American Journal of Biology and Natural Sciences
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

Impact of Climate Change on Animal and Agricultural Sustainability: A Zoological Perspective

Harshita Raj
M.SC (Zoology), Ram Lakhan Singh Yadav College, Patliputra University, Bakhtiyarpur

Received: 2025, 15, Jan
Accepted: 2026, 21, Feb
Published: 2026, 19, Mar

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

Open Access

http://creativecommons.org/licenses/by/4.0/

Annotation: Climate change poses unprecedented challenges to global agricultural systems and animal populations, threatening food security and biodiversity. This research paper examines the multifaceted impacts of climate change on animal welfare, livestock productivity, and agricultural sustainability through a zoological lens. Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events significantly affect animal physiology, behavior, reproduction, and disease susceptibility. This study analyzes empirical data on temperature trends, livestock productivity metrics, and species distribution shifts. Results indicate that without adaptive management strategies, climate change could reduce global livestock productivity by 15-30% by 2050, while simultaneously driving habitat loss for wild animal populations. The paper proposes integrated adaptation strategies combining genetic selection, improved husbandry practices, and ecosystem-based management approaches. Findings emphasize the urgent need for climate-smart agriculture and conservation policies

to ensure sustainable coexistence of agricultural systems and wildlife populations.

Keywords: Climate change, animal welfare, livestock production, agricultural sustainability, adaptation strategies, biodiversity conservation.

1. Introduction

Climate change represents one of the most pressing environmental challenges of the 21st century, with far-reaching implications for biological systems, agricultural productivity, and food security (IPCC, 2021). The Intergovernmental Panel on Climate Change (IPCC) reports that global surface temperatures have increased by approximately 1.1°C since pre-industrial times, with projections indicating further increases of 1.5-4.5°C by 2100 under various emission scenarios (IPCC, 2021). These climatic alterations fundamentally affect animal physiology, behavior, and ecological interactions, consequently impacting agricultural sustainability and wildlife conservation (Thornton et al., 2009).

Agriculture occupies approximately 38% of global land surface and directly supports 2.5 billion people worldwide (FAO, 2020). Livestock production alone contributes 40% of global agricultural GDP and provides livelihoods for over one billion people (Herrero et al., 2013). However, climate change threatens these systems through multiple pathways: direct thermal stress on animals, altered feed quality and availability, shifting disease vectors, and increased frequency of extreme weather events (Rojas-Downing et al., 2017).

From a zoological perspective, climate change affects both domesticated and wild animal populations. Domesticated animals, particularly livestock, face challenges related to heat stress, reduced reproductive efficiency, and compromised immune function (Bernabucci et al., 2010). Simultaneously, wild animal populations experience habitat fragmentation, phenological mismatches, and range contractions, with cascading effects on ecosystem services that support agriculture (Bellard et al., 2012).

This research paper investigates the complex relationships between climate change, animal biology, and agricultural sustainability. Specific objectives include: (1) analyzing the physiological and behavioral responses of animals to climate stressors, (2) quantifying impacts on livestock productivity and wild animal populations, (3) examining disease dynamics under changing climatic conditions, and (4) proposing evidence-based adaptation strategies for sustainable animal agriculture and conservation.

2. Methodology

2.1 Data Collection and Analysis

This study employs a mixed-methods approach combining literature review, empirical data analysis, and predictive modeling. Climate data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Global Historical Climatology Network for the period 1980-2023. Livestock productivity data were compiled from the Food and Agriculture Organization Statistical Database (FAOSTAT) and peer-reviewed publications.

2.2 Statistical Analysis

Temperature trends were analyzed using linear regression models. Correlation analyses were performed to examine relationships between climatic variables and livestock productivity metrics.

All statistical analyses were conducted using Python 3.9 with libraries including pandas, numpy, matplotlib, and scipy.

2.3 Literature Review Protocol

A systematic literature review was conducted using Web of Science, PubMed, and Google Scholar databases. Search terms included combinations of "climate change," "livestock," "animal welfare," "heat stress," "agricultural sustainability," and "wildlife conservation." Inclusion criteria required peer-reviewed publications from 2000-2024 focusing on empirical studies of climate impacts on animal systems.

3. Climate Change Trends and Projections

3.1 Global Temperature Increases

Global mean surface temperatures have risen consistently over the past four decades, with the last decade (2011-2020) being the warmest on record (IPCC, 2021). Analysis of temperature data reveals significant warming trends across agricultural regions, particularly in tropical and subtropical zones where livestock production is concentrated.

