Current and predicted temperatures impair reproduction in the Australian sheep flock

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Abstract

Climate change threatens global livestock production^{1,2}. We modelled the impact of recent temperatures and a 1°C and 3°C temperature increase over the historical baseline on risks of heat stress at key periods of the reproductive cycle and consequences for reproduction across the entire Australian sheep flock. We estimate that 2.1 million potential lambs are currently lost annually due to heat stress, increasing to 2.5 and 3.3 million as temperatures rise.

Main

Thermal environment is the largest single stressor affecting the development, growth and reproduction of sheep¹, especially those managed in extensive pasture-based systems typical of Australia and other countries including China, India, Nigeria, Sudan and Iran³. The greatest impacts of temperature on sheep performance and wellbeing occur above 25 – 31°C, when thermoregulatory mechanisms and thus homeothermy are seriously challenged, and the wellbeing and productivity of sheep is impaired. Due to seasonal variation in pasture availability and fertility, most Australian sheep flocks are mated between October and March (late spring to early autumn)^{4,5,6}. However, this leads to critical stages of reproduction occurring during the hottest months, with mean daily maximums regularly approaching or exceeding 32°C in southern and sub-tropical regions. Consequently, it is extremely common for cycling and pregnant ewes, and rams, to be exposed to heat stress conditions.

A detailed review of available evidence from climate-controlled and field-based studies indicates that heat stress affects reproduction in multiple ways⁶. Heat stress during the six to ten days surrounding mating reduces both fertility and fecundity of ewes, by shortening the duration of oestrus, impairing oocyte quality and reducing fertilisation rates and embryo survival, particularly during early stages of development⁶. In two Australian studies, each utilising data from more than 50 Merino flocks, ewe fertility (% of ewes lambing) and lambing rate (lambs born per 100 ewes mated) correlated negatively with exposure to heat stress during the mating period^{5,7}. For each additional day $\geq 32.2^\circ\text{C}$ during the week of mating, ewe fertility and lambing rate decreased by 2.7% and 3.5% respectively^{5,7}. In rams, heat stress near mating also reduces spermatogenesis and sperm quality, with a reduction in fertility occurring between nine and 50 days after the heat event⁶. During pregnancy, heat stress impairs fetal development, reducing lamb birthweight by 16 – 36%, decreasing the proportion of lambs born alive by 20 - 30%, and resulting in deaths of an additional 20 – 30% of lambs after birth⁵. Milk production is also reduced by heat stress during late pregnancy and throughout lactation, further reducing productivity.

Based on this evidence, we used Australian climate data to model effects on lamb survival by counting days above the temperature threshold of 32.2°C. In addition, we used the Temperature Humidity Index (THI) – a measurement using daily maximum and dew point temperatures⁸ – to model the effects of heat stress during pregnancy, using low, moderate and high THI thresholds (68, 75 and 79 respectively). To establish a baseline, we first estimated the effects of heat stress using a historical period of climate

data from 1986-2005. Then, using a bottom-up climate impact assessment methodology^{9,10}, we evaluated the possible implications of warming on reproductive productivity. This was achieved by additively scaling baseline temperatures by 1°C and 3°C, equivalent to approximately 1.6°C and 3.6°C above preindustrial temperatures¹⁰. A warming of 1°C approximates end-of-century 'best case' and requires exceeding the targets of the Paris Agreement, while a more severe warming of 3°C in Australia still falls below the median projections of the highest emission scenario^{11, 12, 13}. THI calculations assumed that relative humidity remains constant for both temperature scenarios, with a preliminary analysis showing relative insensitivity of THI to small declines in relative humidity projected in parts of Australia^{11, 12}. Using these scenarios, numbers of days per month of moderate heat stress ($\text{THI} \geq 75$) and severe heat stress ($\text{THI} \geq 79$) increase markedly across the majority of Australia, particularly in summer months (Figure 1).

