B) day 7. Skin and fur showing signs of healing after treatment with topical moxidectin, (C) day 14 and (D) day 26. Left shoulder and ventral surface of the proximal forearm.

permit allows for 0.8 mL/kg body weight and a maximum dose of 20 mL on an adult wombat (PER89982). The second permit allows for wombats with generalised mange to be given up to 4 mL/kg body weight and a maximum dose of 80–100 mL on an adult wombat per single treatment (PER90094). Moxidectin is a macrocyclic lactone that is derived from *Streptomyces cyanogriseus*. It is widely used as a veterinary product to treat a wide range of endo and ectoparasites. Within the veterinary field, moxidectin has been formulated into oral pastes/gels, tablets, drenches, pour-ons, or can be administered subcutaneously (Papich 2020). Generally, moxidectin has a high efficacy for treating *Sarcoptes* with few adverse side effects, as reviewed in Schraven, Stannard, and Old (2021).

As well as moxidectin, ivermectin or amitraz can be used to treat wombats in captivity for sarcoptic mange (Ruykys et al. 2013; Skerratt et al. 2004), and more recently fluralaner has been used on a small number of wombats ($n = 3$) (Wilkinson et al. 2021). It is not practical or feasible to bring all free-ranging wombats with sarcoptic mange into captivity for treatment due to their ecology and behaviour, and hence wombats are treated in the field. Field trials of moxidectin treatments have been undertaken using burrow flaps with up to 5 mL of moxidectin, while recovery of individual wombats was observed in the short term, in the longer term, the trials showed no reduction in sarcoptic mange prevalence at the population level and reinfection (Martin et al. 2019; Wolfenden and Old 2012). Old, Skelton, and Stannard (2021) surveyed wildlife carers treating wombats with moxidectin as a direct pour-on and using burrow flaps. They found a variety of treatment regimens were used, with dosage rates from 4 mL to 200 mL of moxidectin used per wombat over varying time periods. Treatment success also varied, with most wombats assessed as recovered or recovering (if still under treatment); however, three died and four had outcomes unknown from a total of 43 wombats (Old, Skelton, and Stannard 2021). Whilst these previous studies have demonstrated efficacy, data have yet to be published on the higher doses recently approved by the APVMA or on absorption into plasma.

Treating animals in the wild is often confounded by not being able to follow and track animals throughout their treatment or being able to provide consistent treatments, leading to unknown outcomes (Rowe, Whiteley, and Carver 2019). Often wombats are only observed and treated once for mange as they move burrows and have large home ranges. There has been a recent trend to use larger doses of moxidectin to treat wombats (Old, Skelton, and Stannard 2021) because smaller doses appear to be less effective, and the APVMA permit allows up to 100 mL. Here, we report on the treatment regimen and clinical blood parameters before and during treatment of sarcoptic mange in two free-living wombats using a topical application of moxidectin. Due to concerns with side effects of moxidectin (Mounsey et al. 2022), we also measured the plasma concentration of moxidectin during the treatment to understand short-term safety.

2 | Case Summary

The two cases described here are free-ranging wombats that live in and around a private property near Nimmitabel, NSW

TABLE 1 | Treatment and blood collection regimen.

Date	Treatment day	Treatment
		Wombat 1
6/1/22	0	Sedated and blood sample collected. 100 mL moxidectin poured on backline. Skin scraping—positive for mites
13/1/22	7	Sedated and blood sample collected. 100 mL moxidectin poured on backline
20/1/22	14	Sedated and blood sample collected. 100 mL moxidectin poured on backline Skin scraping—negative for mites
1/2/23	26	Sedated and blood sample collected. Skin scraping—negative for mites
		Wombat 2
26/7/22	0	Sedated and blood sample collected. 100 mL moxidectin poured on backline. Skin scraping—positive for mites
2/8/22	7	Sedated and blood sample collected. 100 mL moxidectin poured on backline
8/8/22	13	Sedated and blood sample collected. 100 mL moxidectin poured on backline Skin scraping—negative for mites
16/8/22	21	Sedated and blood sample collected. Skin scraping—negative for mites
24/8/22	29	Sedated and blood sample collected.