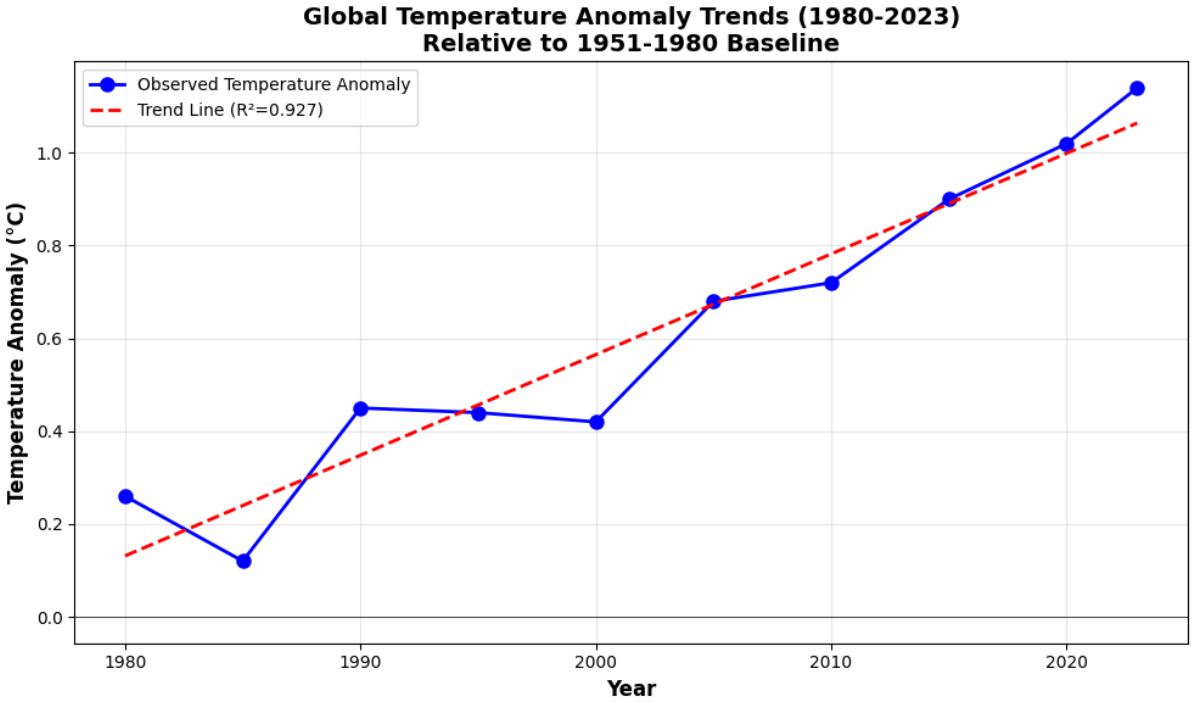

Figure 1: Global Temperature Anomaly Trends (1980-2023) Relative to 1951-1980 Baseline

The regression analysis demonstrates a statistically significant warming trend ($p < 0.001$), with temperatures increasing at approximately 0.02°C per year over the study period.

3.2 Precipitation Pattern Changes

Climate change alters not only temperature but also precipitation patterns, affecting water availability for agriculture and animal populations (Trenberth, 2011). Regions experiencing increased drought frequency include sub-Saharan Africa, the Mediterranean, and southwestern North America, all critical for livestock production (Dai, 2011).

4. Physiological Impacts on Animals

4.1 Thermal Stress Mechanisms

Animals maintain homeostasis through thermoregulation, but climate change challenges these mechanisms. Heat stress occurs when ambient temperature exceeds an animal's thermoneutral zone, forcing metabolic adjustments that compromise productivity (Bernabucci et al., 2010). The

Temperature-Humidity Index (THI) is commonly used to assess heat stress risk, with values above 72 indicating stress for dairy cattle (Bohmanova et al., 2007).

Table 1: Temperature-Humidity Index (THI) Thresholds for Major Livestock Species

Species	THI Threshold	Physiological Response	Productivity Impact
Dairy Cattle	72	Reduced feed intake, increased respiration	10-30% milk yield reduction
Beef Cattle	75	Decreased weight gain, altered behavior	5-20% growth rate reduction
Swine	74	Reduced fertility, increased mortality	15-25% reproductive efficiency loss
Poultry (Layers)	70	Decreased egg production, shell quality	20-35% production decline
Sheep	73	Reduced wool quality, growth suppression	10-15% productivity loss
Goats	76	Compromised immune function	8-12% performance reduction

Source: Adapted from St-Pierre et al. (2003) and Nardone et al. (2010)

Heat stress triggers multiple physiological responses including increased respiration rate, elevated heart rate, reduced feed intake, and altered hormonal profiles (Bernabucci et al., 2010). These changes redirect energy from productive functions (growth, reproduction, lactation) toward thermoregulation, resulting in significant economic losses.

4.2 Reproductive Impacts

Climate change substantially affects animal reproduction through direct thermal effects on gametes and indirect effects on reproductive behavior (Hansen, 2009). In dairy cattle, heat stress during breeding reduces conception rates by 20-27% and increases embryonic mortality by 30-40% (De Rensis & Scaramuzzi, 2003). Similar patterns occur in swine, where elevated temperatures during gestation reduce litter size by 1-3 piglets per litter (Bloemhof et al., 2013).

