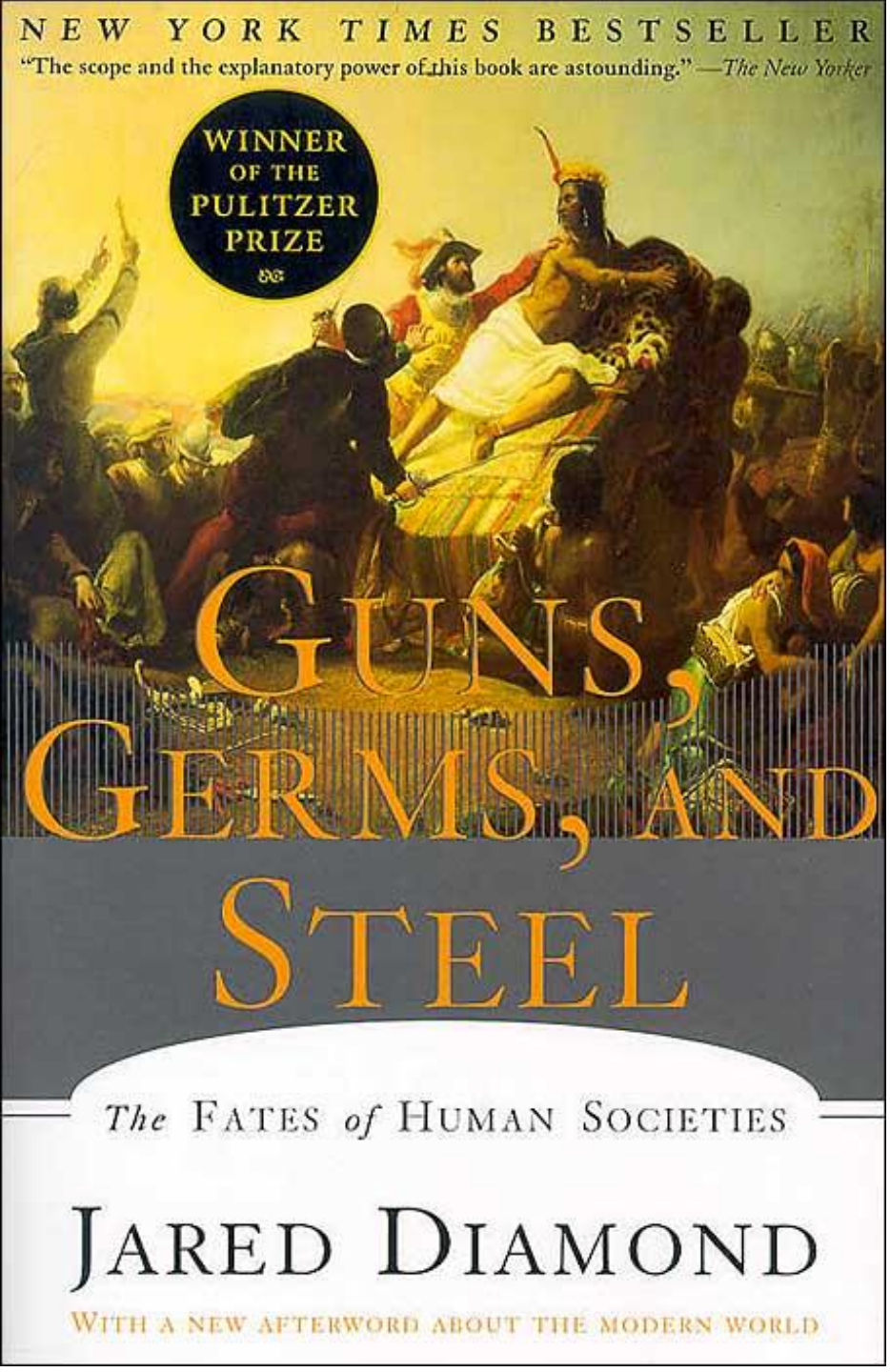


BIO 235
Plants & People
Evolution & Domestication of Crops

Lecture 12 – Guns, Germs & Steel - the causes and consequences of domestication – a global panorama

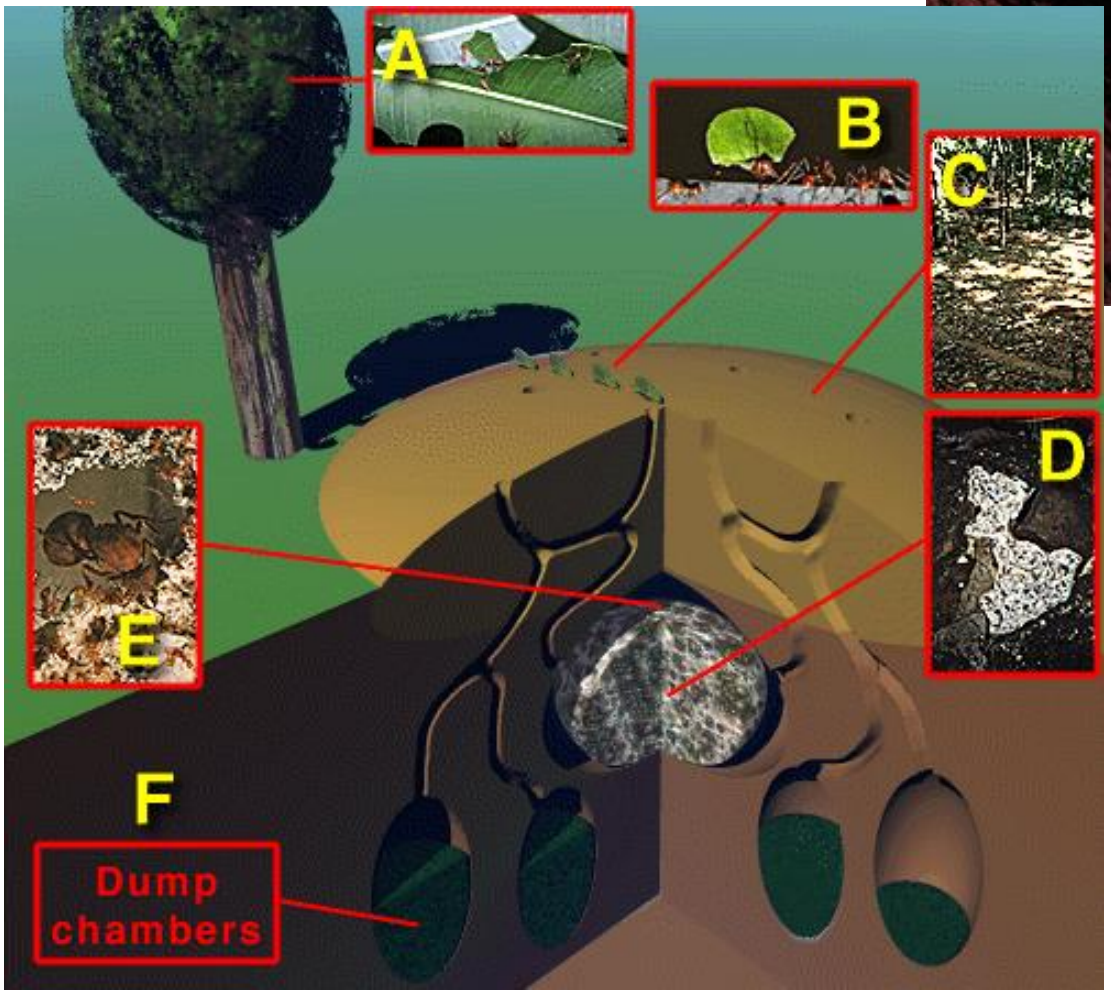
- Non-human agriculture

The causes of domestication
- Why then and not earlier?
- Why there and not elsewhere?
- Theories, common factors in different areas & explanations
- Biogeographic luck

The consequences of domestication
- Why some societies got ahead of others

Colin Hughes
Institute of Systematic Botany
colin.hughes@systbot.uzh.ch

Non-Human Agriculture
Ant Fungiculture



Monophyletic group of 200 ant species – obligate agriculturalists

nature plants

BRIEF COMMUNICATION

PUBLISHED: 21 NOVEMBER 2016 | ARTICLE NUMBER: 16181 | DOI: 10.1038/NPLANTS.2016.181

Obligate plant farming by a specialized ant

Guillaume Chomicki* and Susanne S. Renner

Ants actively and exclusively plant the seeds and fertilize seedlings of six species of epiphytic Squamellaria plants.

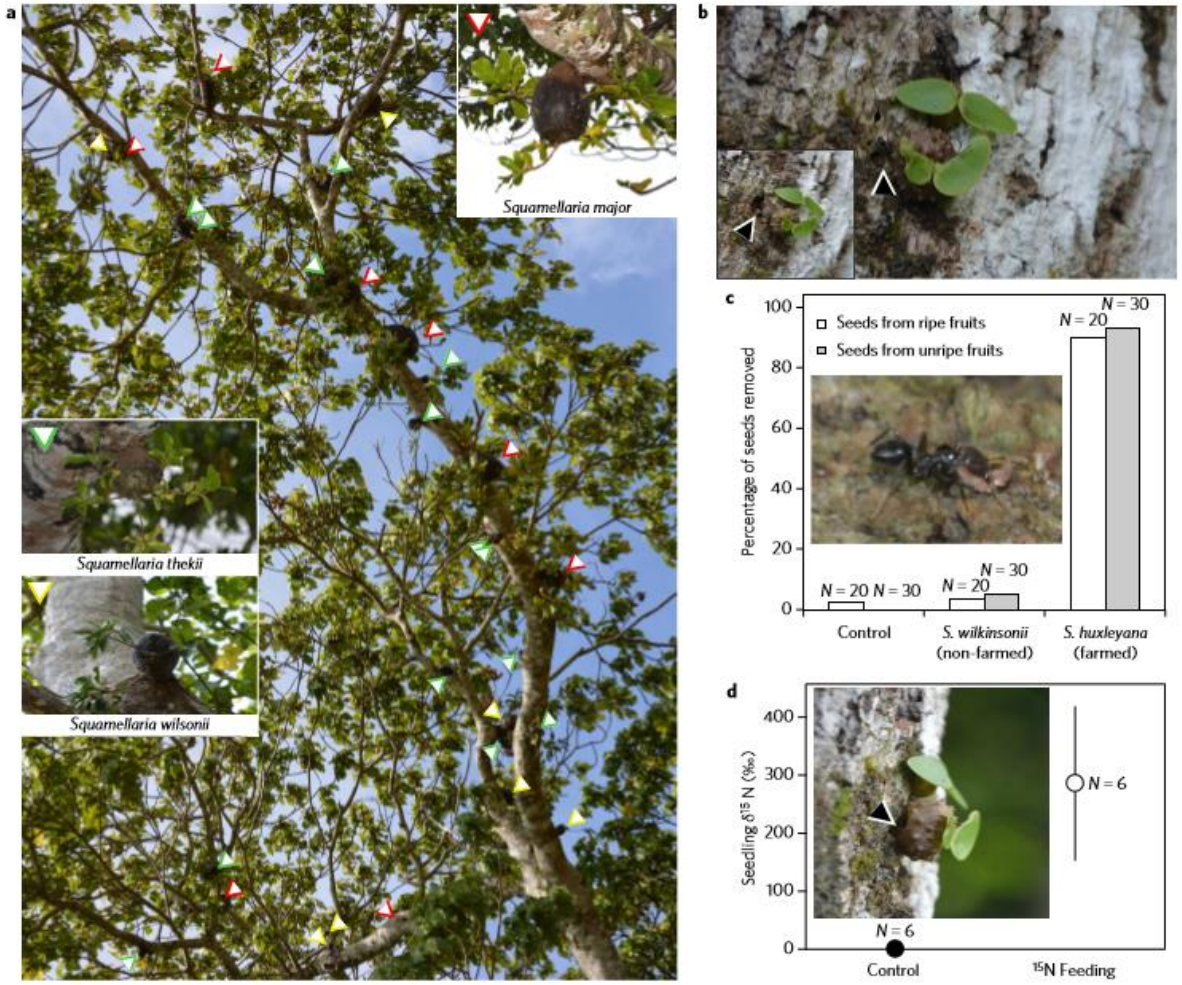
nature plants

BRIEF COMMUNICATION

PUBLISHED: 21 NOVEMBER 2016 | ARTICLE NUMBER: 16181 | DOI: 10.1038/NPLANTS.2016.181

Obligate plant farming by a specialized ant

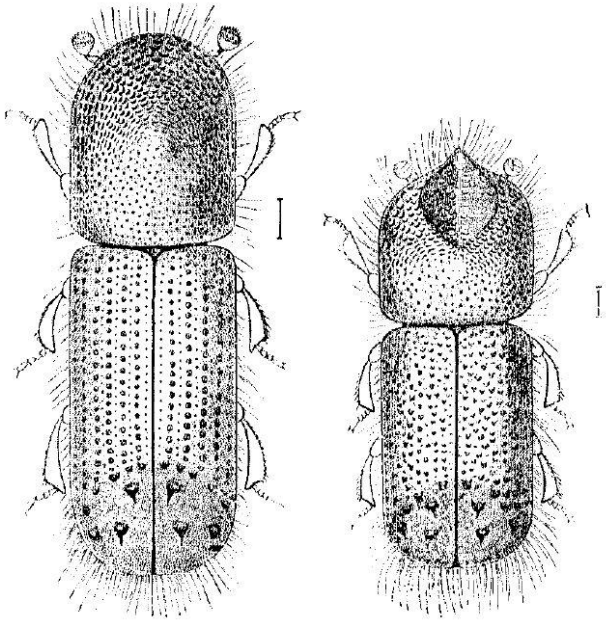
Guillaume Chomicki* and Susanne S. Renner

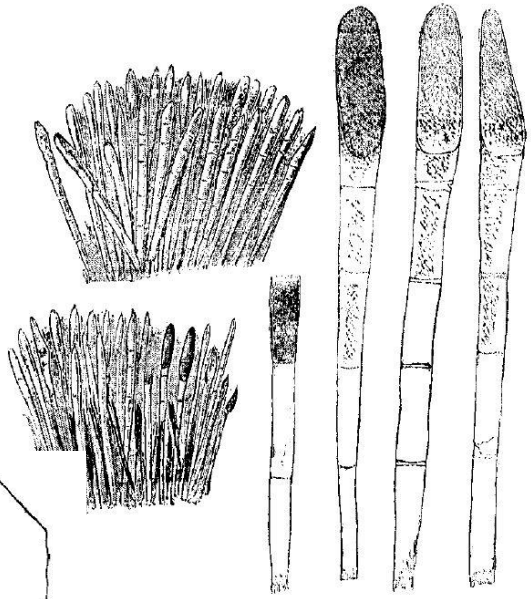


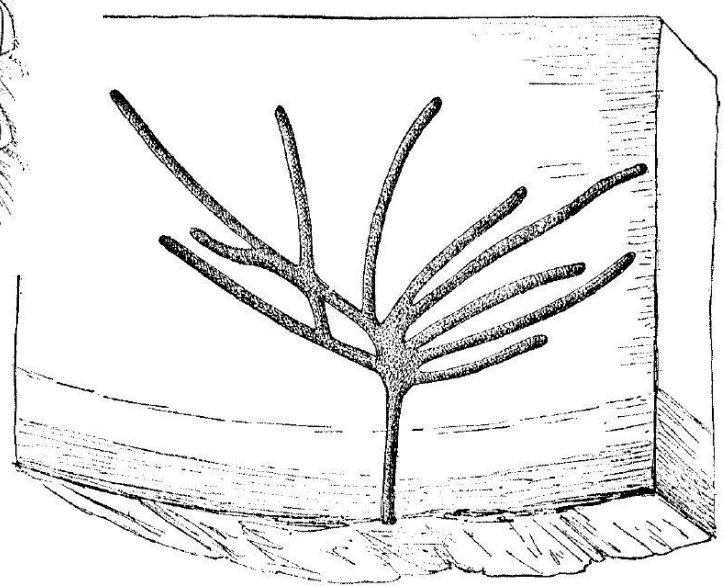
The one species of ant forms large monocultures of Squamellaria plant siblings – a feature common to most farming mutualisms.

