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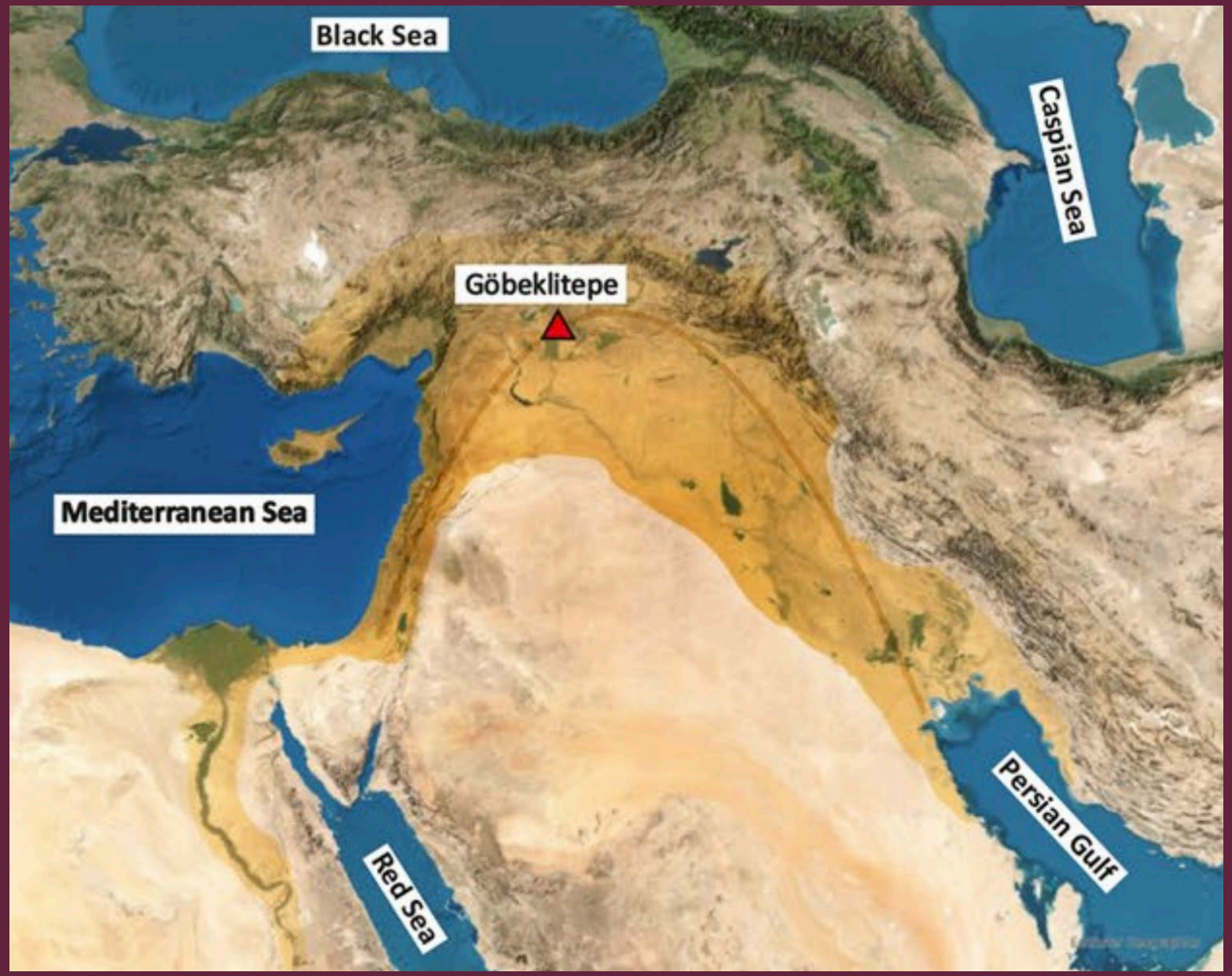
Perspectives on the Food-Environment-Energy-Water Nexus in a Changing Climate in Southern Africa

Prof Guy Midgley, School for Climate Studies

Photo by Stefan Els

Setting the Scene

1. Agricultural origins
2. Human niche changes
3. New risks to 2050



Bitelkin et al. 2024 Plant and Soil



https://history2dot0.com/gobekli-tepe-karahan-tepe-ancient-history-ancient-anatolia/

First dairying in green Saharan Africa in the fifth millennium BC

Julie Dunne[1], Richard P. Evershed[1], Mélanie Salque[1], Lucy Cramp[1], Silvia Bruni[2], Kathleen Ryan[3], Stefano Biagetti[4] & Savino di Lernia[4,5]

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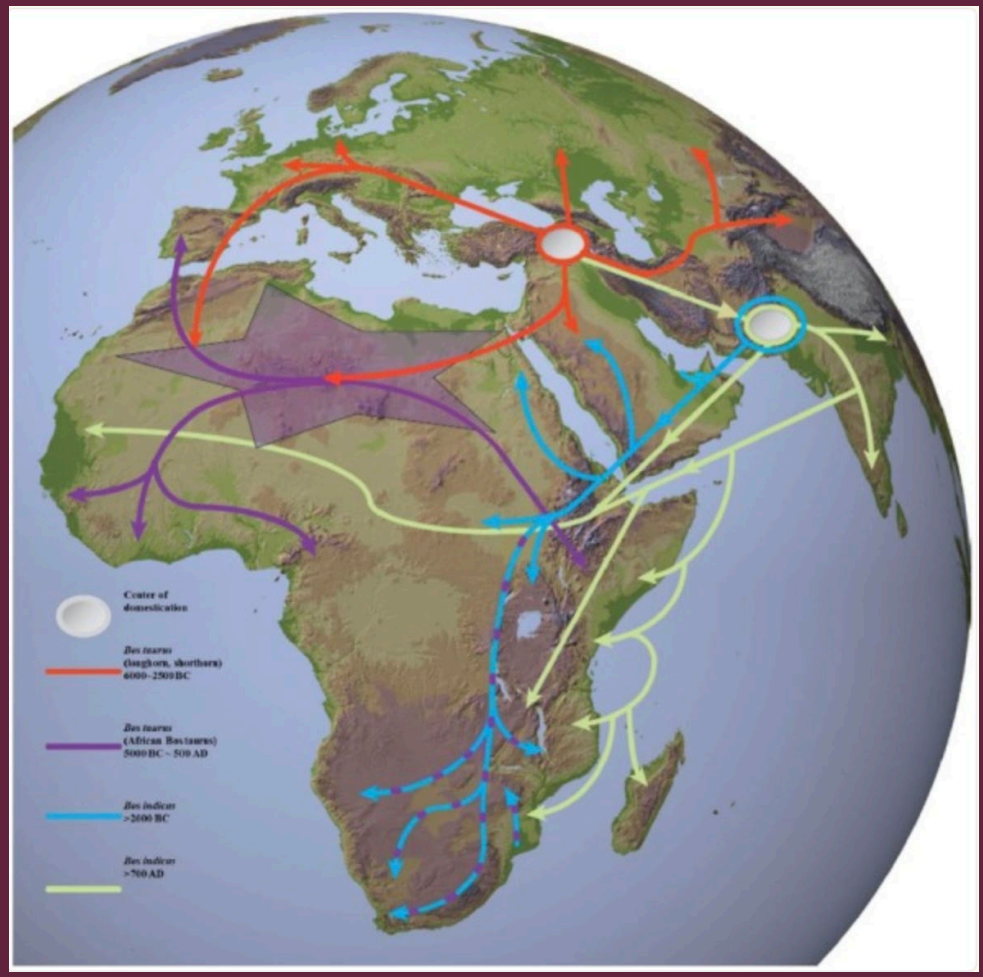