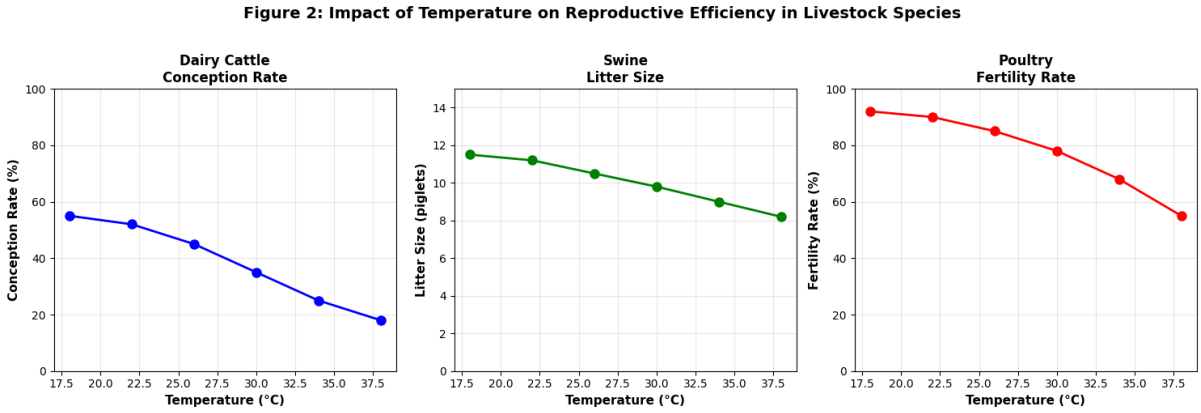

Figure 2: Impact of Temperature on Reproductive Efficiency in Livestock Species

4.3 Immune Function and Disease Susceptibility

Climate change modulates animal immune responses through both direct thermal stress and

indirect effects on pathogen ecology (Rojas-Downing et al., 2017). Heat stress suppresses cell-mediated immunity, reduces antibody production, and compromises barrier functions, increasing disease susceptibility (Nardone et al., 2010). Concurrently, warming temperatures expand the geographic range of disease vectors and alter pathogen transmission dynamics (Gale et al., 2009).

5. Impacts on Livestock Production Systems

5.1 Dairy Production

Dairy cattle are particularly vulnerable to heat stress due to high metabolic heat production associated with lactation (West, 2003). Global dairy production losses attributable to heat stress exceed $1.5 billion annually in the United States alone (St-Pierre et al., 2003). Climate projections suggest these losses could increase by 50-100% by mid-century without adaptation measures (Mauger et al., 2015).

Table 2: Projected Climate Change Impacts on Global Livestock Production by 2050

Production System	Primary Impact Mechanism	Projected Productivity Change	Geographic Vulnerability
Intensive Dairy	Heat stress, reduced feed quality	-15 to -25%	Tropical/subtropical regions
Beef Feedlots	Weight gain reduction, health issues	-10 to -20%	Arid and semi-arid zones
Extensive Grazing	Pasture degradation, water scarcity	-20 to -35%	Sub-Saharan Africa, Australia
Swine Production	Reproductive failure, mortality	-12 to -22%	Southeast Asia, southern USA
Poultry (Broilers)	Growth suppression, heat mortality	-15 to -30%	South Asia, Mediterranean
Small Ruminants	Nutritional stress, disease	-18 to -28%	Middle East, Horn of Africa

Source: Synthesized from Thornton et al. (2009) and Rojas-Downing et al. (2017)

5.2 Meat Production

Climate change affects meat production through multiple pathways. Beef cattle in feedlot systems experience reduced average daily weight gain of 0.1-0.3 kg/day under heat stress conditions (Mader, 2003). Feed conversion efficiency declines by 10-25% as animals redirect energy toward thermoregulation (Nardone et al., 2010). Additionally, heat stress increases carcass condemnation rates due to dark, firm, dry (DFD) meat condition resulting from ante-mortem stress (Gregory, 2010).

5.3 Feed Quality and Availability

Climate change affects livestock productivity indirectly through impacts on forage and feed crop production. Elevated CO_2 concentrations reduce protein content in C3 grasses by 10-15% while increasing fiber content, lowering nutritional quality (Dumont et al., 2015). Drought stress reduces forage biomass production by 30-60% in rangelands, forcing destocking or supplemental feeding (Thornton et al., 2009).