Non-Human Agriculture

- ants, termites, ambrosia beetles and snails farming fungi
- damselfish farming algae
- amoebae farming bacteria







Ambrosia beetle fungiculture
Farrell et al. 2001

Agricultural behaviour of farming ants, termites, ambrosia beetles and humans From Mueller et al. (2005)

Agricultural behaviour	**Ants**	**Termites**	**Ambrosia beetles**	**Humans**
Nutritional dependency on crop for food	Obligate	Obligate	Obligate	Facultative
Engineering optimal growth conditions	YES	YES	YES	YES
Planting crop on improved substrate	YES	YES	YES	YES
Intensive continuous monitoring of growth and disease status of crop - **cultivation**	YES	YES	YES	NO
Sustainable **harvesting** of crop for food	YES	YES	YES	YES
Protection of crop from diseases and consumers	YES	YES	YES	YES
Weeding of alien organisms invading the garden	YES	YES	???	YES
Use of chemical herbicides to combat pests	YES	???	???	YES
Use of microbial symbionts for nutrient procurement for crop	YES	???	???	YES
Use of disease-suppresant microbes for biological pest control	YES	???	???	NO
Sociality	Strictly social	Strictly social	Subsocial /communal	Social
Task partitioning in agricultural processes	YES	???	YES	YES
Artificial selection for crop improvement	???	???	???	YES
Conscious learning and cultural transmission of agricultural innovations	NO	NO	NO	YES

Phylogenetic origins of insect agriculture

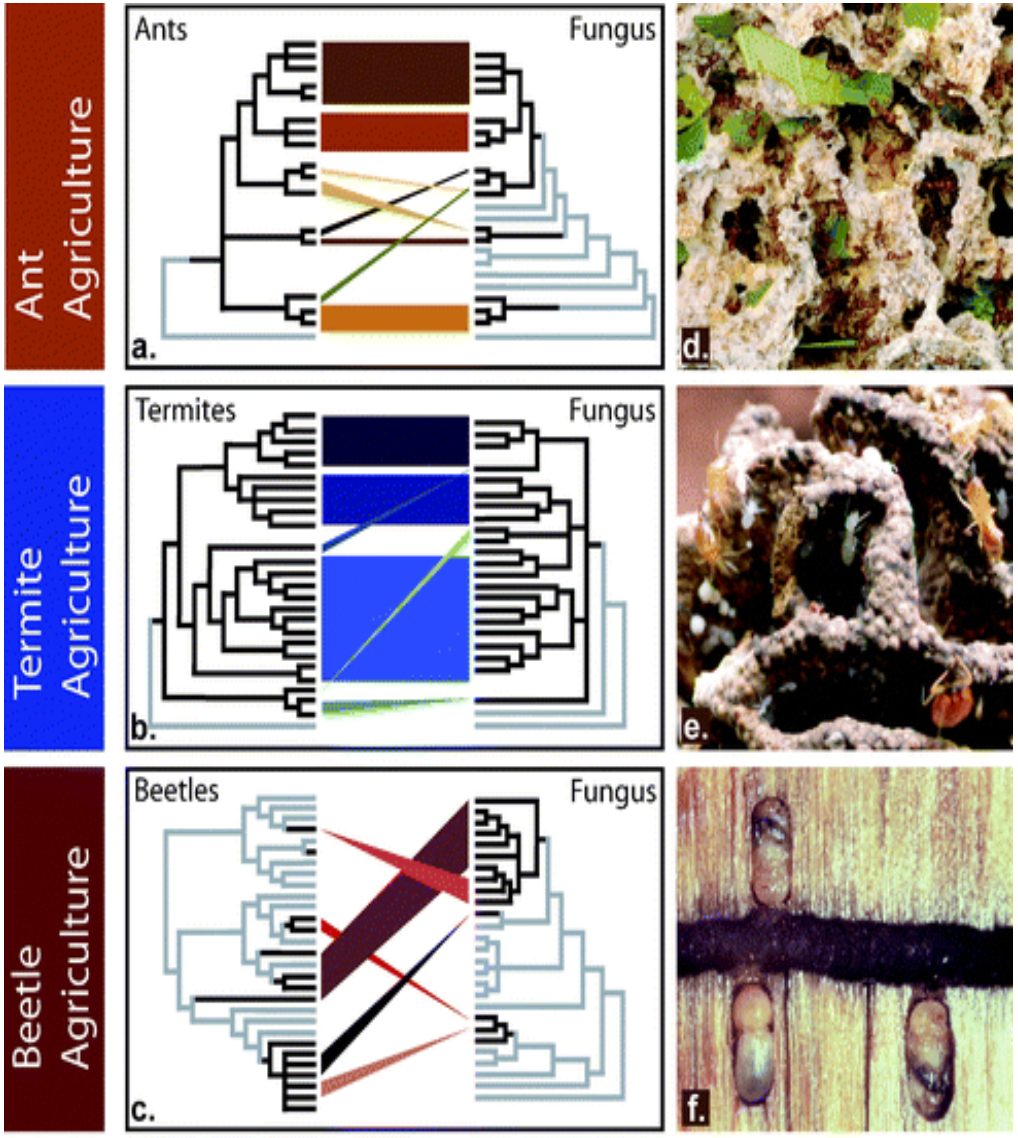
- Ants – single origin 45-65 Mya in the Amazon
- Termites – single origin 24-34 Mya in Africa
- Ambrosia beetles – 7 independent origins 20-60 Mya

- Termites & beetles – single specific cultivar clade to which descendants have adhered

- Ants – multiple independently domesticated cultivar lineages

- No known cases of reversals from agricultural to non-agricultural life in any of the 9 agricultural insect lineages

- cf. humans with 10-?13 independent origins, all within last 10,000 years



Mueller UG, et al. 2005.
Annu. Rev. Ecol. Evol. Syst. 36:563–95

Non-Human Agriculture

Farming mutualisms

An organism promotes the growth of another on which it depends for food
- Dispersal – an essential first step in farming mutualism
- Cultivation that improves the growth conditions before crop maturity

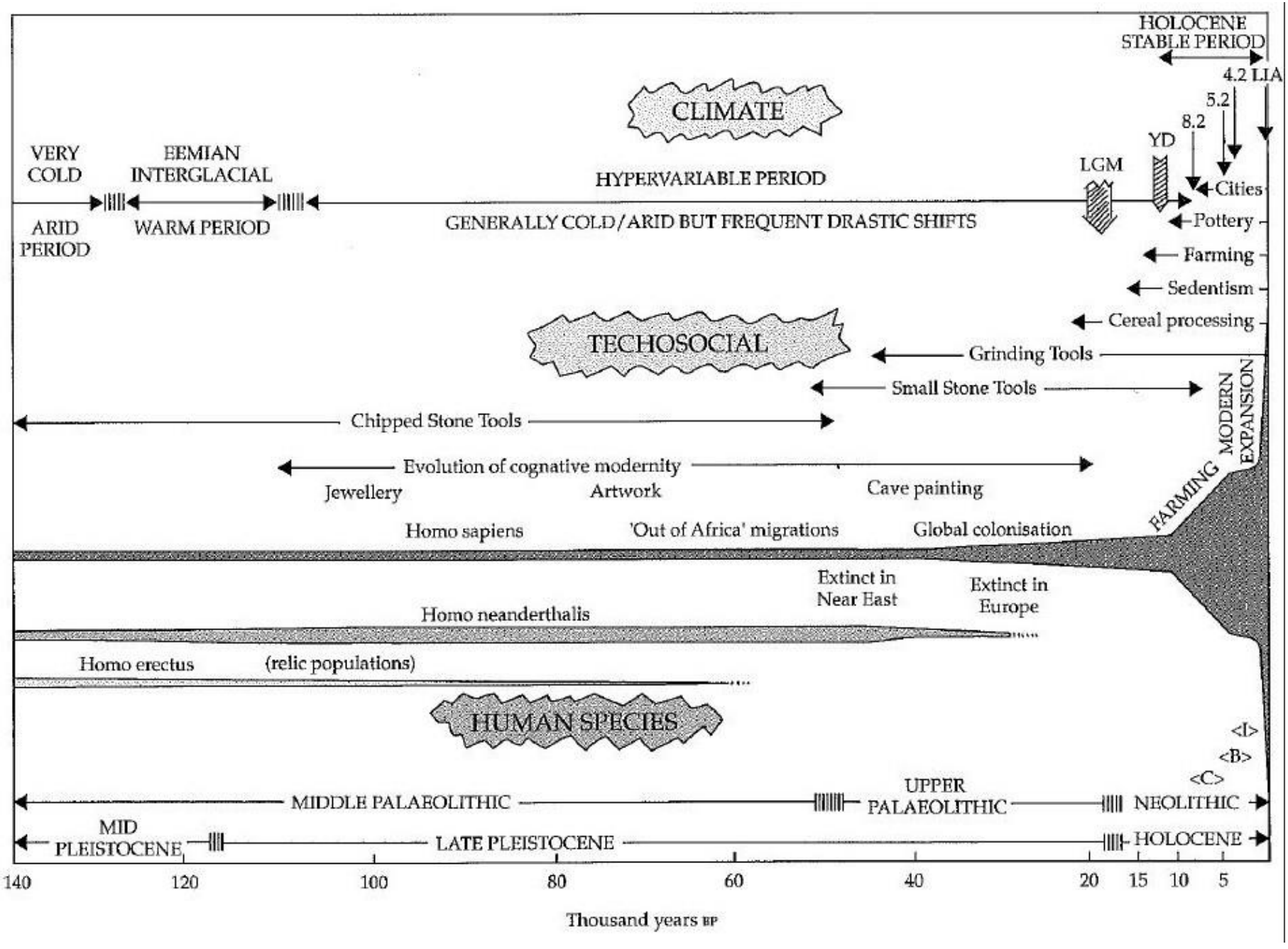
Examples
- ants, termites, ambrosia beetles and snails farming fungi
- ants farming epiphytic plants
- damselfish and sloths farming algae
- amoebae and crabs farming bacteria

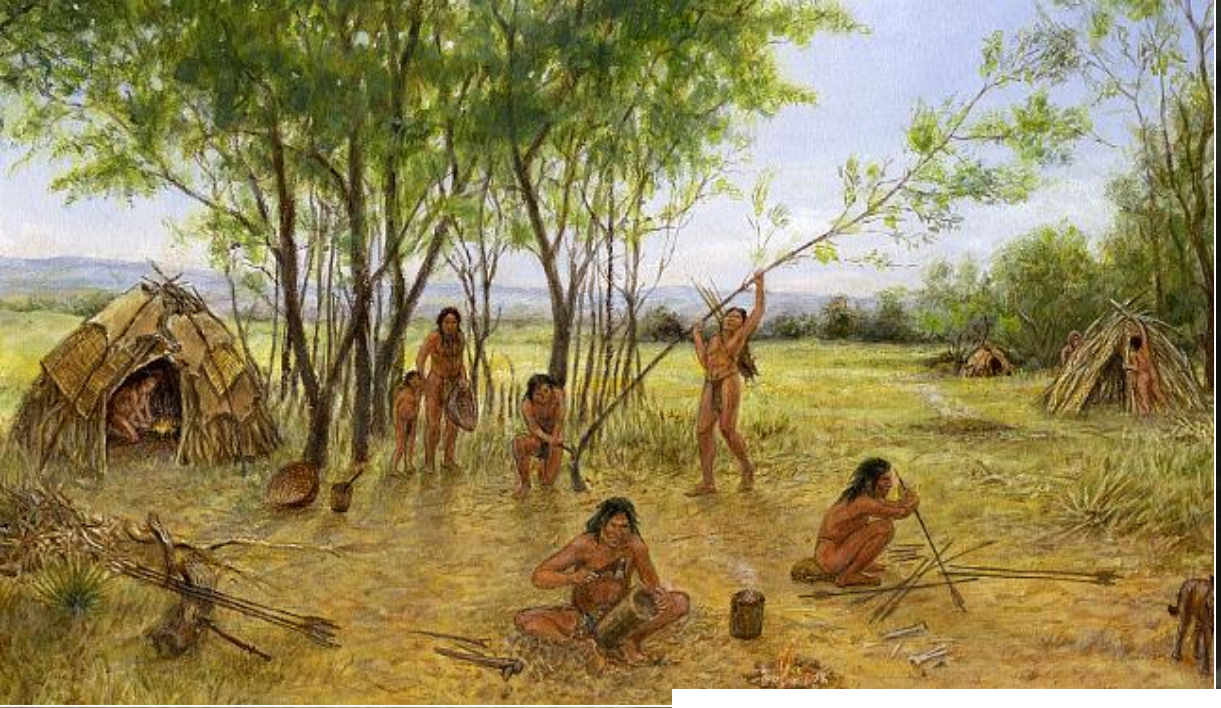
An even broader comparative framework to investigate:
- what common ground there might be between fungus-growing ants, wheat-growing humans and algae farming damsel fish?

- what insights we might gain into why agriculture arose by adopting this much broader evolutionary perspective on agriculture?

- what lessons non-human agriculture might have for modern agriculture, for example to improve disease and pest control strategies?

The evolution of modern humans and human societies





Foraging to Farming

Causes of Domestication Questions ??

- Why did humans become farmers? What were the factors and circumstances that prompted the shift from hunting and gathering to farming?
- Why more or less simultaneous (or apparently simultaneous) origin of agriculture independently in different places? Is there a global explanation?
- Why did agriculture arise in these areas and not others?
- Why then but not earlier?
- Why do these areas not overlap more significantly with areas of most productive modern agriculture?
- Why did domestication involve so few species? – 350,000 flowering plant species, but only c.100 – max 200 important domesticated crops?