(−36.510, 149.26). Wombat 1 was an adult male that weighed 32 kg. In January 2022, Wombat 1 presented with mange on his left shoulder (Figure 1A), side of the neck and lower side of the flank, as well as early signs of mange on his right shoulder. He had a few areas of hyperkeratosis and diffuse erythema and dermatitis. He also had a pungent musty yeasty smell typical of sarcoptic mange.

Wombat 2 was an adult male that weighed 29 kg. Wombat 2 presented with mange in July 2022. The entire ventral side and between arms and legs were erythemic, but no thick scabs were observable underneath the fur. There was hyperkeratosis proximal on the right forelimb and point of the shoulder, and some on the flank.

2.1 | Treatment Regimen

Both wombats were treated with three 100-mL doses of moxidectin poured onto the dorsal surface/backline of the wombat weekly (Table 1). Quantities of moxidectin per kg for each treatment were Wombat 1: 15.6 mg/g and wombat 2: 17.2 mg/kg.

2.2 | Sampling and Analysis

Wombat 1 was caught and sedated a total of four times (Days 0, 7, 14 and 26), and wombat 2 a total of five times (Days 0, 7, 13, 21 and 29). The wombats were sedated in the field and returned to where they were captured to recover. Both wombats remained free, living in between each treatment and following the final sedation and blood collection. Wombat 1 was sedated 8–9 months after this study to confirm no mites were present (using skin scraping and viewing under a microscope) and to reassess blood parameters. At that time, he was mange-free and clinically healthy.

The wombats were sedated with an intramuscular injection of Zoletil (5.8–6.9 mg/kg) to the lateral thigh. A skin scraping was taken from both wombats and live mites were visible under a microscope, confirming both wombats had a sarcoptic mange infection. A blood sample was taken from the saphenous vein using a 21 G scalp vein/butterfly needle with a 10 mL syringe and placed in EDTA and lithium heparin tubes (BD Vacutainer) for haematology and blood chemistry, respectively. Haematology and blood chemistry were analysed using a Vetscan HM5 haematology analyser (Abaxis) and a Vetscan VS2 blood chemistry analyser (Abaxis), respectively.

A sub-sample of blood was centrifuged at 10 min at 3400 rpm (MXU Centrifuge, LW Scientific, Lawrenceville, GA) to remove plasma, which was stored at −20°C until analysis. Moxidectin concentration in plasma was analysed by spiking samples with moxidectin-D3, then precipitating with acetone. The aqueous supernatant was twice extracted with hexane, evaporated under nitrogen at 30°C and resuspended in 5 mM ammonium acetate in acetonitrile for analysis by liquid chromatography with tandem mass spectrometry as described in Doran et al. (2024).

2.3 | Skin and Fur Appearance After Treatment

Seven days after the initial treatment with moxidectin, wombat 1 had erythema in a few areas, and some scabs were starting to lift (Figure 1B). On day 14, the skin was not erythemic or showing signs of dermatitis. A few scabs were still attached to the fur, but there was clean, unbroken skin underneath (Figure 1C). On Day 26, the skin appeared smooth with no dermatitis or erythema (Figure 1D).

The sarcoptic mange infection in Wombat 2 was more diffuse than in wombat 1. Recovery was similar with reduced erythema and scabbing after 13 days, and hair regrowth was observed in previously alopecic affected area (Figure 2).

2.4 | Blood Results

Haematology and blood chemistry data for wombats 1 and 2 were generally consistent with published values (Booth 1999; Bryant and Reiss 2009; Hartley and English 2005; Presidente 1982), with some exceptions (Table 2). On days 0 and 7, elevated levels of monocytes, eosinophils, haematocrit, haemoglobin, red blood cell count and potassium (day 21 only) were observed in wombat 1 (Table 2). Total protein was slightly elevated on day