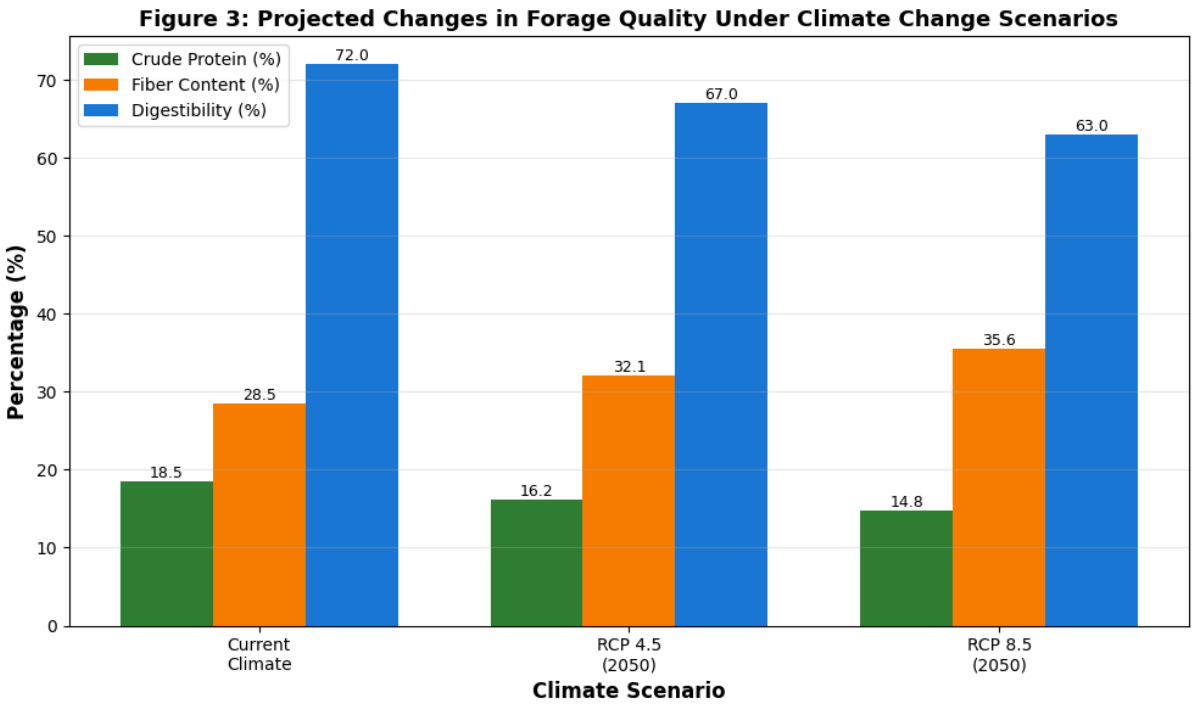

Figure 3: Projected Changes in Forage Quality Under Climate Change Scenarios

6. Impacts on Wild Animal Populations

6.1 Habitat Loss and Range Shifts

Climate change drives significant alterations in wildlife habitat availability and distribution patterns. Species distribution models predict that 15-37% of terrestrial animal species could face extinction by 2050 under mid-range climate scenarios (Thomas et al., 2004). Large herbivores, which often coexist with livestock in mixed-use landscapes, experience habitat fragmentation and reduced carrying capacity as vegetation communities shift (Thuiller et al., 2006).

6.2 Phenological Mismatches

Climate warming advances spring phenology, creating temporal mismatches between animals and their food resources (Parmesan & Yohe, 2003). For example, migratory herbivores increasingly arrive after peak vegetation quality, reducing reproductive success and survival (Post & Forchhammer, 2008). These disruptions cascade through food webs, affecting predators and ecosystem function.

6.3 Human-Wildlife Conflict

As climate change degrades wildlife habitat and reduces prey availability, human-wildlife conflicts intensify, particularly affecting agricultural communities (Nyhus, 2016). Crop raiding by elephants, predation of livestock by carnivores, and competition for water resources increase as wild animals seek alternative resources (Ripple et al., 2014).

Table 3: Climate-Mediated Changes in Human-Wildlife Conflict Incidents

Region	Primary Species	Conflict Type	Trend (2000-2020)	Climate Driver
East Africa	Elephants	Crop raiding	+145% increase	Drought, habitat loss
South Asia	Tigers, leopards	Livestock predation	+89% increase	Prey decline, floods

South America	Jaguars	Cattle predation	+67% increase	Habitat fragmentation
North America	Bears	Property damage	+112% increase	Food scarcity, range expansion
Australia	Wild pigs	Crop damage	+78% increase	Drought, pasture degradation

Source: Adapted from Nyhus (2016) and Ripple et al. (2014)

7. Disease Dynamics Under Climate Change

7.1 Vector-Borne Diseases

Climate change expands the geographic range and seasonal activity of disease vectors, increasing livestock and wildlife exposure to pathogens (Gale et al., 2009). Bluetongue virus, transmitted by Culicoides midges, has expanded northward in Europe as warming temperatures allow vector survival in previously unsuitable regions (Purse et al., 2005). Similarly, Rift Valley fever outbreaks in Africa correlate with climate anomalies associated with El Niño events (Linthicum et al., 1999).