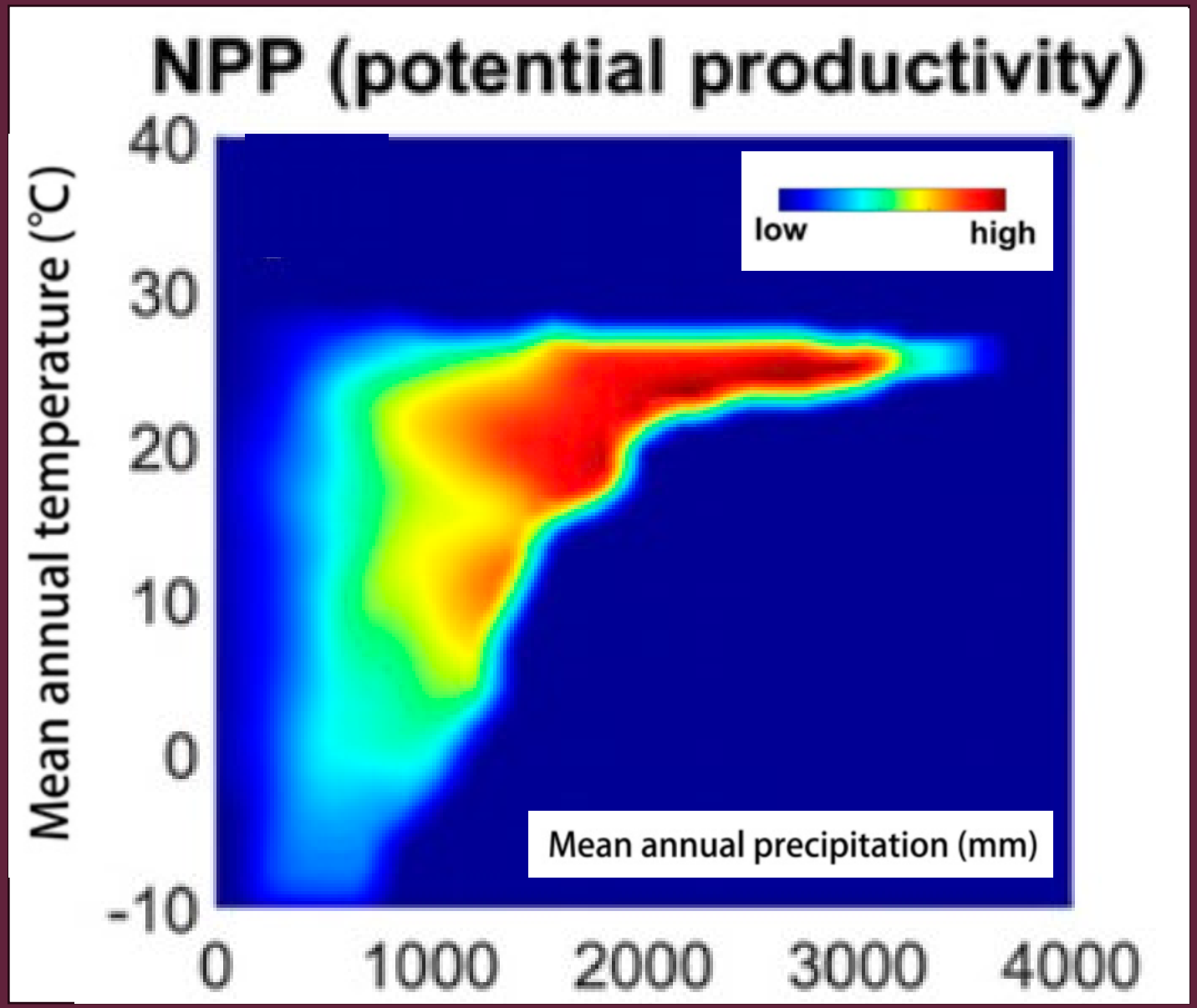
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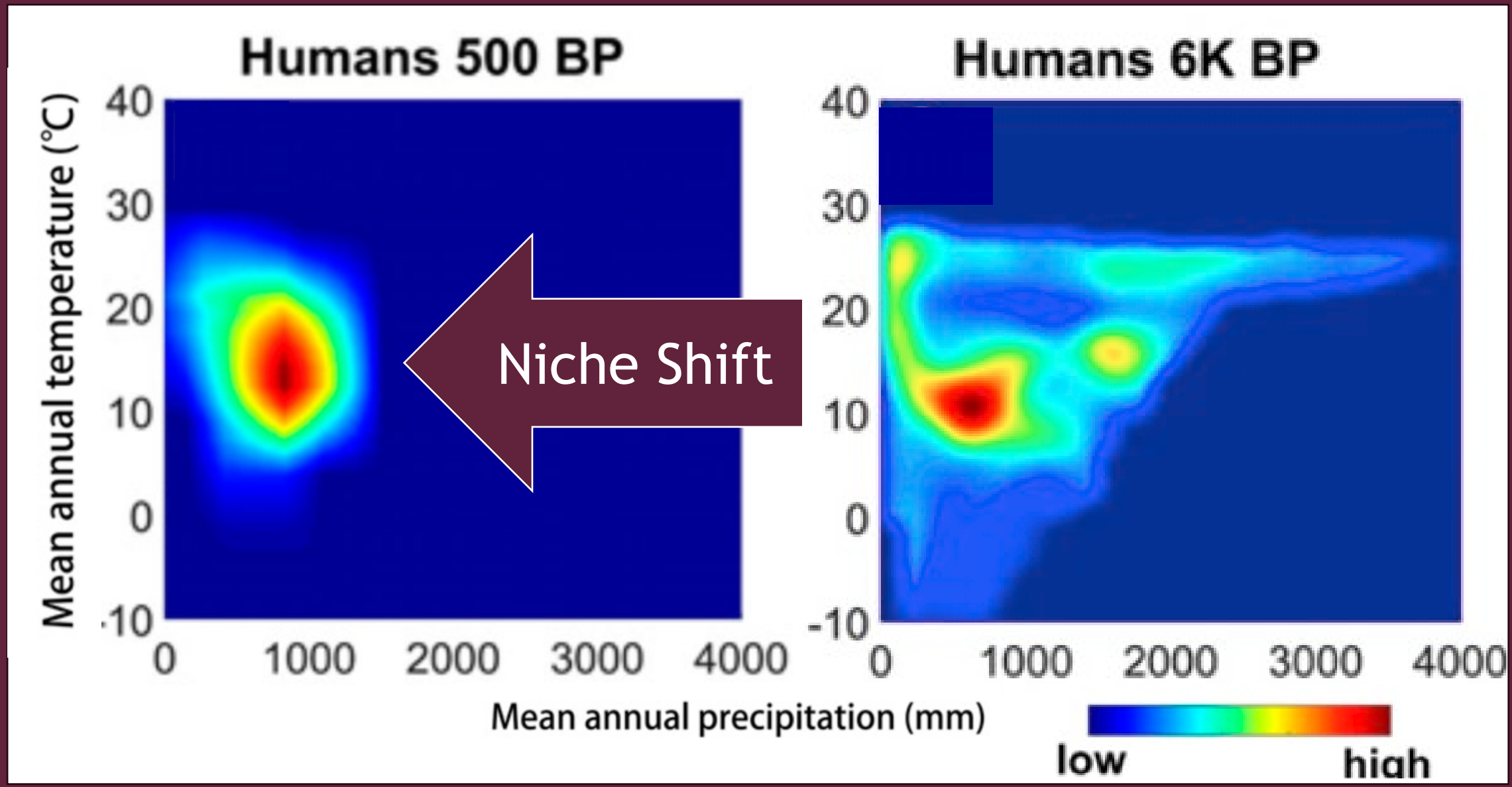
doi:10.1038/nature11186