Origins of Agriculture – established paradigm vs new evidence

- Early dogma that agriculture arose just a few times in parallel
- Rapid – the Neolithic revolution
- Largely as a result of unintended consequences that allowed revolutionary changes in the economy
- Idea of rapid change lent itself to identification of single big universal causes of agricultural origins

Fig. 2–2. Centers and noncenters of agricultural origins: (A1), Near East center, (A2), Afrian noncenter, (B1), North Chinese center, (B2), Southeast Asian and South Pacific noncenter, (C1) Mesoamerican center, and (C2) South American noncenter (from Harlan, 1971; copyright © 1971 by the American Association for the Advancement of Science).

3 independent centres & 3 secondary centres – Harlan (1971)

Vavilov' Centres of Crop Domestication

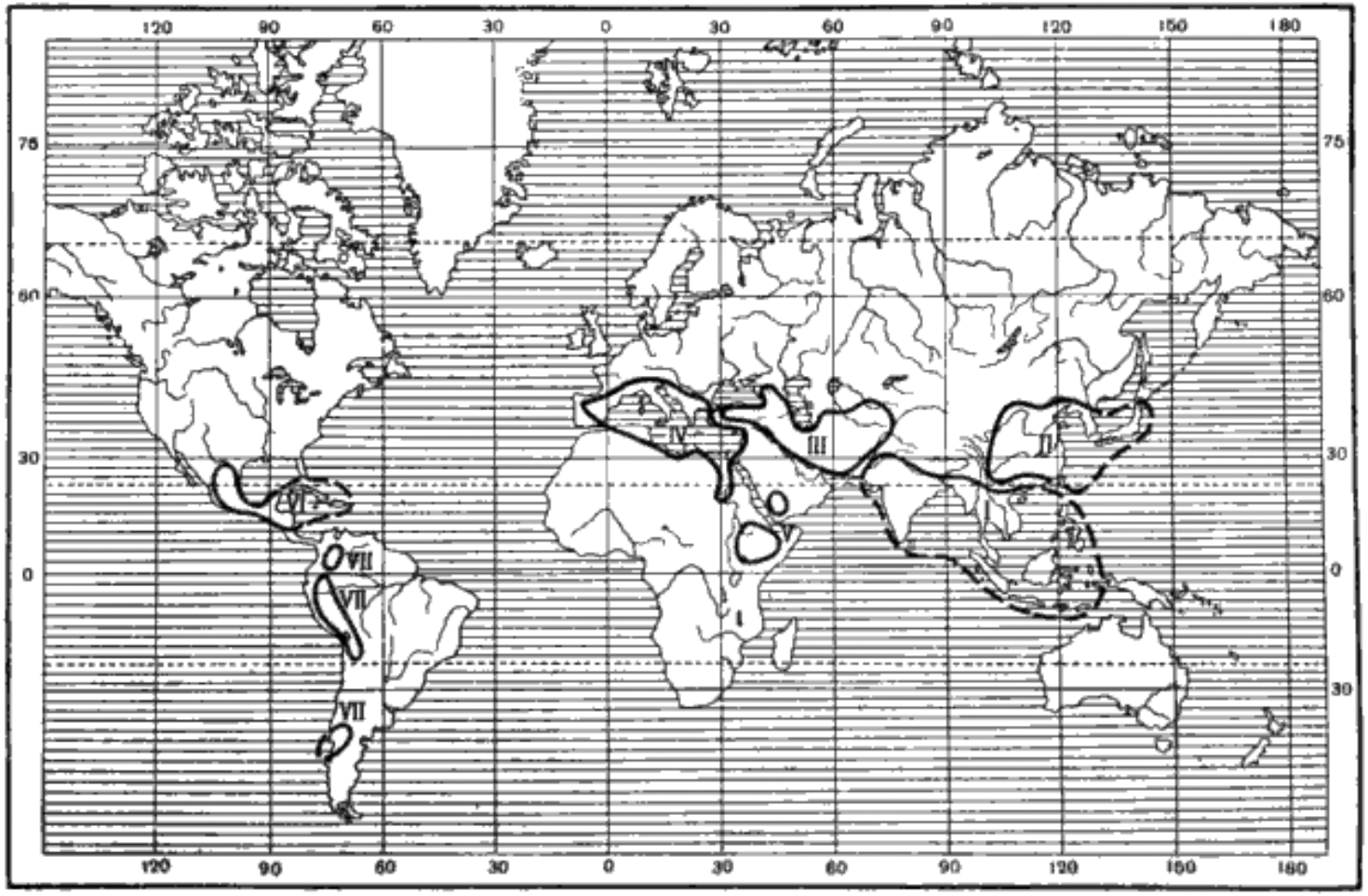
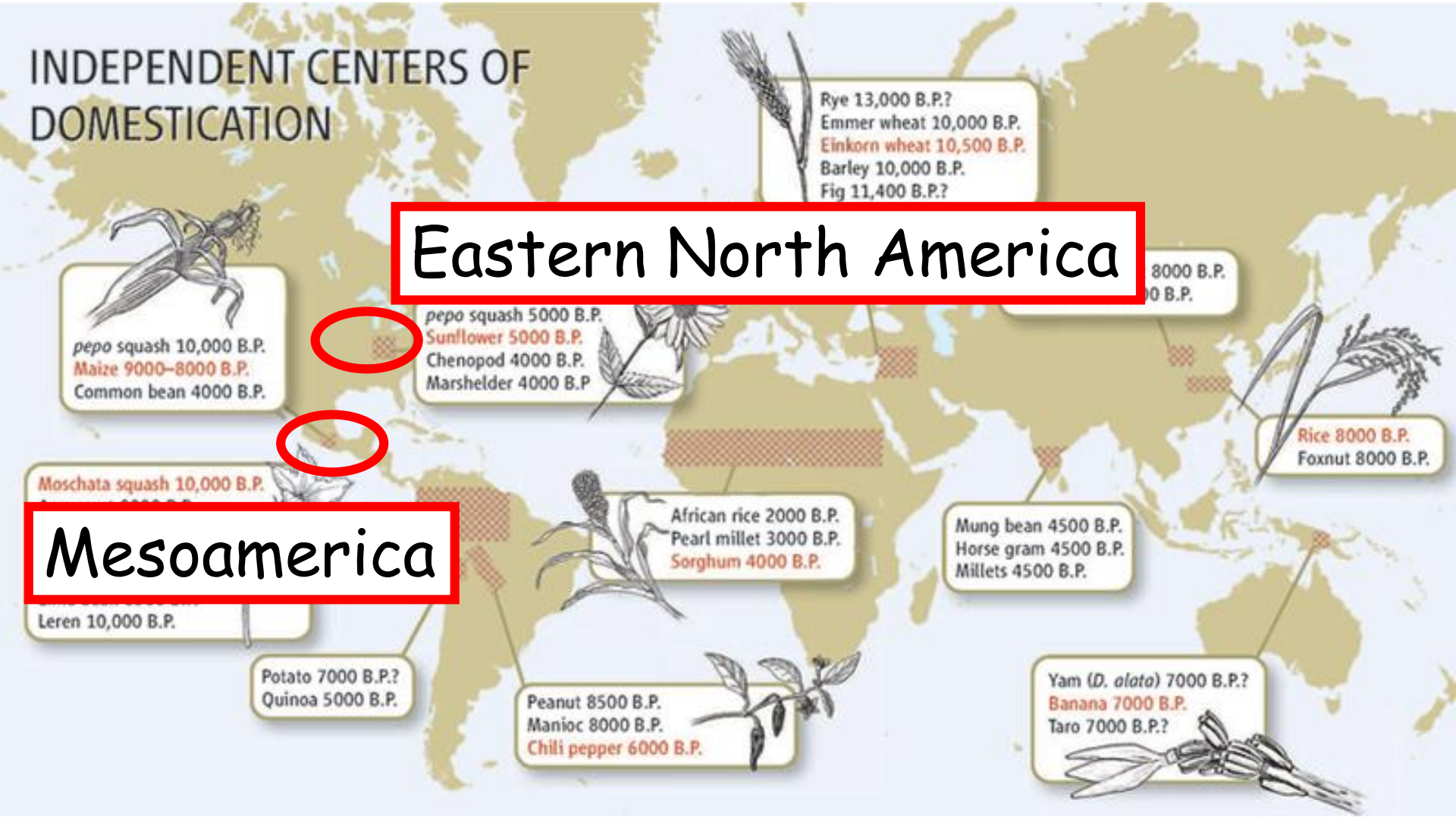


Fig. 1. Center of origin of cultivated plants. I. The tropical south-Asiatic center; II. the east-Asiatic center; III. the southwestern-Asiatic center; IV. the Mediterranean center; V. the Abyssinian center; VI. the Central American center; and VII. The Andean (South American) center.

Independent origins of domestication – 3 Harlan (1971); 6-8 in 1990s; at most 9 (Diamond 2002)

One independent origin of agriculture or two?

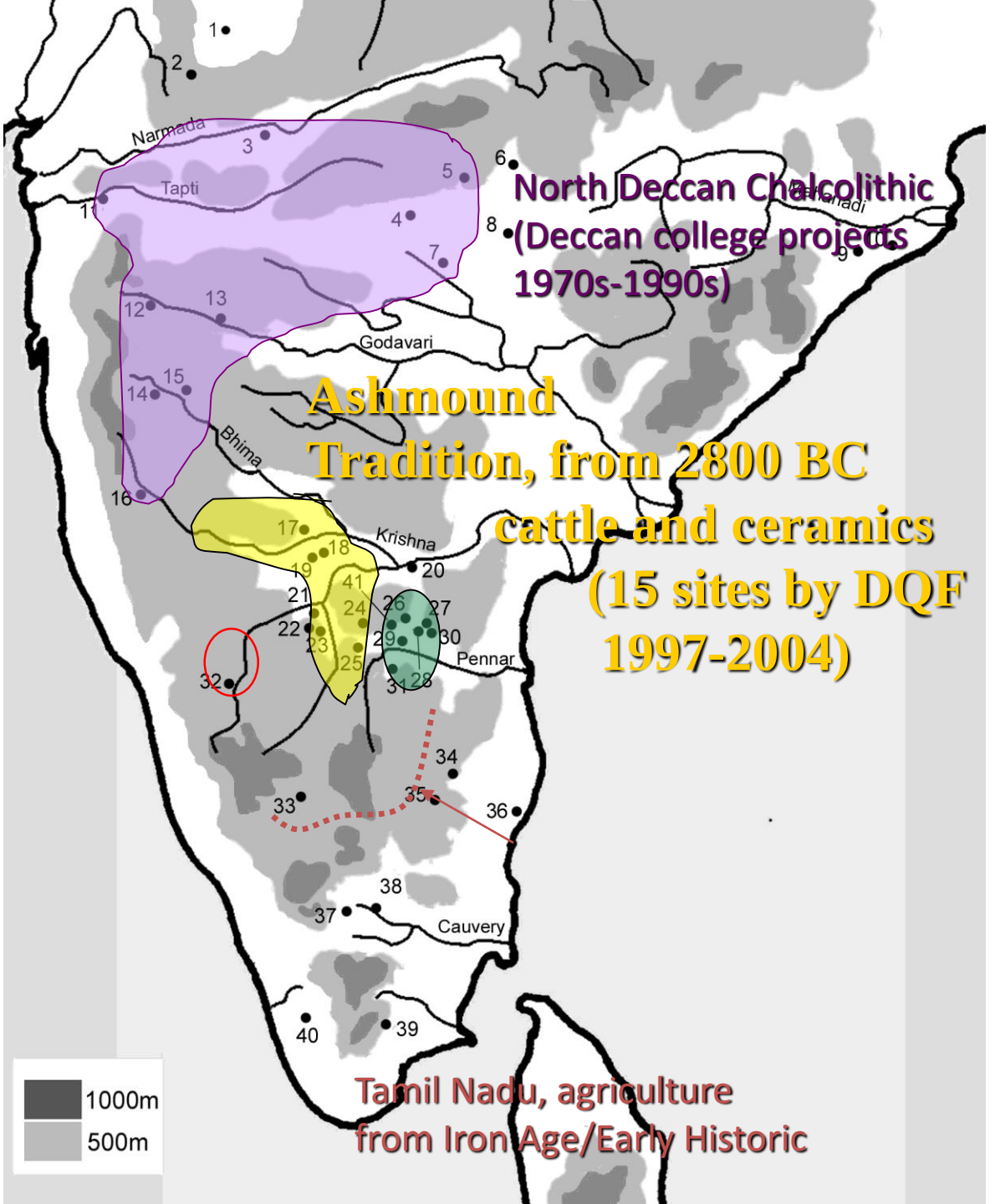


Balter 2007 Science

11 independent origins

Archaeobotany in *India* (from 1997)

flotation



Primary Cultivation: Staple foods in India

Recurrent food plants dominate seed assemblages:

Cultivation based on Peninsular domestication

Native South Indian suite

Setaria verticillata
Bristley foxtail millet
Brachiaria ramosa
Browntop millet
Macrotyloma uniflorum
horsegram
Vigna radiata
mungbean