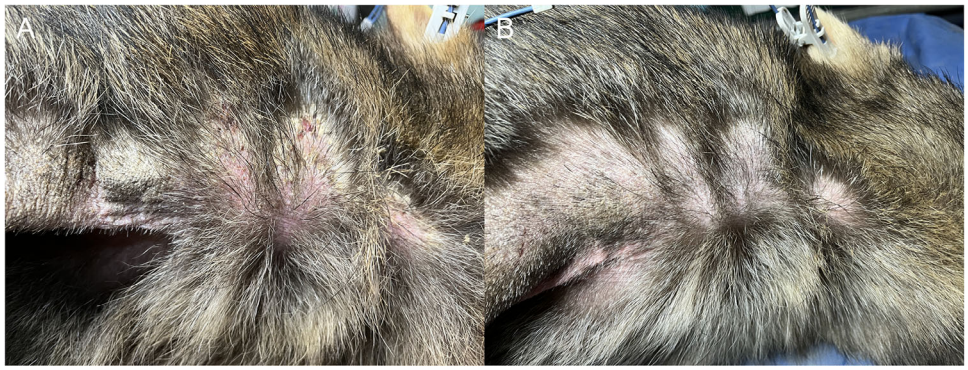

FIGURE 2 | Hyperkeratosis and scabbing of the skin on wombat 2, (A) day 0 and (B) day 13. Skin and fur showing signs of healing after treatment with topical moxidectin. Right shoulder and ventral surface of the proximal forearm.

0 for wombat 2, and alanine aminotransferase (ALT), aspartate aminotransferase (AST) and gamma glutamyl transferase (GGT) levels decreased throughout the study (Table 2). The peak plasma concentration of moxidectin occurred at 13 and 14 days (wombats sampled on different days), with a mean peak plasma level of 0.22 ± 0.02 ng/mL (Figure 3).

3 | Discussion

Sarcoptes scabiei is responsible for high levels of mortality and population declines in bare-nosed wombats (Martin et al. 2018). Treatment is challenging in free-living wombats due to wombat ecology and behaviour, and there are differing methods used for treatment, e.g., subcutaneous injection, topical (pour-on) application and burrow flaps (Old, Skelton, and Stannard 2021). Effective treatment is essential to conserve wombats and prevent further population declines. Here we showed that following three 100-mL topical doses of moxidectin administered weekly, the two infected wombats were free of sarcoptic mange mite infestation. The wombats showed signs of healing skin wounds and hair regrowth by the end of the data collection period.

Treatment regimens used to successfully treat sarcoptic mange using topical doses of moxidectin have included (1) sheep: two topical applications, 2 weeks apart, of 5 mg/mL moxidectin at 0.5 mg/kg body weight; a single dose was insufficient (Danbirni et al. 2011); and (2) goats: three doses of 0.5 mg/kg of 5 mg/mL moxidectin, 15 days apart (Menzano, Rambozzi, and Rossi 2007). Comparatively, our study had shorter intervals between doses and a higher dose rate and showed similar success. Given *Sarcoptes* mites take 10–13 days to mature after hatching (Yotsu, Yoshizumi, and Izri 2023), a single dose of moxidectin is not sufficient to kill all mites, which is evident from our and others studies (Danbirni et al. 2011; Menzano, Rambozzi, and Rossi 2007) showing a minimum of two topical applications is required.

Previously published data on blood chemistry and haematology of severely mange-infected wombats have shown several parameters that are either significantly lower or higher than those reported for healthy animals (Hartley and English 2005; Skerratt, Middleton, and Beveridge 1999). For example, Hartley and English (2005) found that haematocrit, mean corpuscular volume, lymphocytes, albumin and creatinine:albumin ratios were significantly decreased in wombats with sarcoptic mange, and monocyte counts were higher. While Skerratt, Middleton, and Beveridge (1999) found that MCHC, neutrophils, urea, total protein and calcium were significantly lower. The observed changes in haematology and blood chemistry parameters of severely affected animals are consistent with anaemia, inflammation, and starvation (Skerratt, Middleton, and Beveridge 1999). Creatinine levels in our wombats on days 0 (wombat 1) and 7 (wombat 2; 0.9 mg/dL) were similar to levels observed in sarcoptic mange-infected wombats previously reported (0.96 ± 0.24 mg/dL) by Hartley and English (2005). The wombats presented in our study did not have a severe infection, and thus, most blood parameters were consistently inconsistent with those published for sarcoptic mange-infected wombats.