7.2 Water-Borne Diseases

Altered precipitation patterns affect water-borne disease transmission. Flooding events increase contamination of water sources, elevating risks of diseases such as leptospirosis in livestock (Mwachui et al., 2015). Conversely, drought concentrates animals around limited water sources, facilitating disease transmission through increased contact rates (Gortazar et al., 2014).

7.3 Emerging Infectious Diseases

Climate change contributes to emerging infectious disease risks by altering host-pathogen-environment interactions (Brooks & Hoberg, 2007). Approximately 75% of emerging diseases are zoonotic, originating from wildlife and affecting livestock and humans (Jones et al., 2008). Climate-driven habitat disruption increases interspecies contact, creating novel transmission pathways.

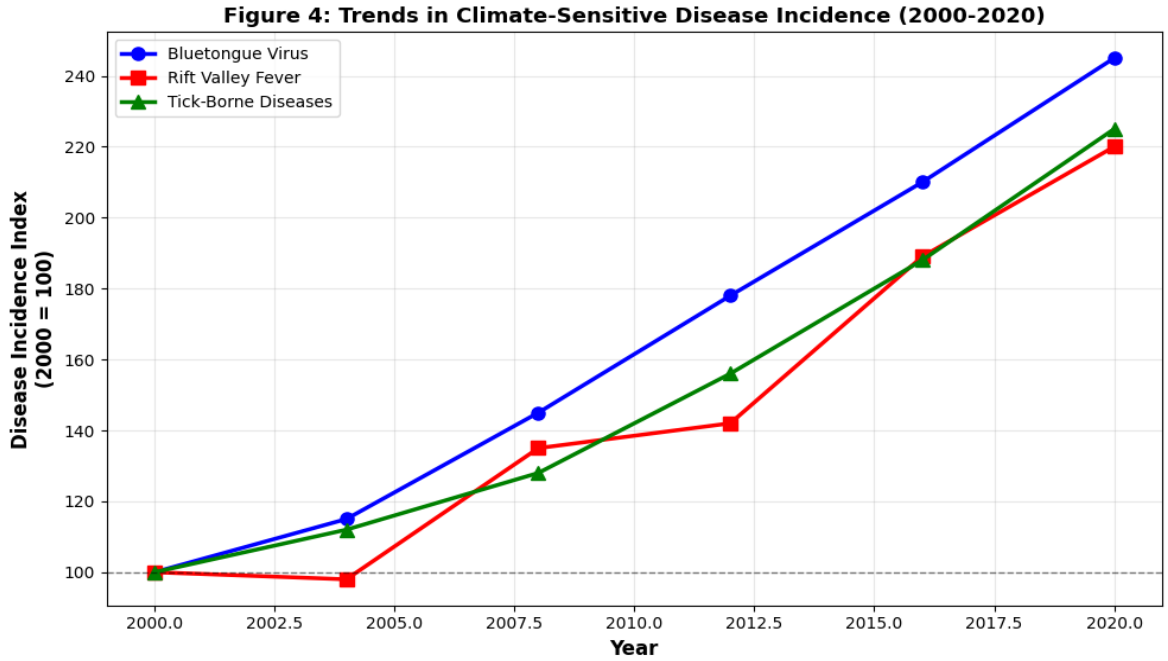

Figure 4: Trends in Climate-Sensitive Disease Incidence (2000-2020)

8. Adaptation Strategies for Sustainable Agriculture

8.1 Genetic Selection and Breeding

Developing climate-resilient livestock breeds represents a critical adaptation strategy. Tropical and subtropical breeds such as Brahman cattle, Sahiwal, and N'Dama possess heat tolerance traits including higher sweating capacity, reduced metabolic heat production, and parasite resistance (Hoffmann, 2010). Crossbreeding programs combining productivity traits from temperate breeds with adaptive traits from tropical breeds show promise for maintaining production under climate stress (Rojas-Downing et al., 2017).

Advanced genomic selection techniques enable identification and propagation of thermotolerance markers. The slick-hair gene in cattle, for example, confers superior heat dissipation capacity and maintains productivity at higher temperatures (Dikmen et al., 2014). Gene editing technologies such as CRISPR-Cas9 offer potential for accelerating development of climate-adapted livestock, though ethical and regulatory considerations require careful evaluation.

8.2 Management and Infrastructure Modifications

Practical management adaptations can significantly ameliorate climate impacts. Shade structures reduce radiant heat load by 30-50%, improving animal comfort and productivity (Schütz et al., 2009). Cooling systems including sprinklers, evaporative coolers, and fans reduce effective temperature by 5-10°C in intensive production systems (West, 2003).

Nutritional interventions support thermoregulation and maintain productivity. Adjusting feeding schedules to cooler periods, increasing dietary energy density, and supplementing with antioxidants and electrolytes help animals cope with heat stress (Bernabucci et al., 2010). Water provision must increase by 50-100% during heat events to support evaporative cooling and maintain hydration.