Setaria verticillata

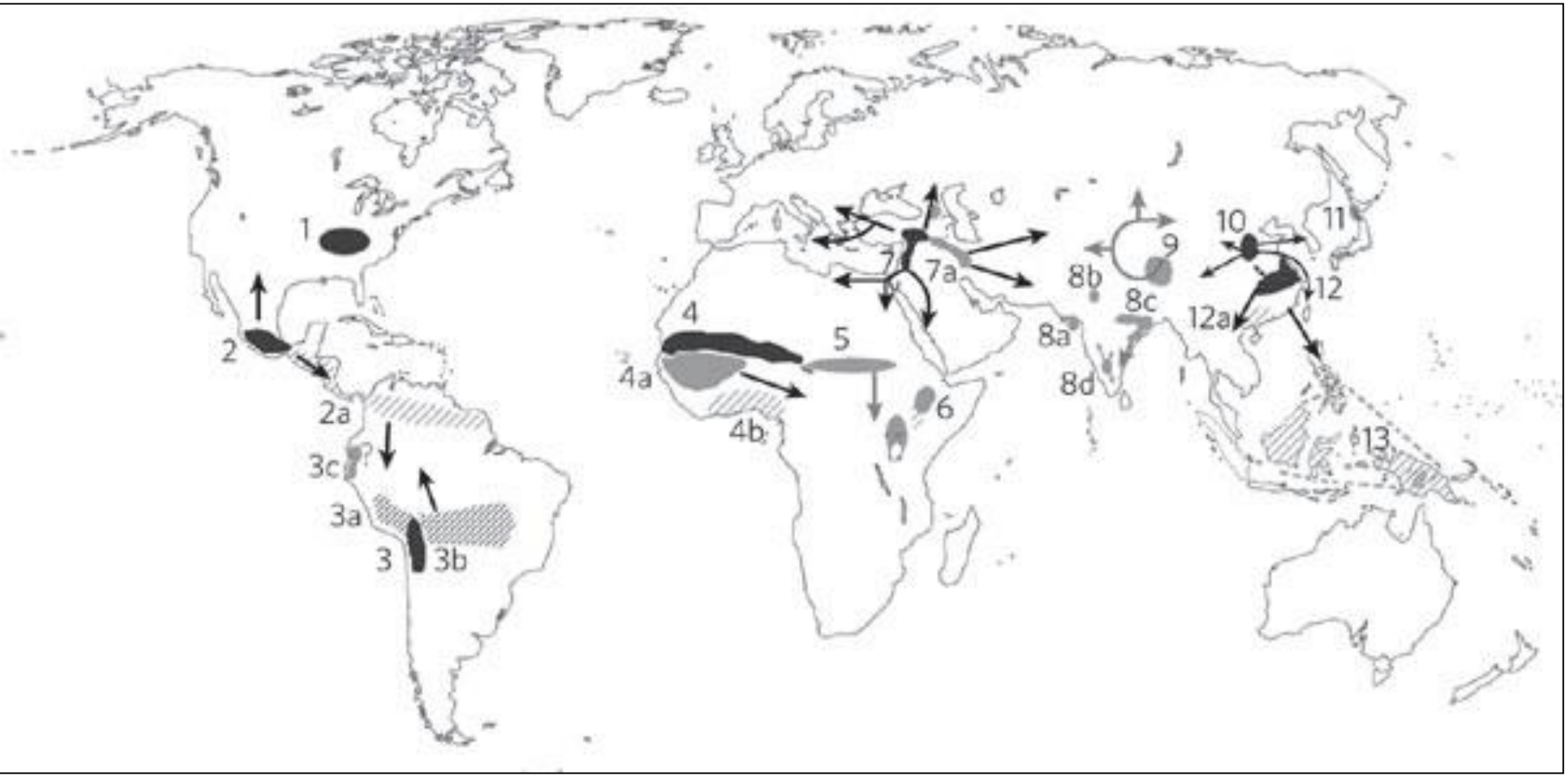
Macrotyloma

Vigna radiata

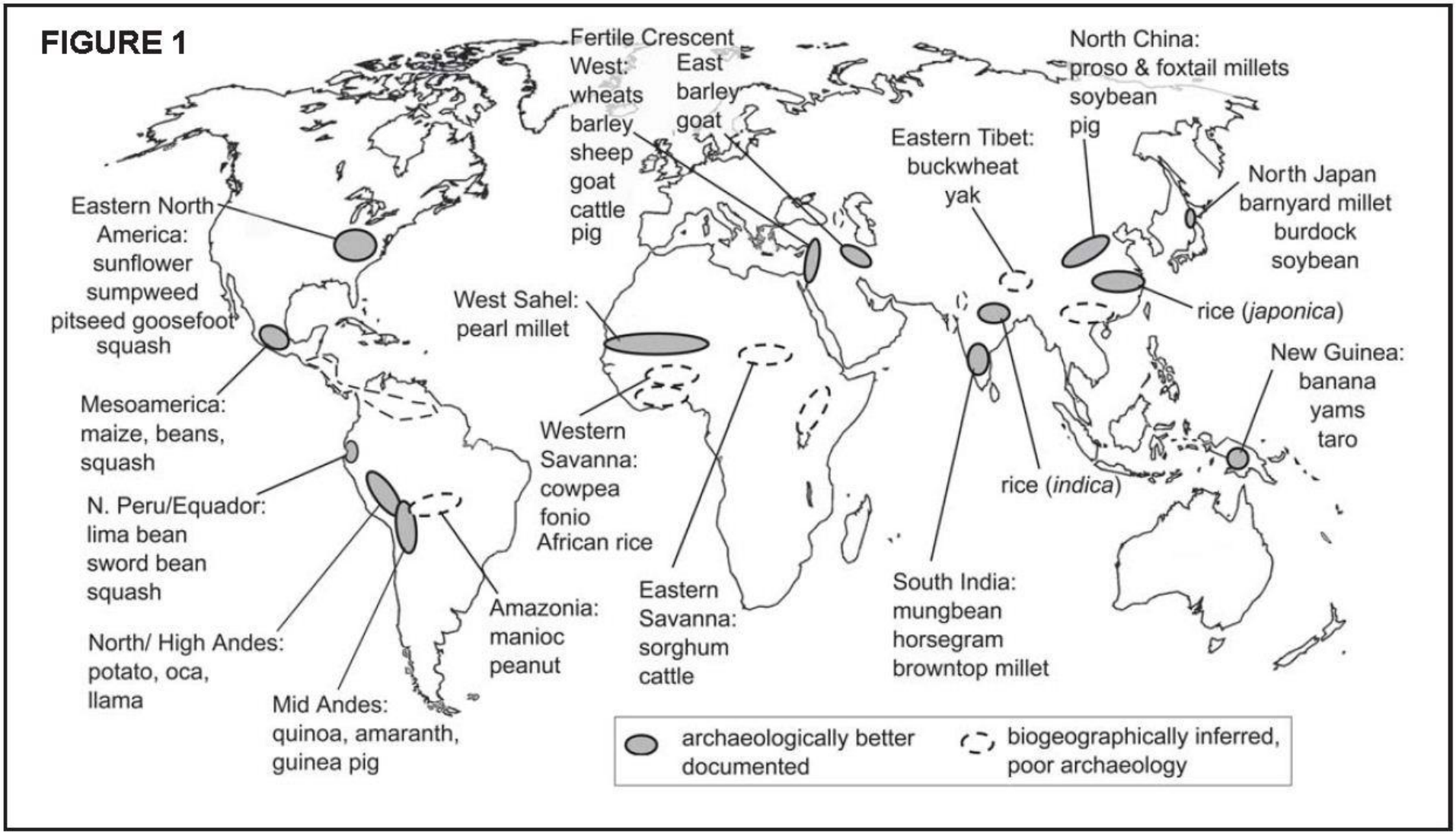
Brachiaria ramosa

Archaeological evidence for transition from foraging still elusive

13 Independent Origins of Agriculture



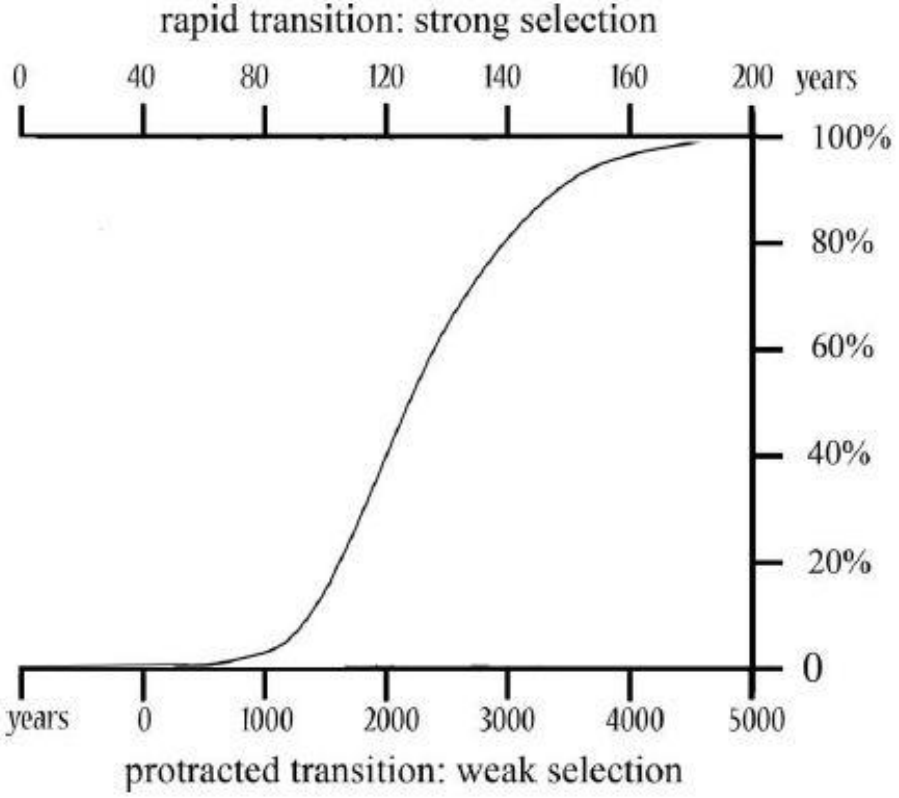
(Purugganan & Fuller, 2009, Nature)

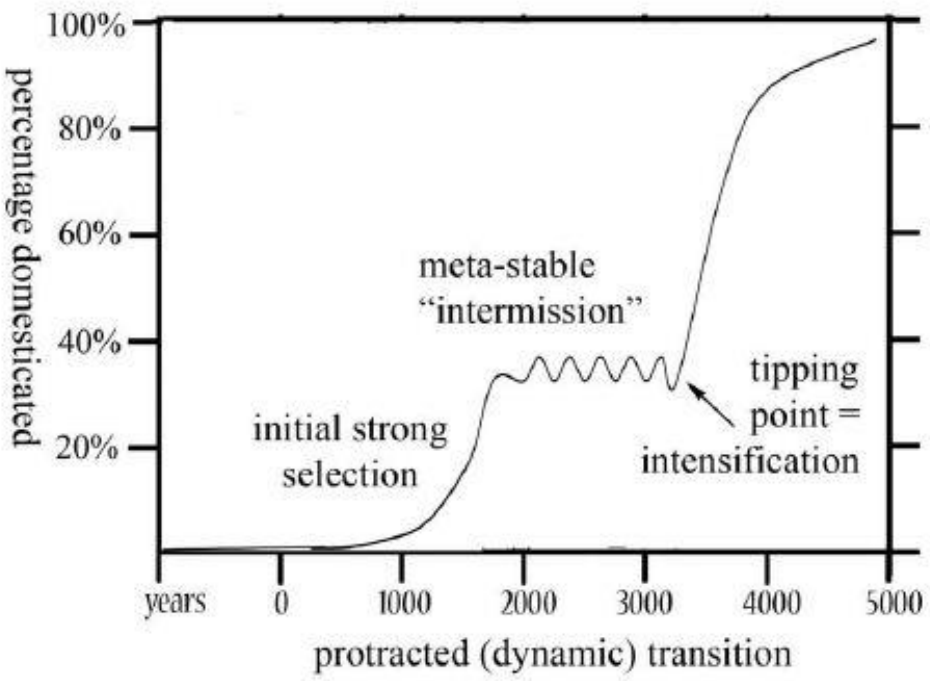


At least 13 (and up to 24) independent origins of agriculture
- possible additions in Central America, the Amazon, west Africa, India, & eastern Tibet – areas not yet subject to systematic archaeology and archaeobotany

Fuller (2010)

Revolution vs evolution

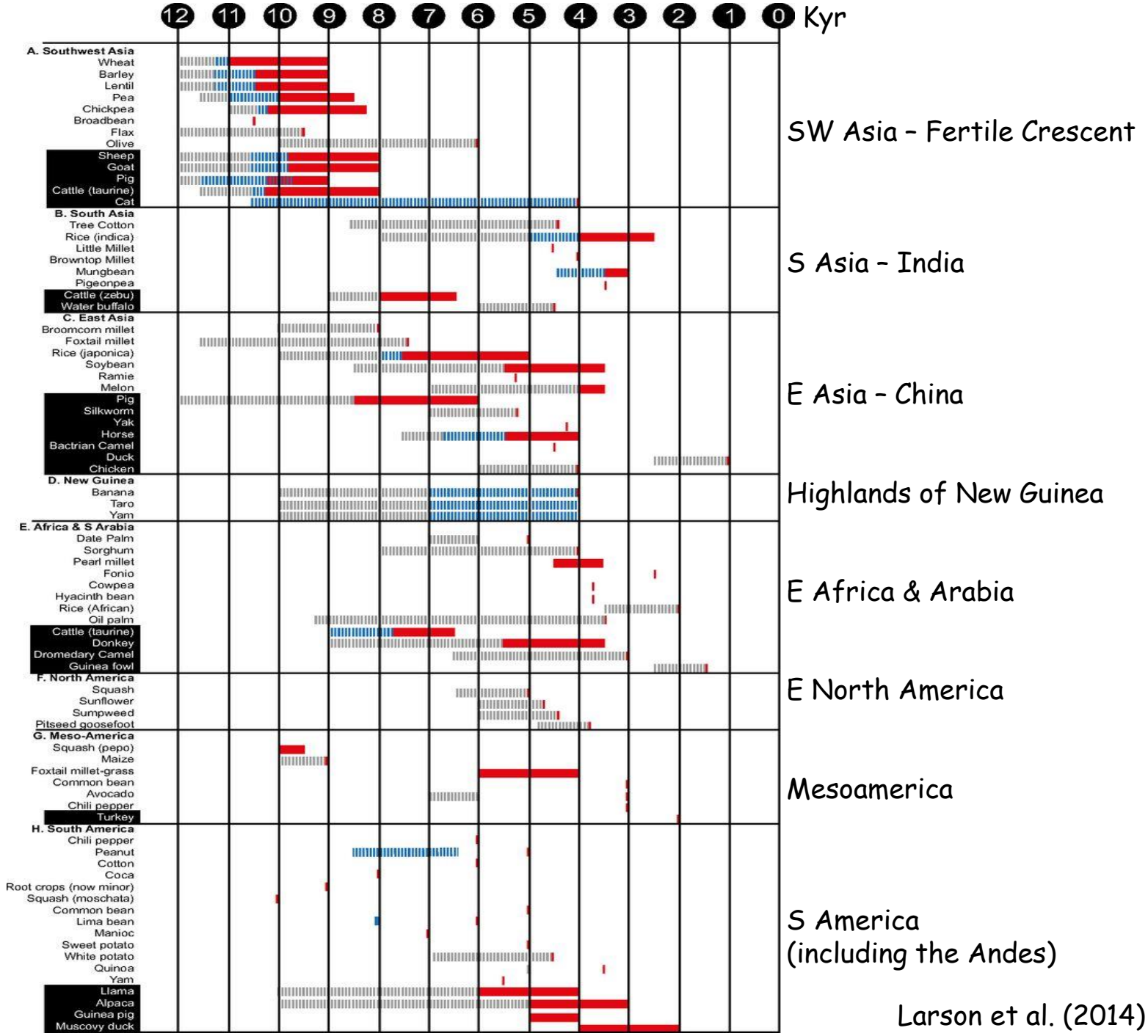




Fuller et al. (2010)