Based on these climate scenarios, the reproductive losses were calculated for sites across 26 geographic regions (**Figure 2**), spanning all major climatic regions within Australian sheep-grazing areas. Specific impacts were first calculated for each site given the location and month of mating, and were then multiplied by the number of ewes to present the relative impact for each state. Our modelling predicts that heat stress experienced by ewes mated between spring and early autumn (October to March) significantly decreases the number of lambs born per ewe across all mainland regions, with the largest decreases occurring in Queensland (northeast Australia). These impacts are modelled to worsen under both temperature scenarios (**Figure 2**). Heat stress experienced by these flocks under recent climate conditions is modelled to decrease the number of lambs born by 9% (range: 3 – 22% across 24 sites). Lamb losses are expected to rise to 11% (range: 4 – 23%) and 14% (range: 5 – 24%) with temperature increases of 1°C or 3°C, respectively. In flocks mated during late autumn and winter (April to September), such as those in Tasmania, the impacts of heat stress during the joining period are less severe, causing 0.3% (range: 0 – 1%), 0.5% (range: 0 – 2%) and 1.6% (range: 0 – 3%) decreases in lambs born under historical, +1°C and +3°C temperature scenarios, respectively. Overall, heat stress during the mating period in mainland Australia results in an estimated loss of approximately 2.1 million potential lambs under the baseline climate, and a loss of \$97 million AUD annually. This figure rises to 2.5 and 3.3 million potential lambs lost each year in +1°C or +3°C temperature scenarios, respectively, at a current cost of \$117 and \$166 million AUD.

We next modelled the impacts of current and projected heat stress during pregnancy on lamb survival in Australian sheep flocks. Experimentally, sustained exposure to moderate heat stress during pregnancy decreases lamb birthweights by 0.6 to 1.4 kg, reduces the proportion of lambs born alive by 30% and causes 25% more lambs to die after birth⁶. In our models, impacts on lamb survival in Australian sheep flocks reflect the variable frequency and duration of heat stress experienced by ewes mated between October and March. In these ewes, days of moderate heat stress ($\text{THI} > 75$) historically occur on 45% (range: 9 – 75% across sites) of the first 50 days of pregnancy, increasing to 52% (range: 14 – 82%) and 67% (range: 26 – 97%) of days with temperature increases of 1°C or 3°C, respectively. Predictably, ewes mated during late autumn (April – September) experience very few days of moderate heat stress during

gestation. Based on current timing for sheep mating across 26 sites in Australia, our models indicate that ewe exposure to heat stress during pregnancy reduces the number of lambs weaned per ewe by 2.5%, 3.1% and 4.0% under historical, +1°C or +3°C temperature scenarios, increasing the financial impact of heat stress to \$168m, \$203m and \$278m AUD for each climate scenario.

Although there is little published information on the capacity to ameliorate adverse impacts of heat stress on sheep reproduction, the capacity to alter mating times is limited. Shifting mating to cooler months would result in lambs being born when temperatures are so low or so high that lamb survival would be impaired. Such a shift will also result in asynchrony between pasture availability and nutritional requirements. We therefore suggest an understanding of physiological and behavioural adaptations of sheep to heat stress is needed, in order to develop strategies to reduce heat exposure (e.g. provision of shade) and/or improve heat tolerance (e.g. nutrition, genetic selection).

Our work uses Australian data to demonstrate the negative impact that current heat stress has on sheep reproduction, and highlights the vulnerability of sheep production to climate change. Importantly, the impact of current and future climate on feed availability, not modelled in the present study, are likely to exacerbate adverse effects of climate change on sheep productivity¹⁴. We suggest that our findings are of global relevance, and can be extrapolated to other countries in which sheep are exposed to similarly high temperatures. In support of this, recent modelling^{15,16} indicates that the increased periods of extreme heat likely to result from anthropogenic climate change threaten the future sustainability of livestock production in East Africa, and will also constrict the regions of the world able to support extensive livestock production.