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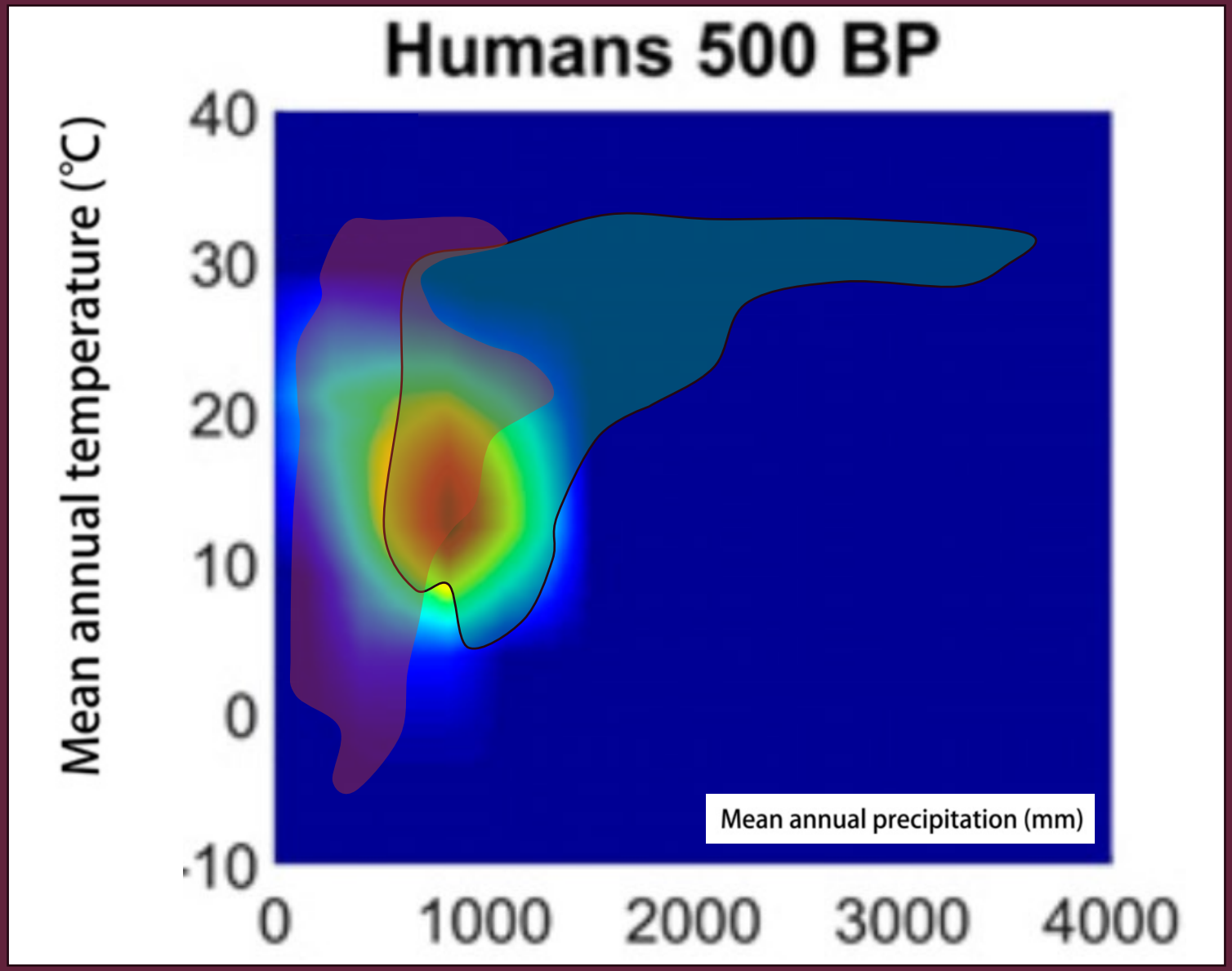




Xu, C., Kohler, T.A., Lenton, T.M., Svenning, J.C. and Scheffer, M., 2020. Future of the human climate niche. *Proceedings of the National Academy of Sciences*, *117*(21), pp.11350-11355.