Revolution vs evolution

- Domestication was a protracted episode (2000-3000 years, ~100-150 human generation) of directional evolution in crops.
- No different from evolution by natural selection
- Subsequent evolution (varietal diversification) was more local. – transition to dependence on farming at least as slow
- This increased role of introgression in adapativeness

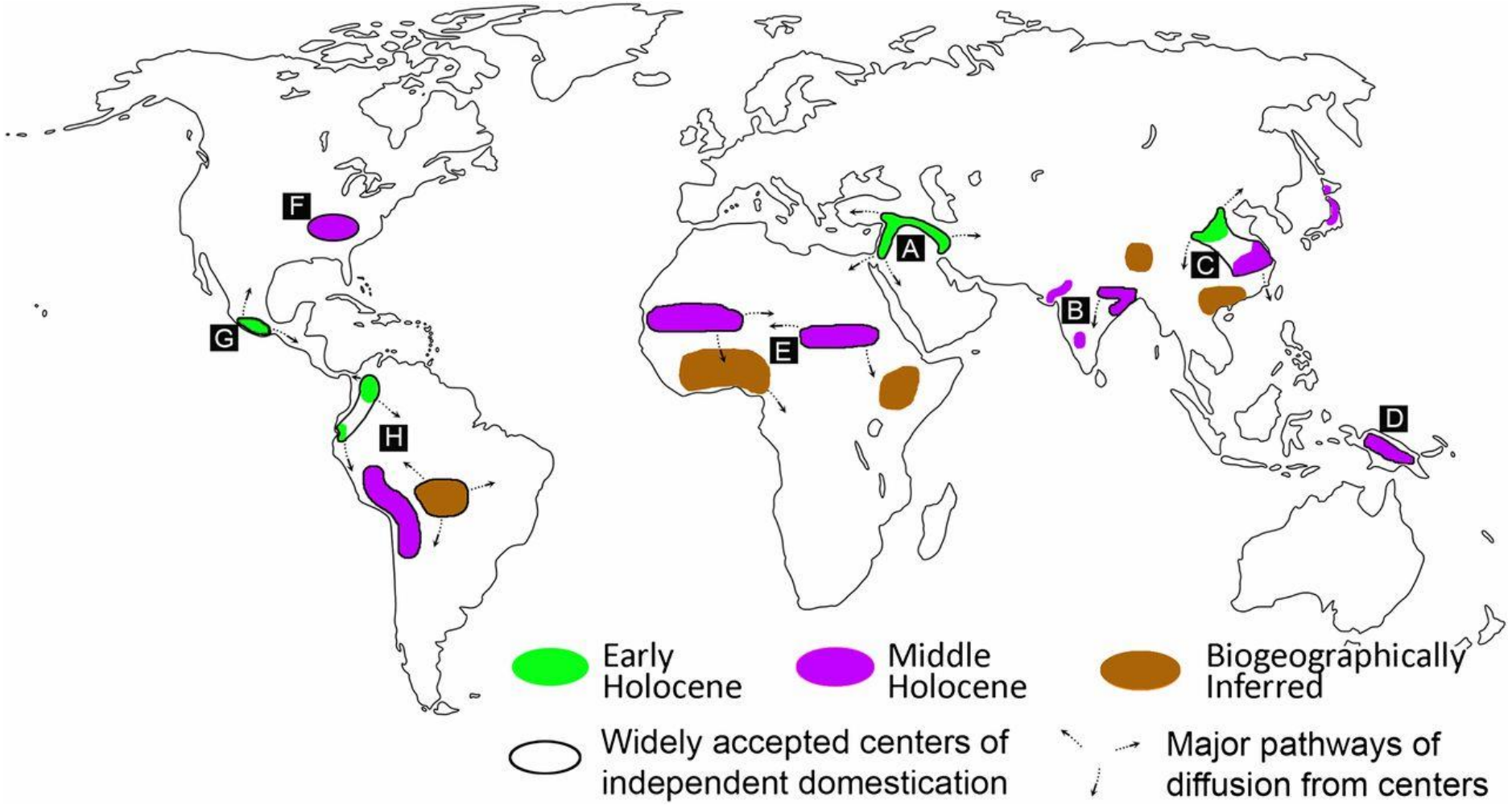


Grey:
Exploitation before domestication

Blue:
Pre-domestication cultivation

Red:
Period of phenotypic modification associated with domestication

Larson et al. (2014)

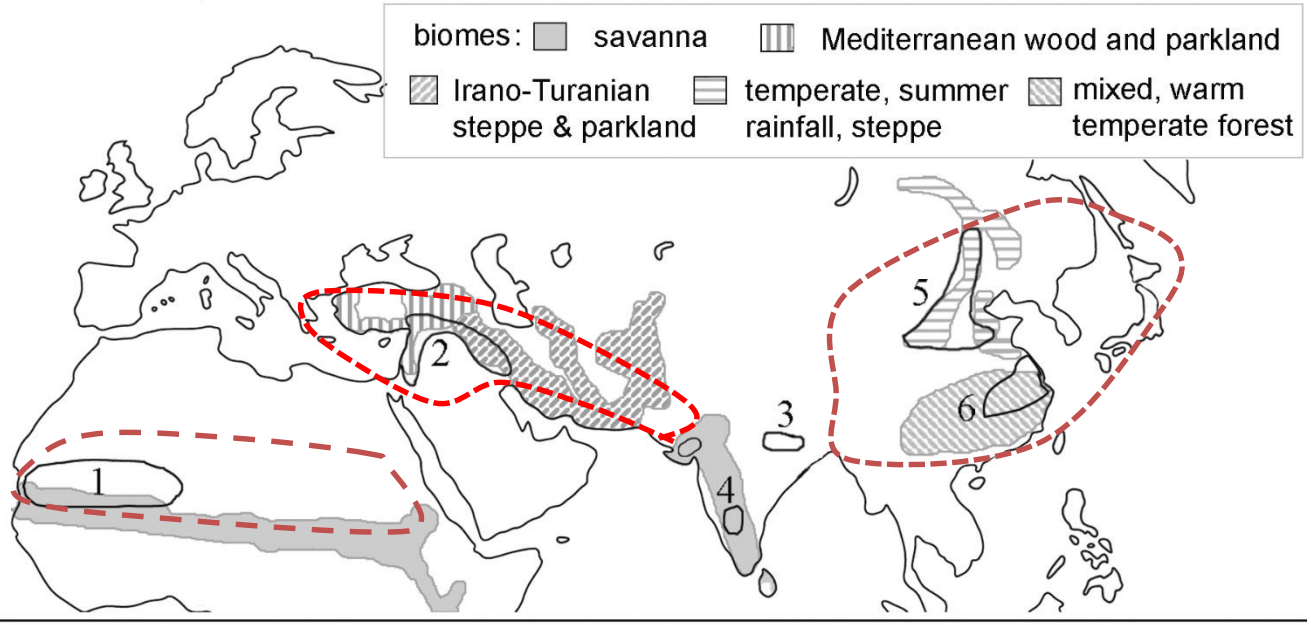


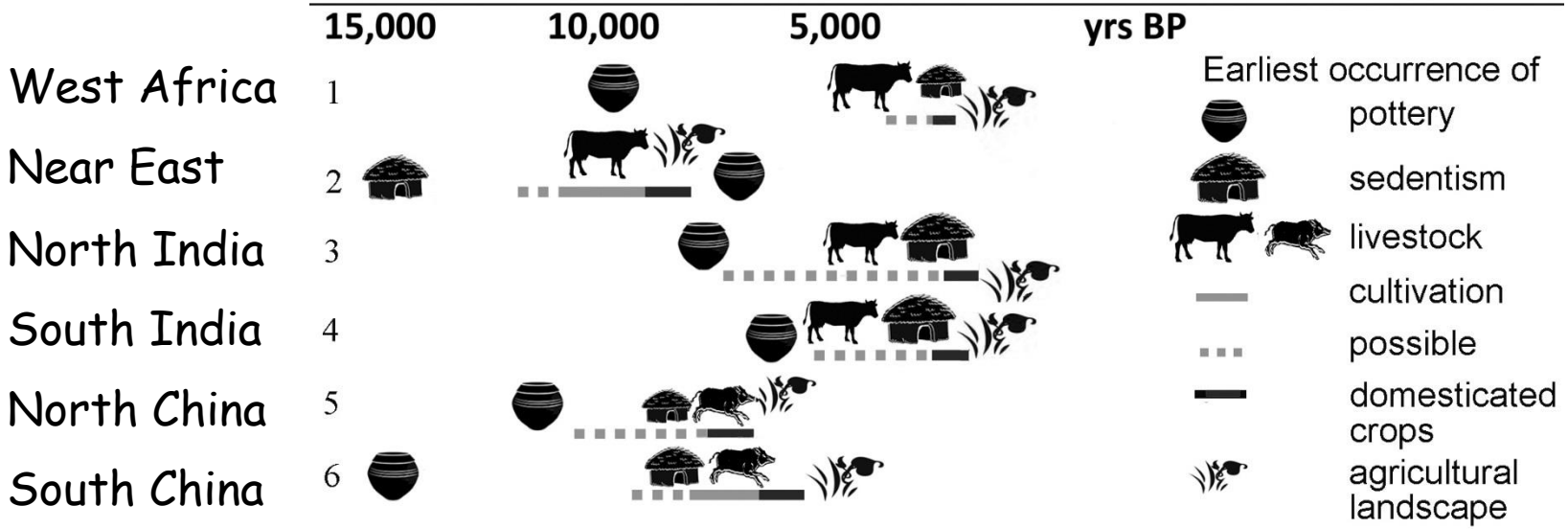
Larson et al. (2014)

Non-Synchronicity but similar rates? Same Cause? - Comparing Pathways to agriculture

Aceramic agriculture

Preagricultural pottery





Explanations & Theories

- Universal vs regional explanations

- Single cause vs multiple causes, and combinations of pre-conditions and contributing factors

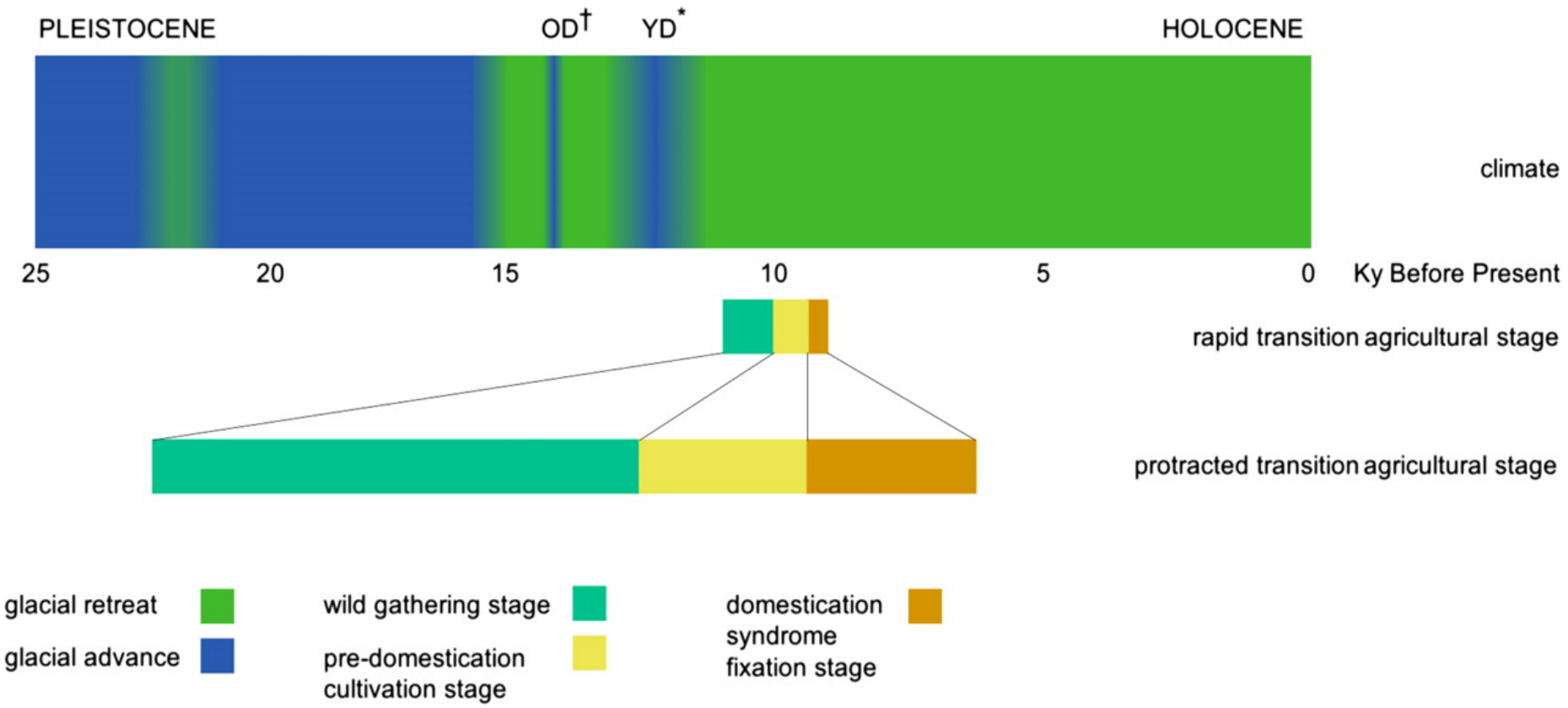
- Natural causes external to human societies vs cultural changes within hunter-gatherer societies. Did agriculture arise out of need or opportunity?

- Climate / environmental change as a trigger for domestication – the oasis theory

- Population pressure as a trigger for domestication

- Changes in social organization. Emergence of sedentary hunter-gatherers with social hierarchy and competitive feasting as an alternative cause

Climate change as a driver for the origins of agriculture?