Although wombat 2 showed a decreasing trend for ALT, AST and GGT levels throughout the study, all were within the ranges of healthy animals from previous studies (Bryant and Reiss 2009; Hartley and English 2005; Presidente 1982). ALT, AST and GGT are very variable amongst individual wombats (Stannard et al. 2024). It should be noted that previously published data on haematology and blood chemistry are very limited and sourced from a small number of mostly captive animals, and therefore may not represent reference intervals for bare-nosed wombats.

The peak plasma concentration of moxidectin for the infected animals was lower than the mean peak concentration (0.5 ± 0.4 ng/mL) determined in a pharmacokinetics trial using topical moxidectin in healthy bare-nosed wombats (Stannard et al. 2024). The peak concentration also occurred at 2 weeks rather than 1 week as reported in wombats given a single 100-mL dose (Stannard et al. 2024). The later peak presumably occurred due to using multiple doses of moxidectin. Moxidectin has a high binding affinity to protein within the plasma of wombats, 97.0%–99.5% (Doran et al. 2024); hence, bioavailability is relatively low. Similarly, a study on moxidectin in the serum of wombats has shown that increasing the concentration of moxidectin decreases the free drug percentage (Stott et al. 2024). Given the relatively low concentration of moxidectin in our plasma, it is possible that using a high volume and repeated doses of moxidectin has reduced the bioavailability of moxidectin in plasma. Absorption across the skin occurs over several days, and during this time excretion in scats is also occurring, with a single dose of 100 mL having a mean half-life of 8 days (Stannard

TABLE 2 | Haematology and blood chemistry values for two bare-nosed wombats infected with sarcoptic mange during treatment with moxidectin.

			Wombat 1[a]				Wombat 2					Previously published values for captive and wild wombats (Booth 1999; Bryant and Reiss 2009; Hartley and English 2005; Presidente 1982) (n = 8–31)
	Day		**0**	**7**	**14**	**26**	**0**	**7**	**3**	**21**	**29**	
Haematology		**Unit**										
Total white blood cell count	WBC	10^9/L	12.9	12.16		7.5	12	12.17	11.75	11.49	12.23	7.5–19.9
Lymphocyte count	LYM	10^9/L	3.08	2.65		1.85	5.63	6.35	6.41	6.27	2.21	1.9–12.8
Monocyte count	MON	10^9/L	0.45	0.08		0.04	0.28	0.37	0.07	0.43	0.87	0.1–1.0
Neutrophil count	NEU	10^9/L	5.59	7.88		4.74	5.35	4.97	4.74	4.17	8.48	2.7–10.8
Eosinophil count	EOS	10^9/L		1.36		0.75	0.61	0.4	0.45	0.52	0.55	0.0–0.6
Basophil count	BAS	10^9/L	0.19	0.18		0.11	0.12	0.08	0.08	0.1	0.11	0.0–0.5
Lymphocyte%	LY%	%	23.8	21.8		24.7	47	52.2	54.6	54.6	18.1	50
Monocyte%	MO%	%	3.5	0.7		0.6-	2.3	3.1	0.6	3.8	7.1	5
Neutrophil%	NE%	%	43.4	64.8		63.2	44.6	40.9	40.3	36.3	69.4	41
Eosinophil%	EO%	%		11.2			5.1	3.3	3.8	4.5	4.5	3
Basophil%	BA%	%	1.5	1.5		1.5	1	0.6	0.7	0.8	0.9	0.3
Red blood cell count	RBC	10^{12}/L	6.91	8.89		6.94	8.04	7.94	7.74	7.19	6.88	5.2–5.3
Haemoglobin	HGB	g/dL	14.6	18.3		14.8	18.9	18.3	18.2	17.1	16.3	11.9–14.2
Haematocrit (PCV)%	HCT	%	53.27	59.03		51.36	62.38	60.62	59.75	54.89	53.76	36–41
Mean corpuscular volume	MCV	fL	77	66		74	78	76	77	76	78	62–76
Mean corpuscular haemoglobin	MCH	pg/L	21.1	20.6		21.4	23.5	23.1	23.5	23.8	23.6	20.0–25.8
Mean corpuscular haemoglobin concentration	MCHC	g/dL	27.4	30.9		28.9	30.3	30.3	30.5	31.2	30.2	32.3–36.8
Red cell distribution width	RDWc	%	16.2	18.4		15.9	16.2	15.5	16	16	16.1	—
Red cell distribution width	RDWs	fL					48.4	46.1	47.7	47.7	48.4	—
Platelet count	PLT	10^9/L		185		161	160	156	146	153	167	220
Platelet haematocrit	PCT	%		0.3		0.23	0.21	0.2	0.19	0.22	0.26	—
Mean platelet volume	MPV	fL		16.1		14.4	13.2	12.6	13	14.6	15.8	—
Platelet distribution width	PDWc	%		45.9		45	44	43.1	43.7	45.4	46.3	—
Platelet distribution width	PDWs	fL					27.9	25.6	27.1	32.8	36.8	—
Biochemistry												
Alanine aminotransferase	ALT	U/L		50	46	42	58	43	34	32	27	7.0–60.0
Albumin	ALB	g/dL		3.4	3.7	3.9	3.8	3.5	3.5	3.5	3.3	2.5–3.7
Alkaline phosphatase	ALP	U/L		112	137	168	199	176	189	193	196	192–342
Alpha-Amylase	AMY	U/L		233	224	244	229	214	224	201	215	—
Aspartate Aminotransferase	AST	U/L		68	80	88	122	72	52	53	51	98–156
Blood urea nitrogen	BUN	mg/dL		21	19	23	17	16	19	17	19	10.4–56.8
Calcium	CA	mg/dL		10.1	10.6	10.7	10.4	10.2	10.4	9.8	9.9	6.73–13.15
Carbon dioxide	TCO2	mmol/L		30	24	29	31	29	29	29	28	33.6