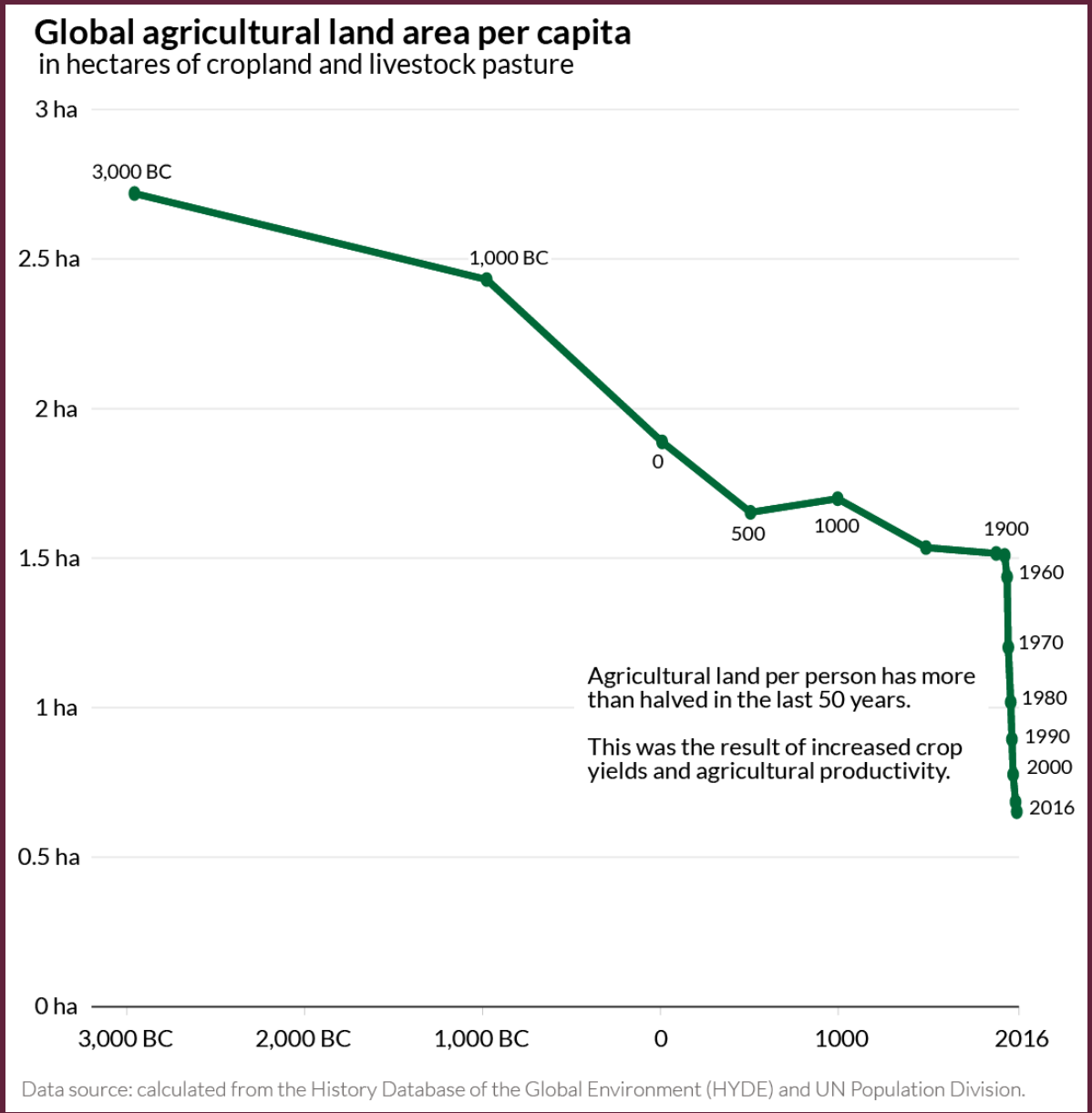


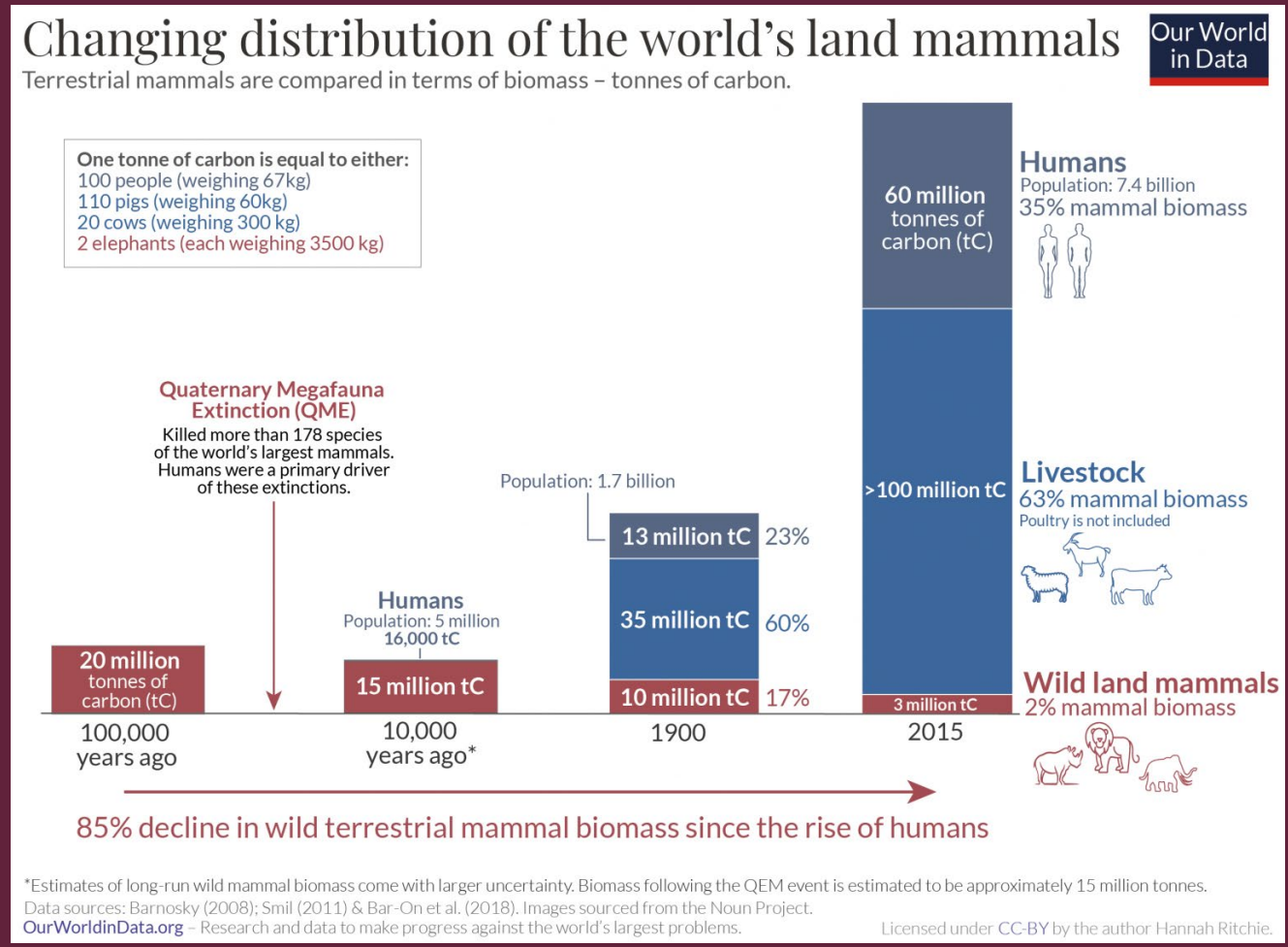
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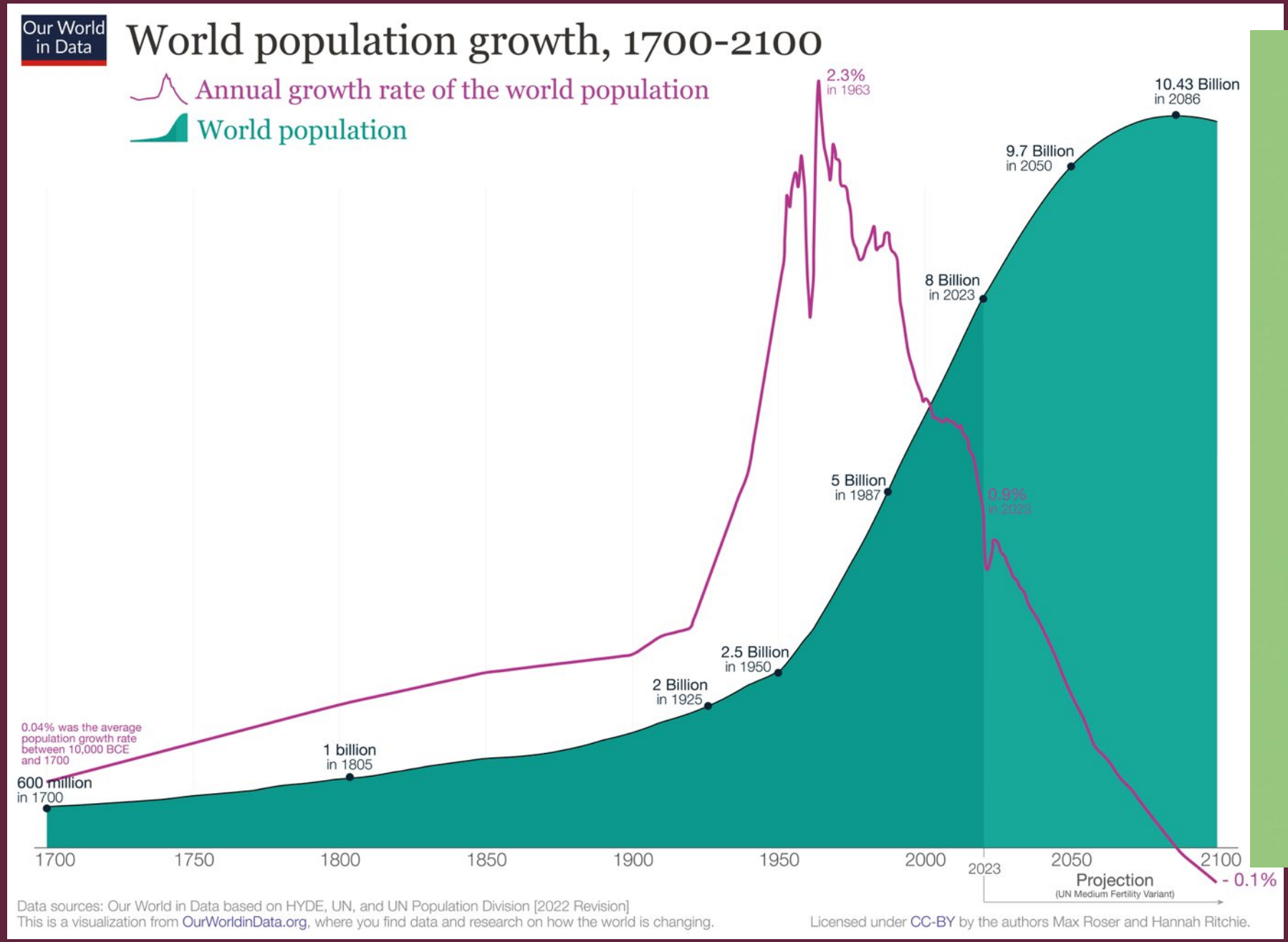