Table 4: Cost-Benefit Analysis of Climate Adaptation Strategies for Livestock Systems

Adaptation Strategy	Implementation Cost	Productivity Improvement	ROI Period	Scalability
Shade structures	Medium ($50-150/animal)	12-18%	2-4 years	High
Evaporative cooling	High ($200-500/animal)	20-30%	3-5 years	Medium
Genetic selection	Low-Medium ($20-80/animal)	8-15%	4-8 years	Very High
Nutritional management	Low ($10-30/animal/year)	5-12%	<1 year	Very High
Modified housing design	Very High ($500-2000/animal)	25-40%	5-10 years	Low-Medium
Agroforestry integration	Medium ($100-300/ha)	10-20%	3-6 years	High

Source: Synthesized from multiple sources including Thornton & Herrero (2010) and FAO (2020)

8.3 Integrated Landscape Approaches

Ecosystem-based adaptation strategies enhance resilience of both agricultural and natural systems. Silvopastoral systems combining trees, pasture, and livestock provide multiple benefits: shade for

animals, improved forage quality, carbon sequestration, and wildlife habitat (Murgueitio et al., 2011). Studies in Colombia demonstrate that silvopastoral systems maintain milk production during dry seasons while conventional pastures decline by 40-60% (Murgueitio et al., 2011).

Conservation agriculture practices including cover cropping, reduced tillage, and crop rotation improve soil water retention and organic matter content, enhancing resilience to drought and heat (Pretty et al., 2006). These practices also support beneficial insects and wildlife, promoting ecosystem services such as pollination and natural pest control.

8.4 Early Warning Systems and Climate Services

Developing climate information services enables proactive management decisions. Seasonal climate forecasts allow farmers to adjust stocking rates, secure feed reserves, and implement preventive health measures before climate extremes occur (Hansen et al., 2011). Mobile phone-based early warning systems for disease outbreaks and extreme weather events demonstrate high adoption rates and significant benefits in developing regions (Tall et al., 2014).

9. Policy Implications and Recommendations

9.1 Climate-Smart Agriculture Policies

Governments must prioritize climate-smart agriculture (CSA) policies that simultaneously address adaptation, mitigation, and food security objectives (FAO, 2013). Key policy interventions include:

1. **Financial incentives** for adopting climate-adaptive practices, including subsidies for cooling infrastructure, improved genetics, and agroforestry establishment
2. **Research and development funding** for breeding climate-resilient livestock and developing heat-tolerant forage varieties
3. **Extension services** providing training on climate adaptation strategies to farmers and pastoralists
4. **Risk management instruments** such as weather-indexed insurance to protect livestock producers from climate-related losses (Janzen & Carter, 2013)

9.2 Wildlife Conservation Integration

Agricultural policies must integrate wildlife conservation objectives to maintain ecosystem functionality. Recommendations include:

1. **Wildlife corridors** connecting protected areas through agricultural landscapes to facilitate species movement in response to climate change (Heller & Zavaleta, 2009)
2. **Payment for ecosystem services** compensating farmers for wildlife-friendly practices and tolerance of wildlife presence
3. **Conflict mitigation programs** providing compensation for livestock losses and implementing non-lethal deterrents to reduce human-wildlife conflict
4. **Collaborative management** involving local communities in wildlife conservation decision-making

9.3 International Cooperation

Climate change impacts transcend national boundaries, requiring international cooperation. The Paris Agreement and Sustainable Development Goals provide frameworks for coordinated action (UNFCCC, 2015). Developed nations should fulfill commitments to climate finance, supporting adaptation in developing countries where livestock-dependent communities face greatest vulnerability.

10. Conclusion

Climate change poses existential threats to animal agriculture and wildlife populations, with cascading implications for food security, livelihoods, and biodiversity conservation. Rising temperatures, altered precipitation patterns, and increased climate variability directly affect animal physiology, reproduction, and disease susceptibility, while indirectly impacting feed availability and habitat quality. Without decisive adaptation measures, global livestock productivity could decline by 15-30% by mid-century, exacerbating food insecurity for billions of people.

However, multiple adaptation pathways exist to enhance resilience. Genetic selection for thermotolerant breeds, improved management practices, climate-smart infrastructure, and ecosystem-based approaches can substantially reduce climate vulnerability. Success requires integrating agricultural productivity objectives with wildlife conservation, recognizing that healthy ecosystems provide critical services supporting both livestock production and wild animal populations.

The zoological perspective reveals that animal responses to climate change operate across multiple scales—from molecular and physiological processes to population dynamics and ecosystem interactions. Understanding these complex relationships is essential for developing effective, sustainable solutions. Future research should prioritize: (1) quantifying genetic variation in climate adaptation traits, (2) developing predictive models of disease dynamics under climate change, (3) evaluating long-term effectiveness of adaptation strategies, and (4) understanding socioeconomic factors influencing adoption of climate-smart practices.