OD = Older Dryas; YD = Younger Dryas = cool, dry climatic episodes between 10,000 and 15,000 BP

The implications of protracted gradual domestication transitions:

- Over the course of 3,000 years, social and environmental circumstances are likely to have changed

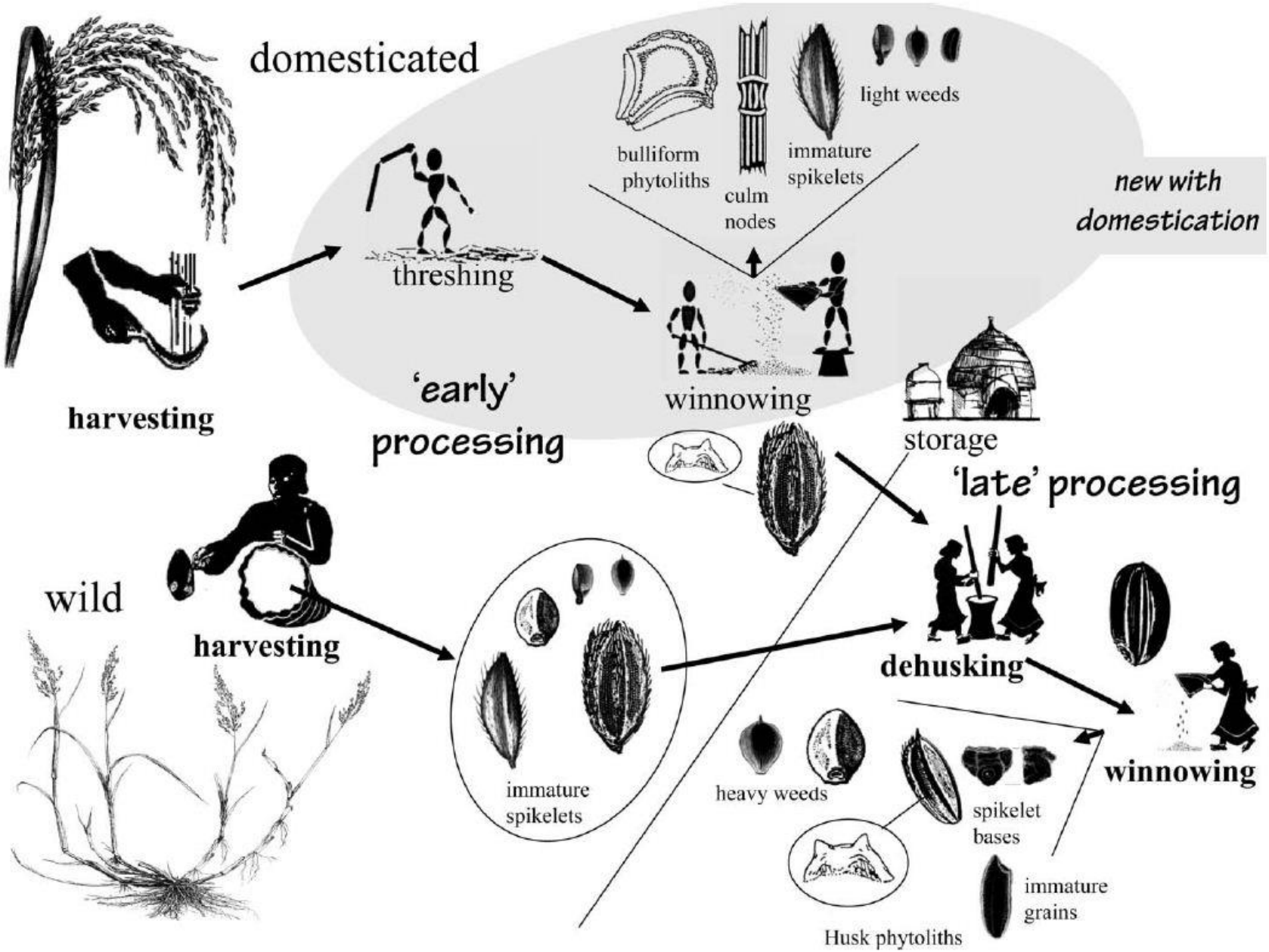
- Domestication would have involved extra work in e.g. soil preparation, threshing

- Need to dispense with the idea of an agricultural revolution

- Unlikely that transitions in different areas followed identical trajectories driven by common causes

- There may be little that is predictable about the relationship between early plant cultivation and animal husbandry – animals only important in some areas.

- Cultivation, animal management and labour demands were entangled in different ways



Fuller et al. (2010)

Common Factors Contributing to the Emergence of Agriculture across Different Regions

- Familiarity with wild plants and animals - agriculture as the endpoint of a long period of use of the wild ancestors of domesticated crops and animals

- Harvesting, processing and storage technologies

- Sedentism – hunter-gatherers living in relatively large permanent settlements through most of the year

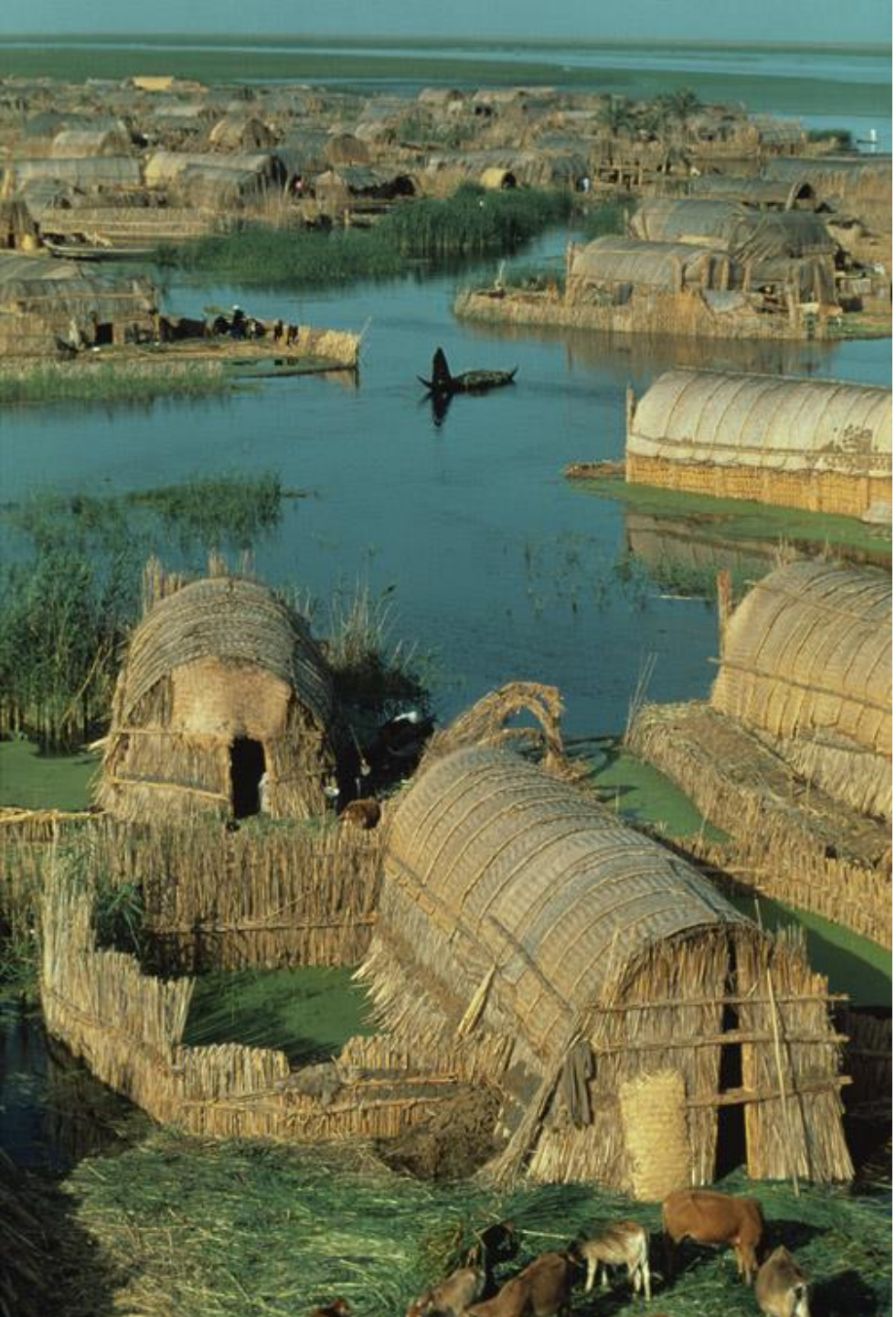
- High resource diversity & the importance of proximity to aquatic environments – farming arose as a supplement in areas where groups already have a diverse and rich diet

- Changes in climate & vegetation and steepening of the boundaries between rich habitats near to water and surrounding harsher and more marginal hunter-gatherer habitats

- Population density – pushing societies to increase food production

- Competition, ownership & social stratification – sedentary communities were larger and more complex than earlier hunter-gatherer societies, encouraging harvest surplus for ceremonial & celebratory occasions as well as lending in time of need

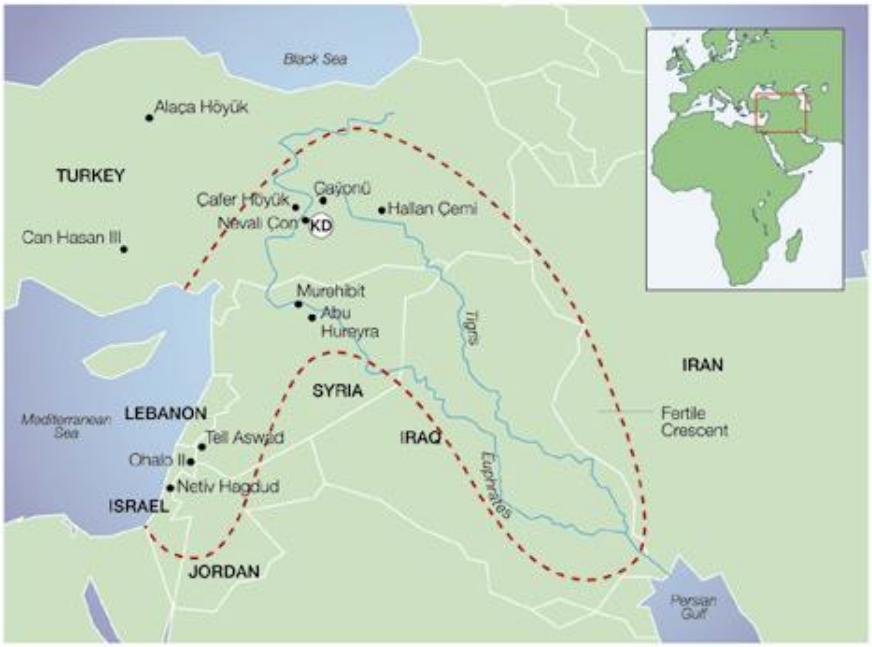
- Good potential domesticates – biogeographic luck



High resource diversity & the importance of aquatic environments

The Fertile Crescent

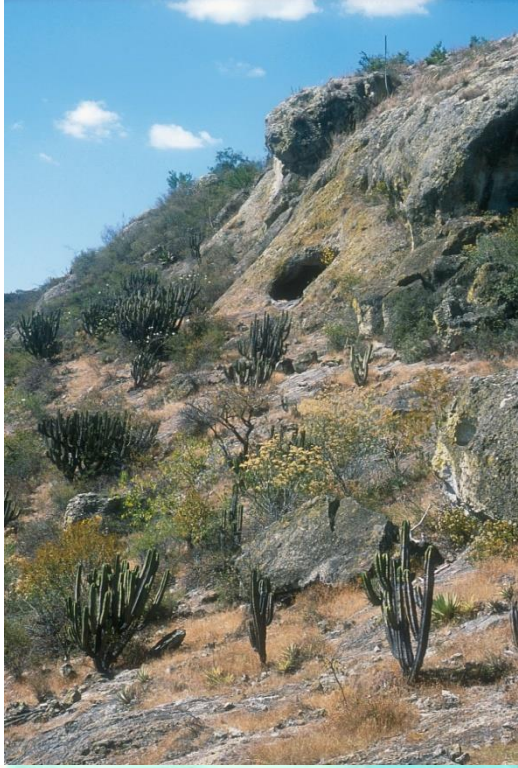
Tigris & Euphrates Rivers
The Marsh Arabs



High resource diversity & the importance of aquatic environments

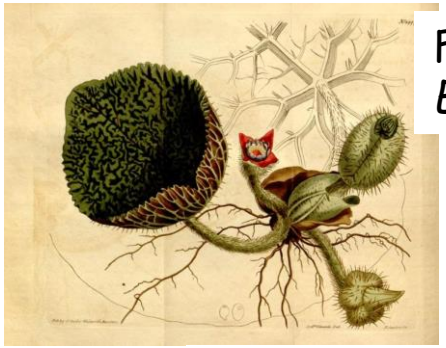
Mesoamerica

The Tehuacan Valley



Lower Yangtze, China

High resource diversity & the importance of aquatic environments



Fox nut
Euryale ferox

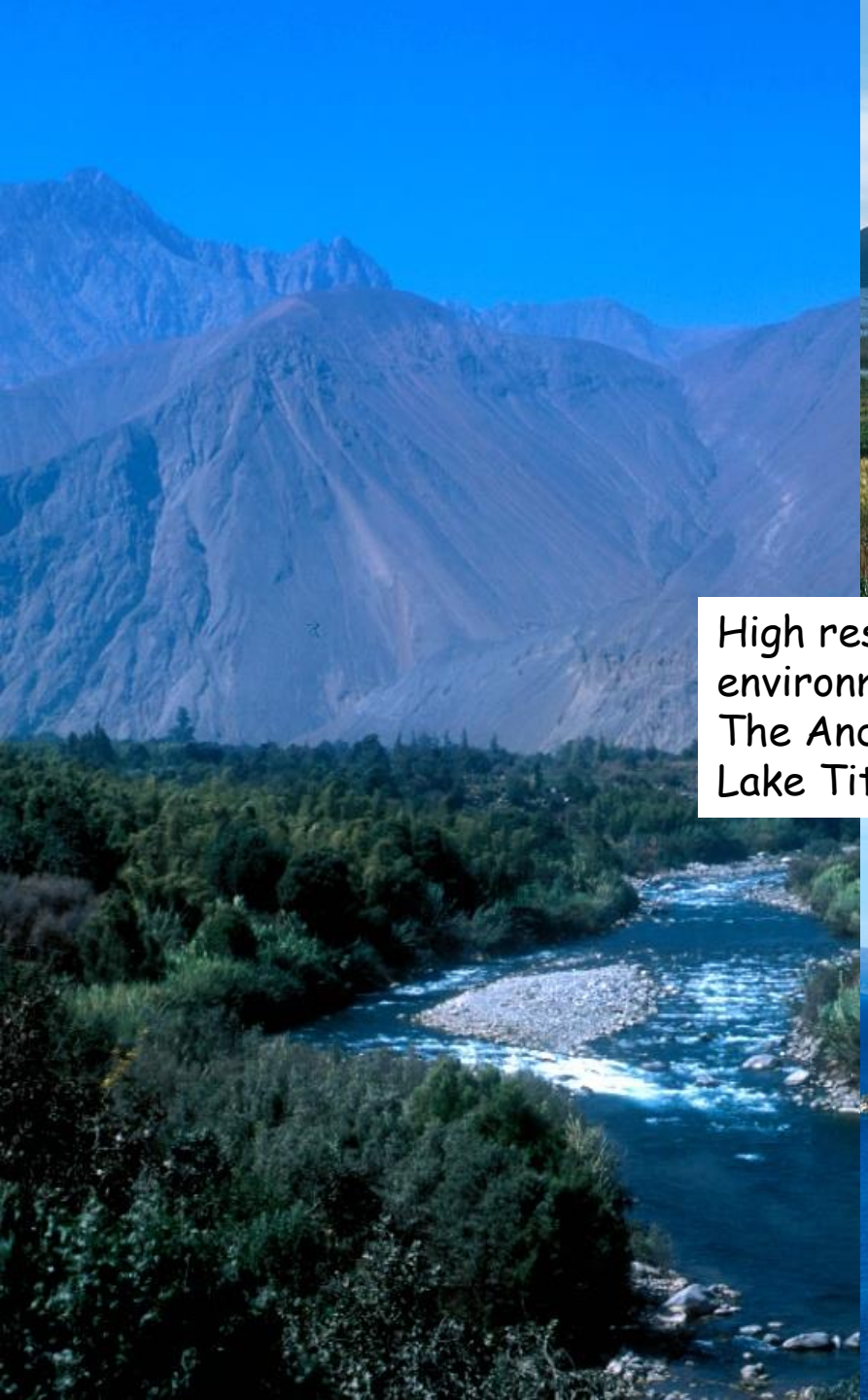
Acorns
Quercus spp

Water chestnut
Trapa natans

rice

& fish & water fowl

Fuller & Qin (2010)