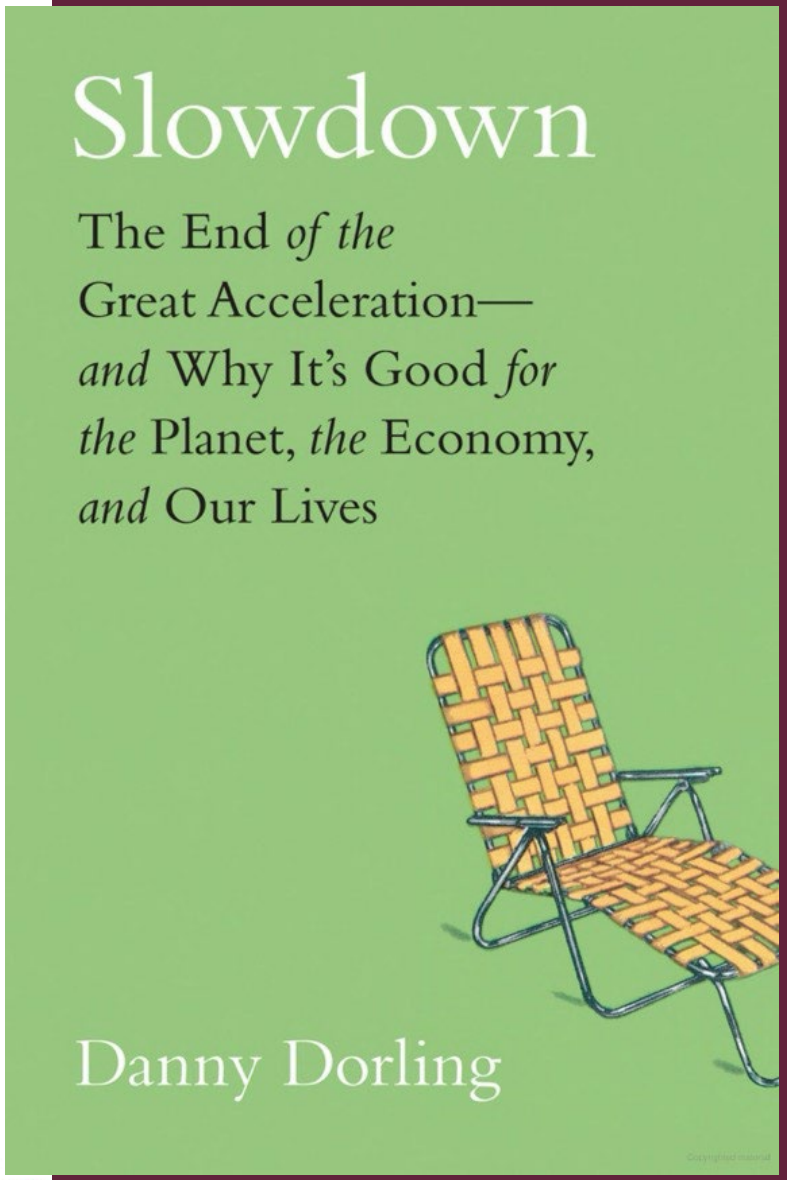
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Green Revolution