(Continues)

TABLE 2 | (Continued)

			Wombat 1[a]			Wombat 2					Previously published values for captive and wild wombats (Booth 1999; Bryant and Reiss 2009; Hartley and English 2005; Presidente 1982) (n = 8–31)
Creatine Kinase	CK	U/L	91	72	58	82	109	83	84	96	233–1837
Creatinine	CRE	mg/dL	0.9	1.1	1.2	1.6	0.9	1.1	1.3	1.2	0.9–1.37
Gamma glutamyl transferase	GGT	U/L	18	38	33	18	13	12	12	10	—
Glucose	GLU	g/dL	31			83	102	96	89	119	2.97–5.2
Globulin	GLOB	mg/dL	4.1	3.8	4.2	5.1	5	5.1	4	3.7	45.9–114.1
Phosphorus	PHOS	mg/dL	3.3			5.9	5.3	4.2	5.5	5.2	2.6–7.9
Potassium	K	mmol/L	5.5	4	6.2	5.1	5.3	6	5.8	5	3.8–9.24
Sodium	NA	mmol/L	140	148	146	138	136	138	137	137	128–154
Total bilirubin	TBIL	mg/dL	0.3	0.3	0.3	0.2	0.4	0.4	0.4	0.4	0.15–0.3
Total protein	TP	g/dL	7.5	7.5	8	8.9	8.4	8.6	7.5	7	5.8–8.3

[a]Haemolysis affected some samples tested and hence values are not reported.