High resource diversity & the importance of aquatic environments
The Andes – lush valleys in the coastal desert
Lake Titicaca & Lake Junin in the Andes

Common Factors Contributing to the Emergence of Agriculture across Different Regions

- Familiarity with wild plants and animals - agriculture as the endpoint of a long period of use of the wild ancestors of domesticated crops and animals

- Harvesting, processing and storage technologies

- Sedentism – hunter-gatherers living in relatively large permanent settlements through most of the year

- High resource diversity & the importance of proximity to aquatic environments – farming arose as a supplement in areas where groups already have a diverse and rich diet

- Changes in climate & vegetation and steepening of the boundaries between rich habitats near to water and surrounding harsher and more marginal hunter-gatherer habitats

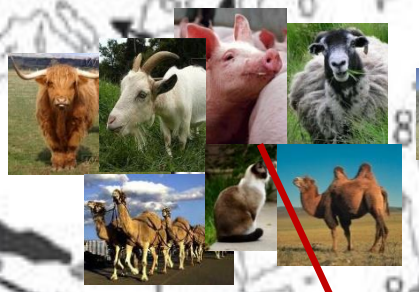
- Population density – pushing societies to increase food production

- Competition, ownership & social stratification – sedentary communities were larger and more complex than earlier hunter-gatherer societies, encouraging harvest surplus for ceremonial & celebratory occasions as well as lending in time of need

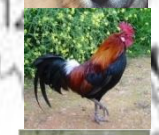
- Good potential domesticates – biogeographic luck

Biogeographic luck and independent Centres of Agriculture & Livestock Domestication

Lapland
- Reindeer



Himalaya
- Yak



SE Asia
- Dog
- Chicken
- Water buffalo

Mesoamerica
- Turkey

Andes
- Llama
- Alpacca
- Guinea pig

NE Africa
- Donkey

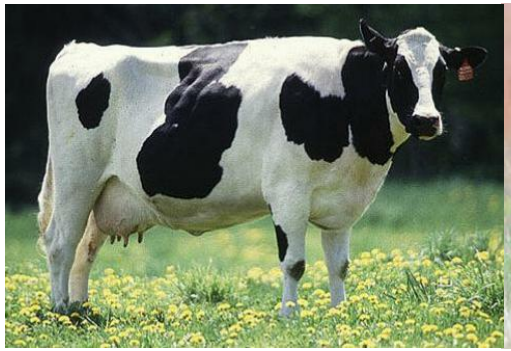
Fertile Crescent / Near East
- Cattle
- Sheep
- Pig
- Goat
- Horse
- Dromedary camel
- Bactrian camel
- Cat

Biogeographic luck - Why were so few wild species domesticated?

Comparisons of domesticated species (left) and their never-domesticated close relatives


Reindeer Elk


Horse Zebra



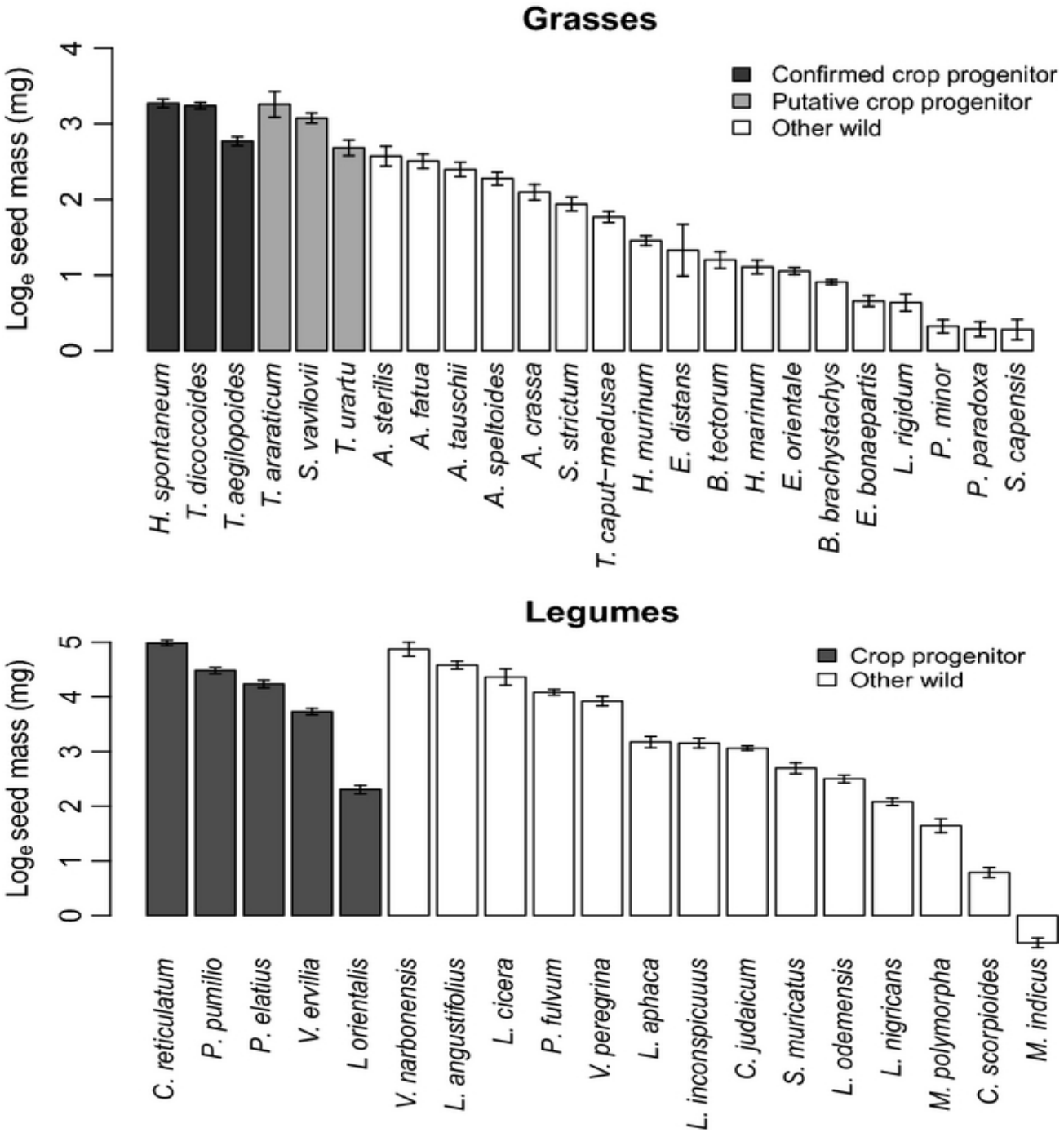

Cow American buffalo


Sheep North American Bighorn Sheep


Goat Rocky Mountain goat

Biogeographic Luck
World Distribution of the 56 Heaviest-Seeded Grasses

Area		Number of species
West Asia, Europe, North Africa		33
	Mediterranean zone	32
	England	1
East Asia		6
Sub-Saharan Africa		4
Americas		11
	North America	4
	Mesoamerica	5
	South America	2
Northern Australia		2
Total		56



Preece et al (2015)

The Causes of Domestication - Conclusions

Slow, complex, a protracted and entangled process

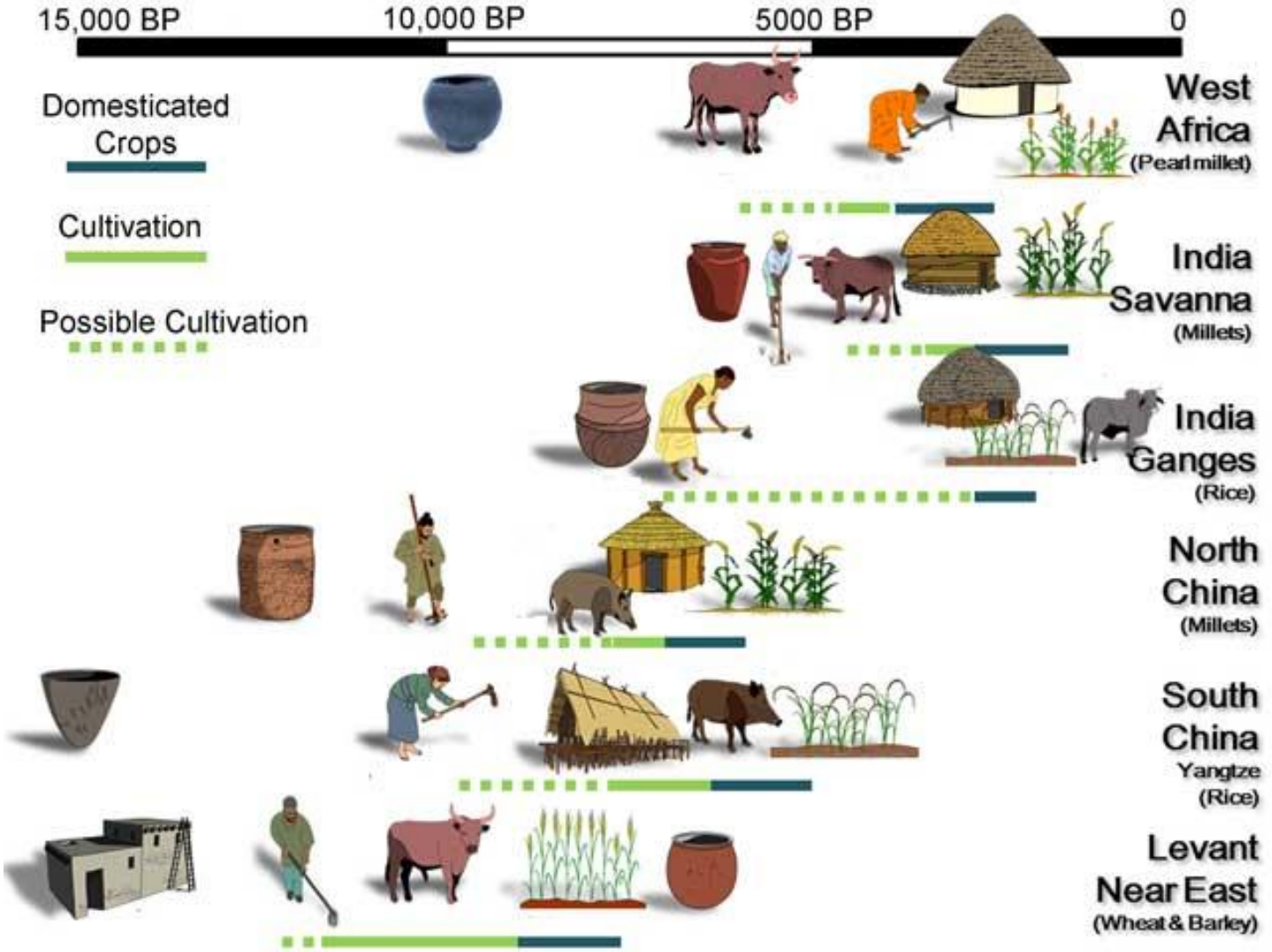
Conditions prompting agricultural origins probably involved both need and opportunity as contributory factors.

In all cases we see: hunter-gatherer communities living in lakeside or river valley habitats so rich in wild food resources that they could establish larger sedentary communities where early experiments in cultivation and domestication would have been possible and where well-watered soils ensured reliable harvests.

External triggers of climate change that accentuated the boundaries between these rich areas and surrounding hinterlands and pressures of growing human population are likely to have been important spurs prompting investigation and experimentation in ways to increase food resources, while intrinsic factors related to new opportunities for social integration in newly sedentary societies could also have played a key role.