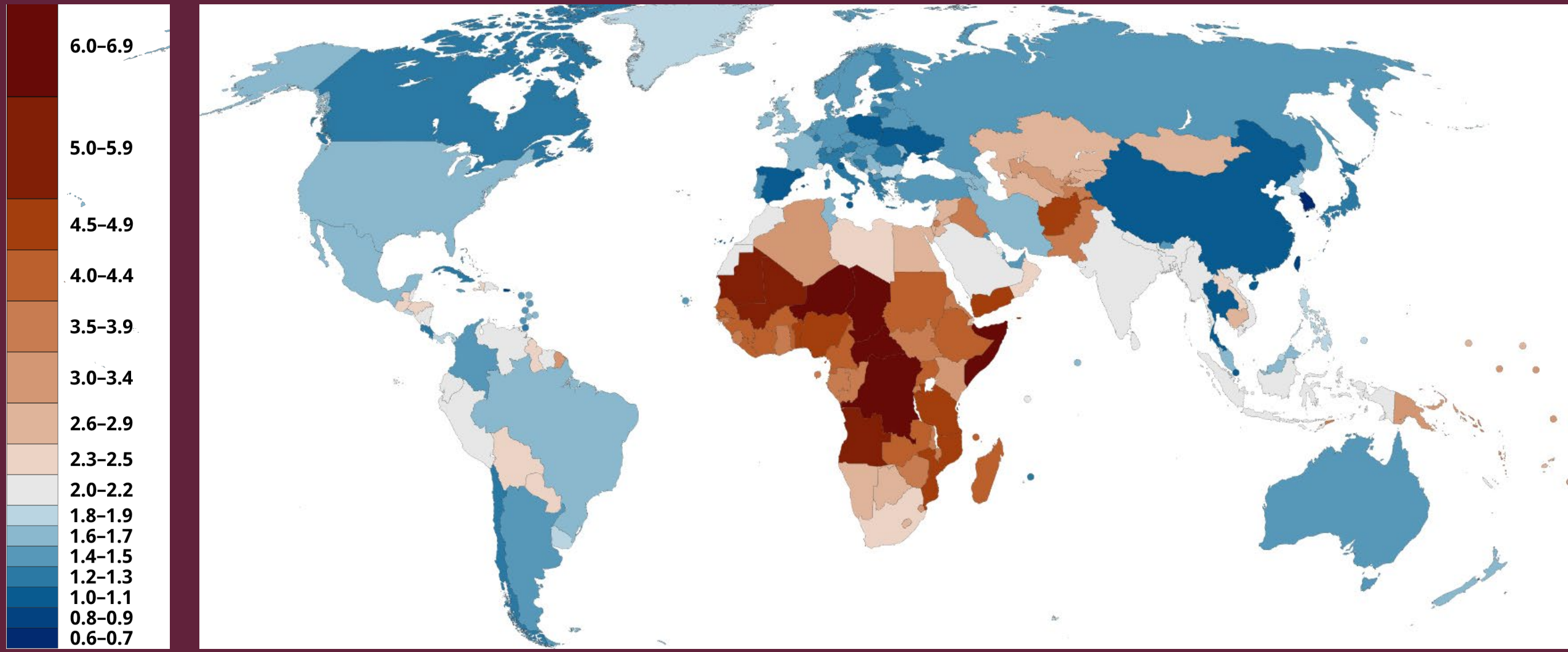





Our World in Data
World population growth, 1700-2100
Annual growth rate of the world population
World population
2.3% in 1963
10.43 Billion in 2086
9.7 Billion in 2050
8 Billion in 2023
5 Billion in 1987
0.9% in 2023
2.5 Billion in 1950
2 Billion in 1925
1 billion in 1805
600 million in 1700
0.04% was the average population growth rate between 10,000 BCE and 1700
1700
1750
1800
1850
1900
1950
2000
2023
2050
2100
Projection
(UN Medium Fertility Variant)
- 0.1%
Data sources: Our World in Data based on HYDE, UN, and UN Population Division [2022 Revision]
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.
Licensed under CC-BY by the authors Max Roser and Hannah Ritchie.


Slowdown
The End *of the* Great Acceleration— *and* Why It's Good *for the* Planet, *the* Economy, *and* Our Lives
Danny Dorling

Two-speed world?



By Korakys - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=92951369

From Niche Expansion to Climate Crisis? An Agricultural Timeline

~10,000 BP

Animal and Crop Domestication

First sustained human-animal contact; pastoralist expansion across Africa

~6,000 BP

Green Sahara Dairying

First dairying in green Saharan Africa; climate shifts drive migration

1700-2000

Great Acceleration

Population explosion; agricultural land area per capita collapses

2024

Two-Speed World

Replacement ratio divergence; SSA faces unique demographic + climate pressure

2050-2100

Critical Threshold

4°C+ world: 35% of SSA cropland unsuitable; growing season failures multiply

Southern Africa: The Scale of the Challenge

60%	30%	-20%	>700M
of workforce in agriculture	**average GDP share**	**precipitation by 2080s**	**people at risk of hunger**
Agriculture is the economic backbone of most SSA countries (Thornton et al., 2011)	Exceeds 50% in some countries; total GDP highly vulnerable to climate shocks	Projected decline in annual rainfall across southern Africa (Conway et al., 2015)	By 2070; number rising as climate change compounds food insecurity

The Food-Energy-Environment-Water (FEEW) Nexus

Interdependencies, Trade-offs and Climate Risks in Southern Africa

Understanding the Food-Energy-Water Nexus

1

Food

Demand set to rise 60-100% by 2050. Rainfed agriculture dominates SSA. Smallholder vulnerability is high. Price shocks due to climate impacts may cascade globally.

2

Energy

Hydropower dependent on water flows. Irrigation requires energy. Pumping costs rise with water scarcity. Bioenergy demand competes for land and water.

3

Water

Projected 20% decline precipitation. Irrigation hotspots generate water debt. Trade redistributes embedded water. Transboundary basins create interdependencies.

Climate as a Cross-Cutting Driver of the FEEW Nexus

- **Regional interdependencies**

  River basins and aquifers spanning borders mean climate anomalies and resource stress cross national boundaries, reinforcing the need for regional cooperation (Conway et al., 2015)

- **Water-food trade linkages**

  Regional food trade redistributes embedded water; imports play a critical role during severe droughts, but concentrate pressure on water-scarce exporters such as South Africa (Dalin & Conway, 2016)

- **Irrigation demand surge**

  Projected country-scale irrigation demand increases of 6.5-32% by 2090 for South Africa; certain crops generate high water debts in already vulnerable arid areas (Bonetti et al., 2022)

- **Energy-water feedbacks**

  Hydropower generation declines as river flows reduce; irrigation pumping costs increase as water tables fall — the energy and water sectors are deeply intertwined

The spatial interdependence of climate impacts across basins means that projected rainfall decreases propagate into reduced water and yields, requiring integrated regional policy responses.

— Conway et al., Nature Climate Change, 2015

Climate and southern Africa's water-energy-food nexus

Agricultural Impacts

Evidence from Statistical, Ricardian and Integrated Modelling Approaches

How Much Will Climate Change Harm African Agriculture?

-22%

Maize production loss by mid-century

Median estimate for Sub-Saharan Africa under A1b scenario

(Schlenker & Lobell, 2010)

95%

probability damages exceed 7%

For maize, sorghum, millet and groundnut — robust across all model specifications

-27%

Farm net revenue (severe scenario)

CCC hot/dry scenario by 2100; across all farm types in Africa

(Seo et al., 2009)

-5.4

Livestock revenue temperature elasticity

Livestock income most sensitive to warming; dryland crops elasticity -1.9

(Kurukulasuriya et al., 2006)

What Drives Yield Losses?

Temperature Effects

Temperature changes drive far larger yield losses than precipitation changes across SSA.

Maize, sorghum, millet and groundnut all show strong negative responses to temperatures above 30°C.

Higher-yielding, better-fertilised varieties are MORE susceptible — countries with highest average yields show the largest projected losses.

The relative effect of temperatures above 30°C in Zimbabwe and South Africa is similar to estimates for maize in the United States.

Precipitation Effects

Precipitation changes contribute less to yield losses than temperature in most models.

However, projected rainfall DECLINES in southern Africa compound temperature stress.

Rainwater harvesting, soil moisture management and irrigation remain critical buffers.

Farming systems in the East, West and Sahel regions of Africa are especially at risk from precipitation declines combined with warming.

Source: Schlenker & Lobell (2010)

Not All Zones Are Equal: Agro-Ecological Zone Heterogeneity

- **Productive savannas most vulnerable**

  Dry and moist savanna AEZs — currently the most productive agricultural zones — are most vulnerable to climate change under the severe CC scenario (Seo et al., 2009)

- **Humid/sub-humid zones may benefit**

  Currently less productive humid forest and sub-humid AEZs may become more productive under mild warming (PCM scenario); a net 12-19% gain is possible for Africa as a whole

- **Crop + livestock resilience**

  Combined crop-and-livestock net revenue is more climate-resilient than crops alone; farmers who switch to heat-tolerant livestock species reduce climate vulnerability

- **A quilt, not a blanket**

  Policy makers should apply targeted interventions by AEZ rather than uniform approaches — the range of impacts across zones demands location-specific strategies

In a 4°C+ World: Projected Risks for Sub-Saharan Africa

1 Growing Season Loss

Most of SSA below 15°S: at least 20% reduction in growing season length; nearly all rain-fed agriculture may fail one year in two.

2 Crop Yield Declines

-24% mean maize yield; -71% beans; even with increases in LGP in East Africa, increased season failure rates cancel out gains.

3 Land Suitability Shifts

~35% of current cropland in East and southern Africa becomes unsuitable. Up to 1.2 million km² may flip from mixed farming to rangeland.

4 No Historical Analogues

By 2050, ~25% of African countries will face climatic conditions for which there are no current historical analogues — farmers' experience and indigenous and local knowledge severely compromised.

Economic Dimensions

How Climate Change Shapes Agricultural Economies and Food Prices

Development Pathway vs. Climate Scenario: What Matters More?