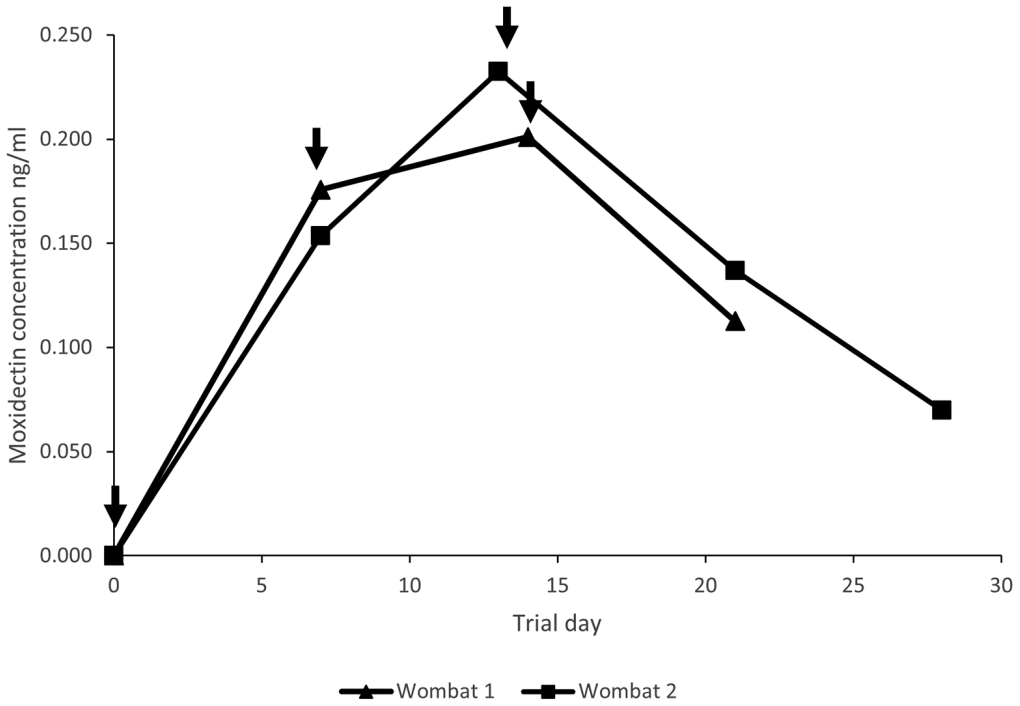

FIGURE 3 | Moxidectin concentration (ng/mL) in plasma of two bare-nosed wombats treated with three 100-mL doses of moxidectin pour-on. Wombats were treated with 100 mL of moxidectin on days 0 and 7, wombat 1 received its third dose on day 13, and wombat 2 on day 14 (indicated with arrows).

et al. 2024). There would be both absorption and excretion occurring during our study that would account for plasma concentration. The concentration is also affected by individual physiology, e.g., liver and kidney function, body mass, age and sex (Hedaya 2024). The relatively low concentration in plasma, compared to healthy animal data, could imply less damage to tissues that are already compromised from a sarcoptic mange infestation.

4 | Conclusion

This study has demonstrated an effective therapeutic protocol for the treatment of sarcoptic mange in wombats. Our study has shown that three topical doses of 100 mL of moxidectin administered 7 days apart to be successful in treating sarcoptic mange in bare-nosed wombats. While no adverse effects were noted in our study, we only used blood parameters and observations on sampling days and opportunistically during the study. Side effects of moxidectin are often neurological, reviewed in Schraven, Stannard, and Old (2021), and hence more work is needed to understand any longer-term side effects of the treatment. Topical administration of moxidectin is less invasive, causes less stress to wombats than subcutaneous injection and requires minimal training. Hence the method presented here can be easily applied by wildlife carers in the field. Further research should investigate methods and treatment success at the population level.

Author Contributions

Hayley J. Stannard: conceptualisation, writing–original draft, writing–review and editing, methodology, data curation, project administration, funding acquisition, formal analysis. **Marie B. Wynan**: conceptualisation, data curation, methodology, writing–review and editing, investigation. **Ray J. Wynan**: data curation, writing–review and editing, investigation. **Amanda Cox**: conceptualisation, methodology, writing–review and editing. **Howard Ralph**: conceptualisation, methodology, writing–review and editing. **Gregory S. Doran**: data curation, methodology, formal analysis, writing–review and editing.

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Ethics Statement

This study was in compliance with the ethical policies of the journal, as noted on the journal's author guidelines page and was approved by the Charles Sturt University Animal Ethics Committee, approval number: A21410.

Conflicts of Interest

The authors would like to declare that MBW and AC are directors on the board of the Wombat Protection Society of Australia who funded this study.

Data Availability Statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Peer Review

The peer review history for this article is available at https://publons.com/publon/10.1002/vms3.70089.

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