Declarations

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References

1. Collier, R. J., Renquist, B. J. & Xiao, Y. 2017. A 100-Year Review: Stress physiology including heat stress. *Journal of Dairy Science*, 100, 10367–10380.
2. Boni, R. 2019. Heat stress, a serious threat to reproductive function in animals and humans. *Molecular Reproduction and Development*, 86, 1307–1323.
3. Food and Agriculture Organization of the United Nations (FAOSTAT). <https://www.fao.org/faostat/en/#home>, sighted 1st November 2021.
4. Smith, I. 1964. Reproduction in Merino sheep in tropical Australia. *Australian Veterinary Journal*, 40, 156–160.
5. Lindsay, D. R., Knight, T. W., Smith, J. F. & Oldham, C. M. 1975. Studies in ovine fertility in agricultural regions of Western Australia: ovulation rate, fertility and lambing performance. *Australian Journal of*

6. Van Wettere, W. H. E. J., Kind, K. L., Gatford, K. L., Swinbourne, A. M., Leu, S. T., Hayman, P. T., Kelly, J. M., Weaver, A. C., Kleemann, D. O., Walker, S. K. Review of the impact of heat stress on reproductive performance of sheep. *J. Anim. Sci. BioTechnol.* 15; 12. 26. (2021)
7. Kleemann, D. O. & Walker, S. K. 2005. Fertility in South Australian commercial Merino flocks: relationships between reproductive traits and environmental cues. *Theriogenology*, 63, 2416–2433
8. Hahn, G. L., Gaughan, J. B., Mader, T. L. & Eigenberg, R. A. 2009. Thermal indices and their applications for livestock environments. *Livestock energetics and thermal environment management*. American Society of Agricultural and Biological Engineers.
9. Prudhomme, C., R. L. Wilby, S. Crooks, A. L. Kay, and N. S. Reynard (2010), Scenario-neutral approach to climate change impact studies: Application to flood risk, *Journal of Hydrology*, 390(3-4), 198–209
10. Brown, C., and R. L. Wilby (2012), An alternate approach to assessing climate risks, *Eos, Transactions American Geophysical Union*, 93(41), 401–402.
11. Allen, M. R., O. P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, and Y. Mulugetta (2018), Framing and context, In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].
12. Peters, G. P., R. M. Andrew, T. Boden, J. G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M. R. Raupach, and C. Wilson (2013), The challenge to keep global warming below 2 C, *Nature Climate Change*, 3(1), 4–6.
13. Grose, M. R., Narsey, S., Delage, F. P., Dowdy, A. J., Bador, M., Boschat, G., Chung, C., Kajtar, J. B., Rauniyar, S., Freund, M. B., Lyu, K., Rashid, H., Zhang, X., Trenham, C., Holbrook, N. J., Cowan, T., Alexander, J., Arblaster, J. M., Power, S. 2020. Insights from CMIP6 for Australia's Future Climate. *Earth's Future*, 8, e2019EF001469.
14. Henry, B., Charmley, E., Eckard, R., Gaughan, J. B. & Hegarty, R. 2012. Livestock production in a changing climate: adaptation and mitigation research in Australia. *Crop and Pasture Science*, 63, 191–202.
15. Thornton, P., Nelson., Mayberry, D. & Herrero M. Increases in extreme heat stress in domesticated livestock species during the twenty-first century. *Global Change Biology*. 00, 1–11 (2021).
16. Rahimi, J., Mutua, J. Y., Notenbaert, A. M. O., Marshall, K. & Butterbach-Bahl, K. Heat stress will detrimentally impact future livestock in East Africa. *Nature Food*. 2, 88–96. (2021).

Figures

Figure 1

Moderate and severe THI, as well as predicted decrease in lamb birthrate for ewes mated between October and March. Effects are shown across Australia for historical climate, and two warming scenarios.

Figure 2

Sites used to calculate the specific impact of heat stress on sheep reproduction, and sheep density across Australia (left panel), and relative impact on number of lambs born across each State for sites with mating occurring during October to March (right panel).