3-35x

larger impact from SSP pathway

Socioeconomic development pathway has 3-35 times larger impact than climate scenario on GDP, crop prices and land use (Ren et al., 2018)

>40%

lower GDP in SSP3 vs SSP5

For all regions globally — fragmented, low-growth pathway dwarfs the effect of different warming levels

11x

SSP effect on total cropland use

Compared to climate scenario effect; land-use is overwhelmingly driven by population and technology, not climate

35x

SSP effect on GDP

The single most important lever for food security in SSA could be the development pathway, not the climate scenario

Economic Cascades: From Yield Loss to Food Insecurity

- **Yield → Price → Hunger**

  Without CO_2 fertilisation, global average yield changes of -4% to -20% by 2050 translate to 3-79% increases in crop prices — SSA households, as net food buyers, hardest hit

- **Trade as shock absorber (and amplifier)**

  Regional food trade redistributes embedded water and can buffer droughts — but as 2007-08 showed, national export bans and import tariffs can amplify rather than dampen price shocks

- **SSA most exposed economy**

  Agriculture contributes ~17% of GDP across SSA and exceeds 50% in some countries; total GDP and per capita income are uniquely vulnerable to climate shocks

- **Irrigation as economic adaptation**

  Investment in successful irrigation in SSA costs $3,600-$5,700/ha but the difference in net revenue between dryland and irrigated farms reaches $150-$5,000/ha — viable payback in many contexts

“There is arguably little scope for substantial poverty reductions in SSA without large improvements in agricultural productivity. Climate change will make this challenge even more difficult.

— Schlenker & Lobell (2010)

Environmental Research Letters 5: 014010

Adaptation

Frameworks, Options, Barriers and the Case for Transformative adaptation

The Adaptation Spectrum: From Coping to Transformative approaches

Incremental (coping)

Varieties, planting times

Adjustments within existing systems. Stubble, water, nutrient and canopy management. Low risk, fast payback.

Systems

Crop-livestock balance, precision ag

Changes to an existing system. New crop types, diversification, irrigation planning. Medium complexity.

Transformational

Land use change or relocation

Major, non-marginal change. New goals, new locations. Required when climate moves beyond coping range. High risk, high reward.

Failure

Migration, exit from farming

When options are exhausted. Urban transition, livelihood diversification. Policy support critical.

Transformational Adaptation: What, Why and When?

What it is

Major purposeful action at farm or supra-farm level in response to potential or actual climate change impacts.

Two core types:
1. Change in GOAL / land use
(e.g., shift from cereals to farm forestry for carbon sequestration)

2. Change in LOCATION
(relocation of agricultural activity to more climatically amenable areas)

Source: Rickards & Howden (2012)

Why it matters

As the degree and pace of climate change accelerates, combined with limits on land, water, fossil fuels and biodiversity, more systemic adaptation is increasingly needed.

Incremental adaptation alone may create "lock-in" — increasing investment in existing systems and narrowing options for change.

By 2050, ~25% of African countries will face conditions with NO current historical analogues — farmers' past experience will be an insufficient guide.

Source: Thornton et al. (2011)

Adaptation Options for Southern African Agriculture

1 Crop Management

Drought/heat-tolerant varieties. Changed planting times. Soil moisture conservation. Water harvesting. Diversification of crop mix.

2 Livestock Strategies

Shift to heat-tolerant species (camels, goats). Index-based weather insurance. Mobility as key pastoral strategy. Species mix adjustment.

3 Water & Irrigation

Nexus-aware irrigation planning. Rainwater harvesting. Deficit irrigation. Water-debt monitoring. Drip and precision systems.

4 Livelihood Diversification

Off-farm income. Ecosystem service payments. Carbon sequestration schemes. Rural-urban linkages. Climate-smart value chains.

Barriers Preventing Effective Adaptation in Southern Africa

1 Financial Constraints

Most smallholders face cash constraints. Access to credit is limited. Suboptimal technologies persist because better ones are unaffordable. Insurance markets are thin.

2 Institutional Weakness

Weak policy coordination. Siloed institutions. Limited extension services. Advisory systems under-resourced. Poor market infrastructure.

3 Knowledge & Uncertainty

Future climate uncertainty raises transaction costs. Long lead times on transformational decisions create hesitation. No historical analogues for future conditions.

4 Diminishing Options

As warming intensifies, the number of viable adaptation options decreases. At 4°C+, variety selection narrows from 87% to 54% of available wheat cultivars (Thornton et al., 2011).

The Role of Government and Institutions in Enabling Adaptation

- **Market failures require intervention**

  Climate change constitutes an unprecedented market failure (Stern, 2007); this legitimates government intervention in agricultural R&D, extension, infrastructure and risk management

- **Focus RDE on large, indivisible decisions**

  Government investment should focus on decisions too large or risky for individual farmers: land purchase, exit from agriculture, major irrigation infrastructure (Pannell, cited in Rickards & Howden, 2012)

- **Anticipatory policy**

  Pro-active and anticipatory adaptation — addressing market failures such as moral hazard and adverse selection in risk management — is more effective than reactive crisis response

- **Integrated, transdisciplinary research**

  Agricultural research can no longer remain insulated from off-farm, non-science knowledge; transformation requires cross-scale, cross-sectoral approaches integrating resilience, innovation studies and rural geography

Research Gaps & Priorities

What We Still Need to Know to Act Effectively

Critical Research Gaps Across the FEW Nexus

1 Integrated Regional Tools

WEF nexus indicators and integrated assessment models needed at SADC scale. National-level links between rainfall variability and macroeconomic outcomes remain weakly resolved.

2 CO_2 Fertilisation

The single most critical uncertainty in all projections. CLM shows stronger CO2 response than AgMIP models. For C4 crops dominating SSA, benefits likely minimal.

3 Local-Scale Evidence

More place-based experiments needed to validate soil-water-crop interventions. Downscaled, context-specific data essential for scaling pathways in rainfed systems.

4 Governance & Adoption

Empirical studies on barriers to CSA and nexus-informed irrigation (finance, extension, gender, market access) are limited. Water sustainability monitoring for trade-mediated balances inadequate.

Back to Basics: Critical Data and Monitoring Gaps

- **Land-based observation decline**

  Weather data, land-use data, and crop/livestock distribution data have been in decline in SSA for decades. Estimates of cropland extent in Africa range from 1 to 6 million km² depending on data source (Thornton et al., 2011)

- **Germplasm response data**

  Specific crop variety responses to weather and climate are rarely collected systematically. This limits our ability to identify and deploy climate-adapted varieties before analogues disappear

- **Water sustainability monitoring**

  Persistent knowledge gaps on long-term sustainability of trade-mediated water balances and on identifying irrigated crop hotspots that threaten local water supplies (Bonetti et al., 2022)

- **Socio-economic thresholds**

  While understanding of physical tipping points is growing, we have almost no understanding of socio-economic and cultural thresholds — the point at which adaptation options are truly exhausted

Synthesis & Conclusions

Key Messages for Research, Policy and Practice

Synthesis: Three Interconnected Challenges

1. Climate is already reshaping the agricultural landscape of southern Africa

2. The FEEW Nexus approach allows assessment of how sector responses can be managed integratively

3. Development pathway choices control vulnerability more than climate scenario alone

Key Messages for Policy and Practice

1 Invest in Development

The SSP development pathway dwarfs climate scenario effects. Investing in technology, irrigation, institutions and infrastructure is likely the highest-leverage intervention for SSA food security.

2 Adopt a Nexus Lens

No sector can be managed in isolation. WEEF Nexus governance frameworks, integrated assessment tools and transboundary cooperation are essential for southern Africa.