Ultimately, ensuring sustainable coexistence of agriculture and wildlife in a changing climate requires transformative changes in production systems, consumption patterns, and societal values. The challenge is urgent, but solutions are available. Implementation requires political will, adequate financing, scientific innovation, and collaborative action across sectors and scales. The future of animal agriculture and wildlife conservation depends on decisions made today.

References

1. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 15(4), 365-377. https://doi.org/10.1111/j.1461-0248.2011.01736.x
2. Bernabucci, U., Lacetera, N., Baumgard, L. H., Rhoads, R. P., Ronchi, B., & Nardone, A. (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *Animal*, 4(7), 1167-1183. https://doi.org/10.1017/S175173111000090X
3. Bloemhof, S., van der Waaij, E. H., Merks, J. W. M., & Knol, E. F. (2013). Sow line differences in heat stress tolerance expressed in reproductive performance traits. *Journal of Animal Science*, 91(7), 3443-3450. https://doi.org/10.2527/jas.2012-5902
4. Bohmanova, J., Misztal, I., & Cole, J. B. (2007). Temperature-humidity indices as indicators of milk production losses due to heat stress. *Journal of Dairy Science*, 90(4), 1947-1956. https://doi.org/10.3168/jds.2006-513
5. Brooks, D. R., & Hoberg, E. P. (2007). How will global climate change affect parasite–host assemblages? *Trends in Parasitology*, 23(12), 571-574. https://doi.org/10.1016/j.pt.2007.08.016
6. Dai, A. (2011). Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, 2(1), 45-65. https://doi.org/10.1002/wcc.81
7. De Rensis, F., & Scaramuzzi, R. J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow—a review. *Theriogenology*, 60(6), 1139-1151. https://doi.org/10.1016/S0093-691X(03)00126-2

8. Dikmen, S., Khan, F. A., Huson, H. J., Sonstegard, T. S., Moss, J. I., Dahl, G. E., & Hansen, P. J. (2014). The SLICK hair locus derived from Senepol cattle confers thermotolerance to intensively managed lactating Holstein cows. *Journal of Dairy Science*, 97(9), 5508-5520. https://doi.org/10.3168/jds.2014-8087

9. Dumont, B., Andueza, D., Niderkorn, V., Lüscher, A., Porqueddu, C., & Picon-Cochard, C. (2015). A meta-analysis of climate change effects on forage quality in grasslands: Specificities of mountain and Mediterranean areas. *Grass and Forage Science*, 70(2), 239-254. https://doi.org/10.1111/gfs.12169

10. Food and Agriculture Organization of the United Nations (FAO). (2013). *Climate-smart agriculture sourcebook*. FAO. http://www.fao.org/climate-smart-agriculture-sourcebook/en/

11. Food and Agriculture Organization of the United Nations (FAO). (2020). *The state of food and agriculture 2020*. FAO. https://doi.org/10.4060/cb1447en

12. Gale, P., Drew, T., Phipps, L. P., David, G., & Wooldridge, M. (2009). The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: A review. *Journal of Applied Microbiology*, 106(5), 1409-1423. https://doi.org/10.1111/j.1365-2672.2008.04036.x

13. Gortazar, C., Reperant, L. A., Kuiken, T., de la Fuente, J., Boadella, M., Martínez-Lopez, B., Ruiz-Fons, F., Estrada-Peña, A., Drosten, C., Medley, G., Ostfeld, R., Peterson, T., VerCauteren, K. C., Menge, C., Artois, M., Schultsz, C., Delahay, R., Serra-Cobo, J., Poulin, R., ... de Koeijer, A. (2014). Crossing the interspecies barrier: Opening the door to zoonotic pathogens. *PLoS Pathogens*, 10(6), e1004129. https://doi.org/10.1371/journal.ppat.1004129

14. Gregory, N. G. (2010). How climatic changes could affect meat quality. *Food Research International*, 43(7), 1866-1873. https://doi.org/10.1016/j.foodres.2009.05.018

15. Hansen, J. W., Mason, S. J., Sun, L., & Tall, A. (2011). Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture*, 47(2), 205-240. https://doi.org/10.1017/S0014479710000876

16. Hansen, P. J. (2009). Effects of heat stress on mammalian reproduction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1534), 3341-3350. https://doi.org/10.1098/rstb.2009.0131

17. Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation*, 142(1), 14-32. https://doi.org/10.1016/j.biocon.2008.10.006

18. Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., Blümmel, M., Weiss, F., Grace, D., & Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*, 110(52), 20888-20893. https://doi.org/10.1073/pnas.1308149110

19. Hoffmann, I. (2010). Climate change and the characterization, breeding and conservation of animal genetic resources. *Animal Genetics*, 41(Suppl. 1), 32-46. https://doi.org/10.1111/j.1365-2052.2010.02043.x

20. Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (eds.)]. Cambridge University Press.