3 Plan for Transformative Adaptation

Incremental adaptation will be insufficient under high warming. Proactive, anticipatory transformation — starting now, before analogues disappear — reduces future costs and preserves options.

4 Fill the Data Gaps

Observations, germplasm records, waterand climate monitoring and socio-economic threshold research could be usefully scaled up. We cannot adapt to what we are not measuring.

A Research Agenda for the FEEW Nexus in Southern Africa

- **Integrated regional modelling**

  Develop WEF nexus indicators and integrated assessment models at SADC scale that can monitor trade-offs and guide investment allocation across water, energy and food sectors

- **Resolve the CO_2 fertilisation question**

  The single most important scientific uncertainty for SSA: design field experiments in tropical cropland systems to quantify real CO2 response under African conditions

- **Local-scale validation and scaling**

  More downscaled, place-based experiments to validate soil-water-crop interventions; co-design scaling pathways with farmer communities, extension services and local government

- **Social and governance research**

  Empirical studies on adoption barriers, gender dimensions, market access, institutional capacity and the socio-economic thresholds beyond which adaptation is no longer viable

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Thank you
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Photo by Stefan Els

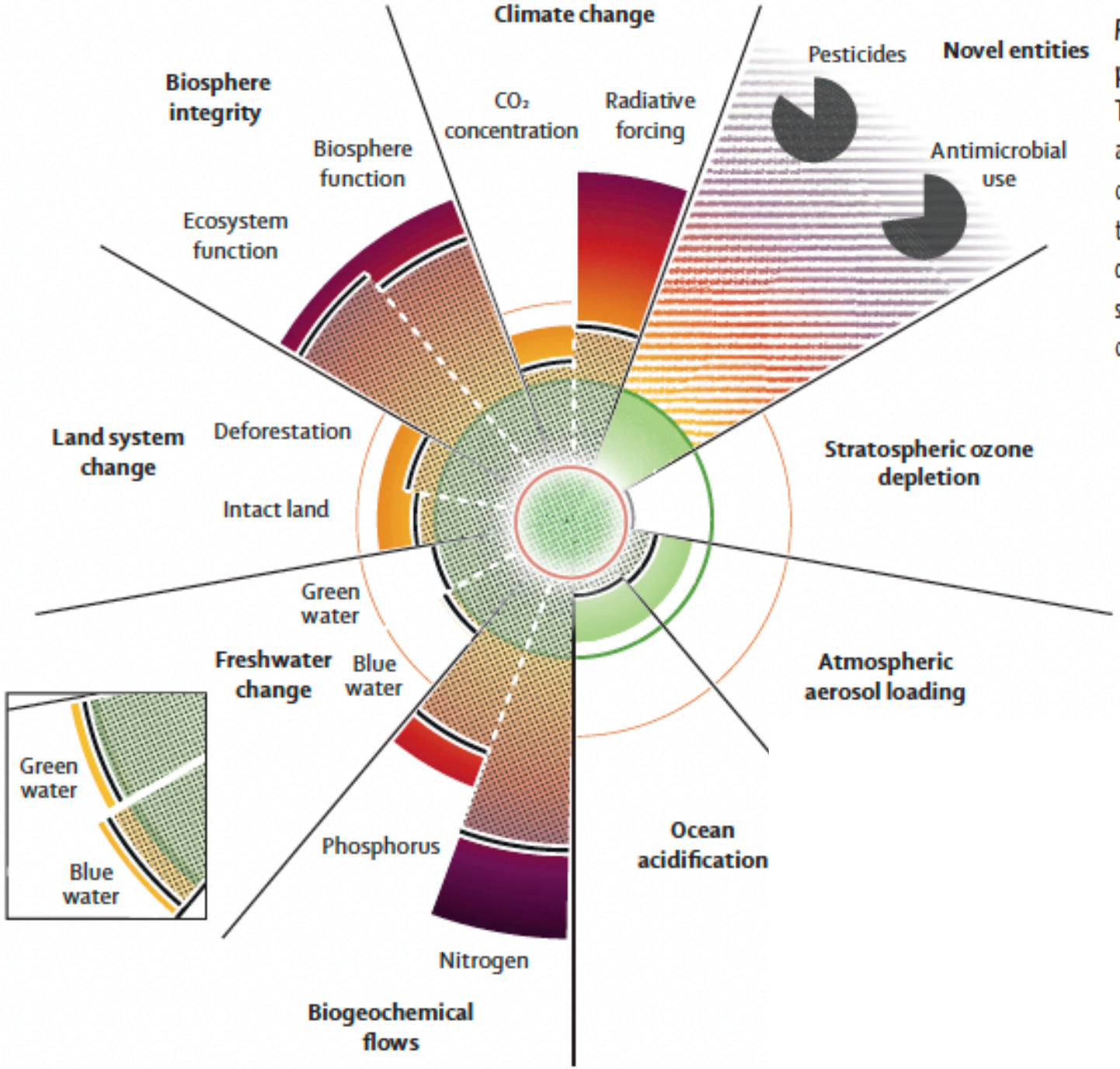
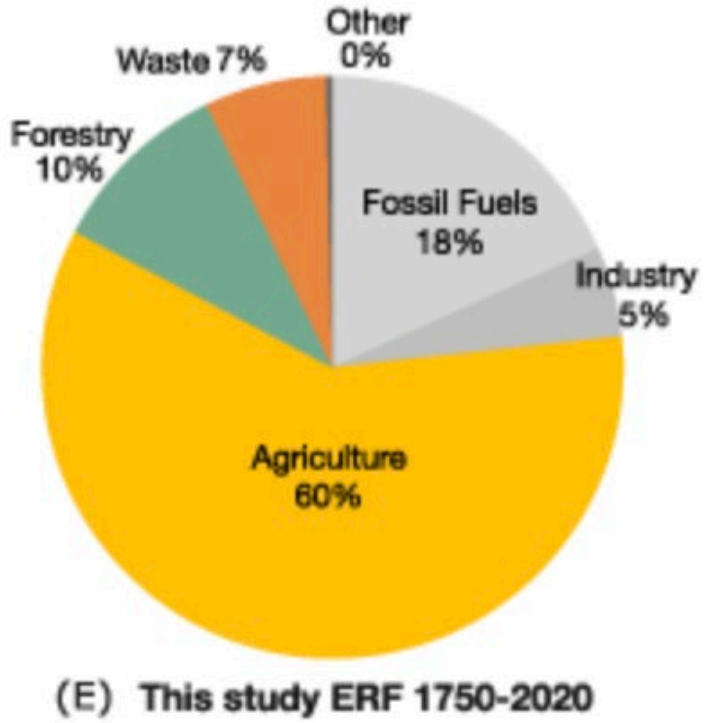


Figure 1: **Status of food system pressures across all nine planetary boundaries (indicated by the black dotted pattern) and the food system boundaries (red line)**

The food system boundaries are normalised in relation to planetary boundaries (green sphere). The radar plot is adapted with permission from Richardson et al (data)[14] and Rockström et al (visual).[15] The food system contribution (in percentages) is projected based on the wedges' lengths, starting from the planetary boundary for the six transgressed boundaries, and the food boundary for the three other boundaries (see te Wierik et al[16] for details). The food system's contributions to pesticides and antimicrobial use are shown as pie charts (with the food system share in grey) within the larger set of all novel entities (which were previously unquantified). Note that CO_2 concentration is provided in terms of CO_2 equivalents, as in table 2. Adapted from te Wierik et al.[16]



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