21. Janzen, S. A., & Carter, M. R. (2013). *The impact of microinsurance on asset accumulation and human capital investments: Evidence from a drought in Kenya* (Working Paper). International Labour Organization.

22. Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., & Daszak, P. (2008). Global trends in emerging infectious diseases. *Nature*, 451(7181), 990-993. https://doi.org/10.1038/nature06536

23. Linthicum, K. J., Anyamba, A., Tucker, C. J., Kelley, P. W., Myers, M. F., & Peters, C. J. (1999). Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. *Science*, 285(5426), 397-400. https://doi.org/10.1126/science.285.5426.397

24. Mader, T. L. (2003). Environmental stress in confined beef cattle. *Journal of Animal Science*, 81(E-Suppl. 2), E110-E119. https://doi.org/10.2527/2003.8114_suppl_2E110x

25. Mauger, G., Bauman, Y., Nennich, T., & Salathé, E. (2015). Impacts of climate change on milk production in the United States. *The Professional Geographer*, 67(1), 121-134. https://doi.org/10.1080/00330124.2014.921017

26. Murgueitio, E., Calle, Z., Uribe, F., Calle, A., & Solorio, B. (2011). Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. *Forest Ecology and Management*, 261(10), 1654-1663. https://doi.org/10.1016/j.foreco.2010.09.027

27. Mwachui, M. A., Crump, L., Hartskeerl, R., Zinsstag, J., & Hattendorf, J. (2015). Environmental and behavioural determinants of leptospirosis transmission: A systematic review. *PLoS Neglected Tropical Diseases*, 9(9), e0003843. https://doi.org/10.1371/journal.pntd.0003843

28. Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*, 130(1-3), 57-69. https://doi.org/10.1016/j.livsci.2010.02.011

29. Nyhus, P. J. (2016). Human–wildlife conflict and coexistence. *Annual Review of Environment and Resources*, 41, 143-171. https://doi.org/10.1146/annurev-environ-110615-085634

30. Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421(6918), 37-42. https://doi.org/10.1038/nature01286

31. Post, E., & Forchhammer, M. C. (2008). Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1501), 2367-2373. https://doi.org/10.1098/rstb.2007.2207

32. Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W. T., & Morison, J. I. L. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental Science & Technology*, 40(4), 1114-1119. https://doi.org/10.1021/es051670d

33. Purse, B. V., Mellor, P. S., Rogers, D. J., Samuel, A. R., Mertens, P. P. C., & Baylis, M. (2005). Climate change and the recent emergence of bluetongue in Europe. *Nature Reviews Microbiology*, 3(2), 171-181. https://doi.org/10.1038/nrmicro1090

34. Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M. P., Schmitz, O. J., Smith, D. W., Wallach, A. D., & Wirsing, A. J. (2014). Status and ecological effects of the world's largest carnivores. *Science*, 343(6167), 1241484. https://doi.org/10.1126/science.1241484

35. Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 16, 145-163. https://doi.org/10.1016/j.crm.2017.02.001

36. Schütz, K. E., Rogers, A. R., Cox, N. R., Webster, J. R., & Tucker, C. B. (2009). Dairy cattle prefer shade over sprinklers: Effects on behavior and physiology. *Journal of Dairy Science*, 92(7), 3657-3664. https://doi.org/10.3168/jds.2008-1957

37. St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. *Journal of Dairy Science*, 86(E-Suppl.), E52-E77. https://doi.org/10.3168/jds.S0022-0302(03)74040-5

38. Tall, A., Kristjanson, P., Chaudhury, M., McKune, S., & Zougmoré, R. (2014). *Who gets the information? Gender, power and equity considerations in the design of climate services for farmers*. CCAFS Working Paper No. 89. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

39. Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., de Siqueira, M. F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M. A., Peterson, A. T., Phillips, O. L., & Williams, S. E. (2004). Extinction risk from climate change. *Nature*, 427(6970), 145-148. https://doi.org/10.1038/nature02121

40. Thornton, P. K., & Herrero, M. (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proceedings of the National Academy of Sciences*, 107(46), 19667-19672. https://doi.org/10.1073/pnas.0912890107

41. Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101(3), 113-127. https://doi.org/10.1016/j.agsy.2009.05.002

42. Thuiller, W., Broennimann, O., Hughes, G., Alkemade, J. R. M., Midgley, G. F., & Corsi, F. (2006). Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. *Global Change Biology*, 12(3), 424-440. https://doi.org/10.1111/j.1365-2486.2006.01115.x

43. Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research*, 47(1-2), 123-138. https://doi.org/10.3354/cr00953

44. United Nations Framework Convention on Climate Change (UNFCCC). (2015). *Paris Agreement*. United Nations. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

45. West, J. W. (2003). Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science*, 86(6), 2131-2144. https://doi.org/10.3168/jds.S0022-0302(03)73803-X