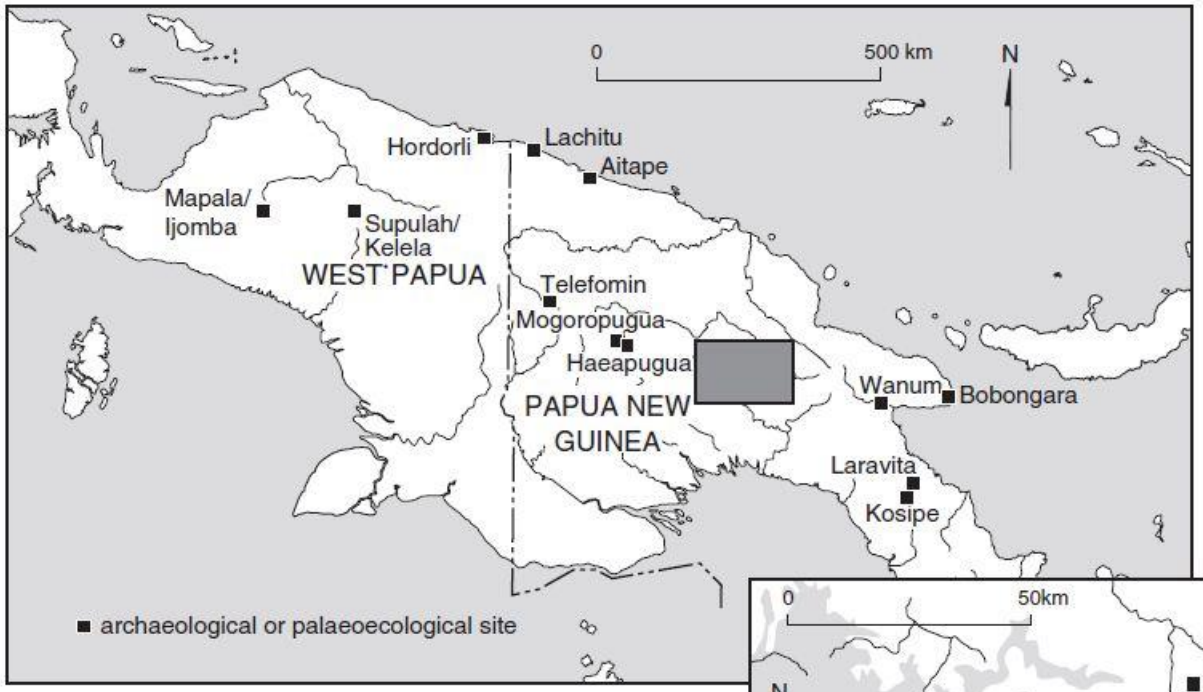
Once started, process was autocatalytic – a one-way ticket

Comparing Pathways to Agriculture - ComPAg Project



Fuller et al. (2015)

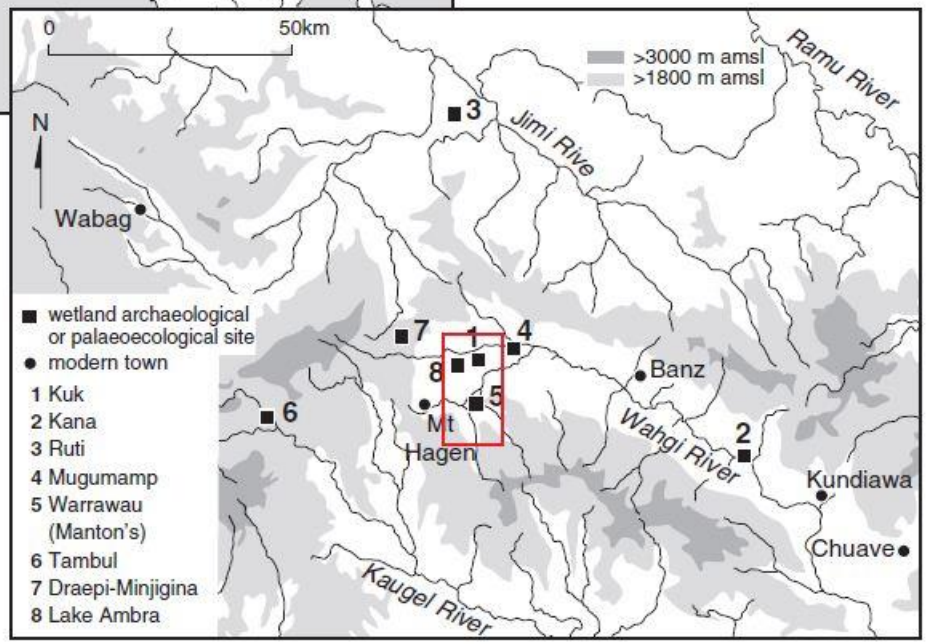
Consequences of Domestication



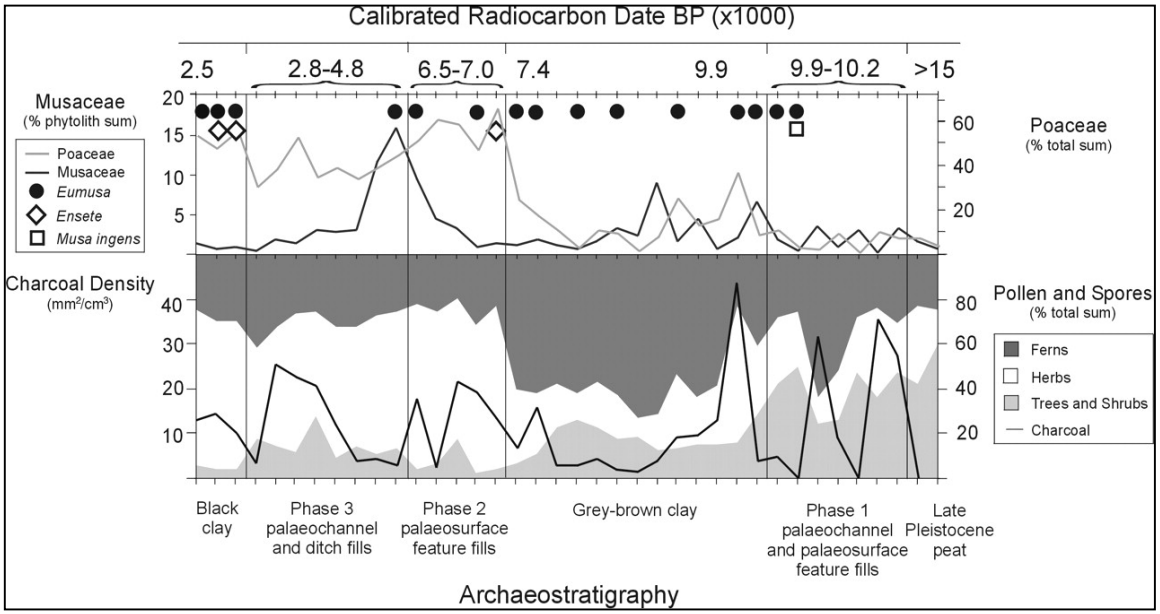
Highlands of Papua New Guinea

Kuk Swamp in the River Wahgi Valley

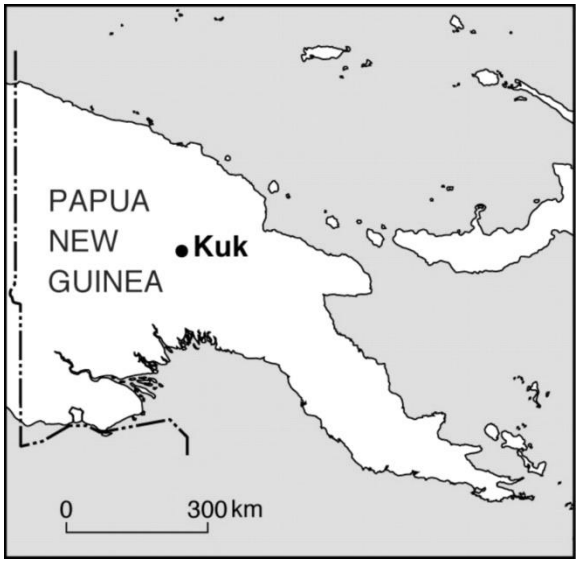
b)



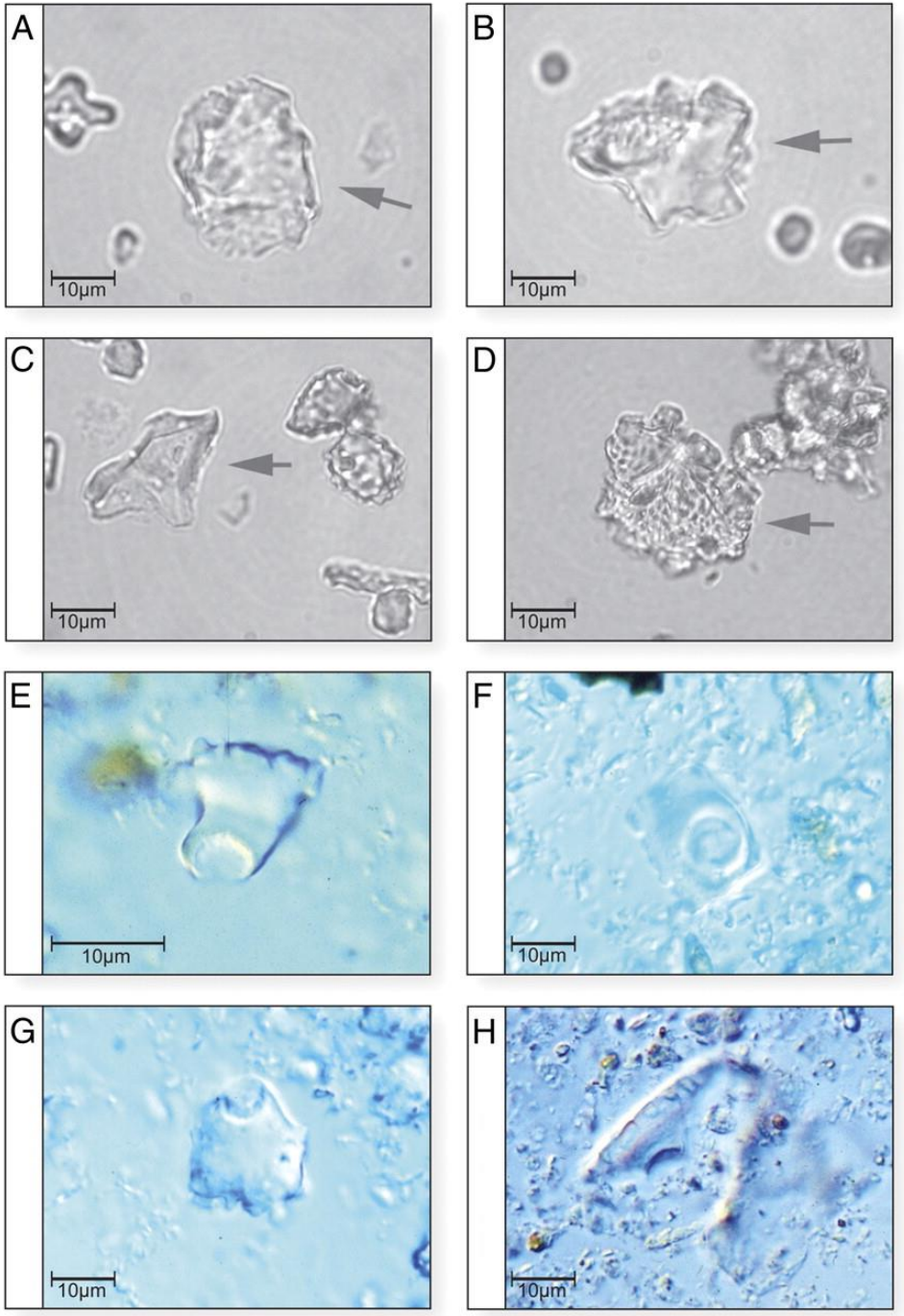
Kuk Swamp


Calibrated Radiocarbon Date BP (x1000)
2.5
2.8-4.8
6.5-7.0
7.4
9.9
9.9-10.2
>15
Musaceae
(% phytolith sum)
Poaceae
Musaceae
Eumusa
Ensete
Musa ingens
Poaceae
(% total sum)
Charcoal Density
(mm²/cm³)
Pollen and Spores
(% total sum)
Ferns
Herbs
Trees and Shrubs
Charcoal
Black clay
Phase 3 palaeochannel and ditch fills
Phase 2 palaeosurface feature fills
Grey-brown clay
Phase 1 palaeochannel and palaeosurface feature fills
Late Pleistocene peat
Archaeostratigraphy

Banana domestication



Leaf phytoliths matching *M. acuminata* subsp. *banksii* from archaeological excavations at Kuk Swamp, demonstrate that bananas were in cultivation in New Guinea 6,950-6,440 BP.



Perrier et al. 2011

- Taro
- *Colocasia esculenta*
- Araceae
- Edible starchy corm

New Guinea

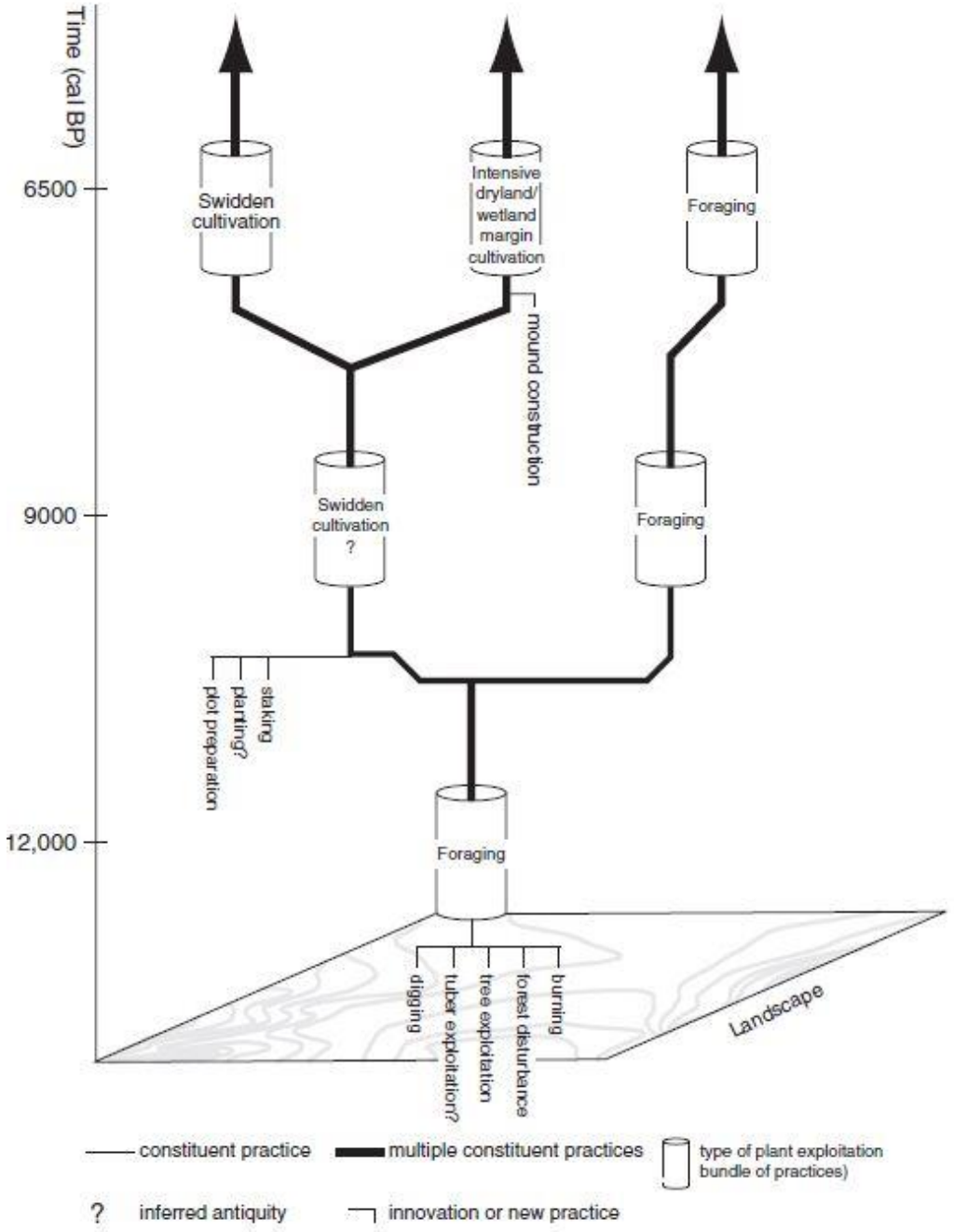
Lack of obvious protein crops – dependent on hunting meat

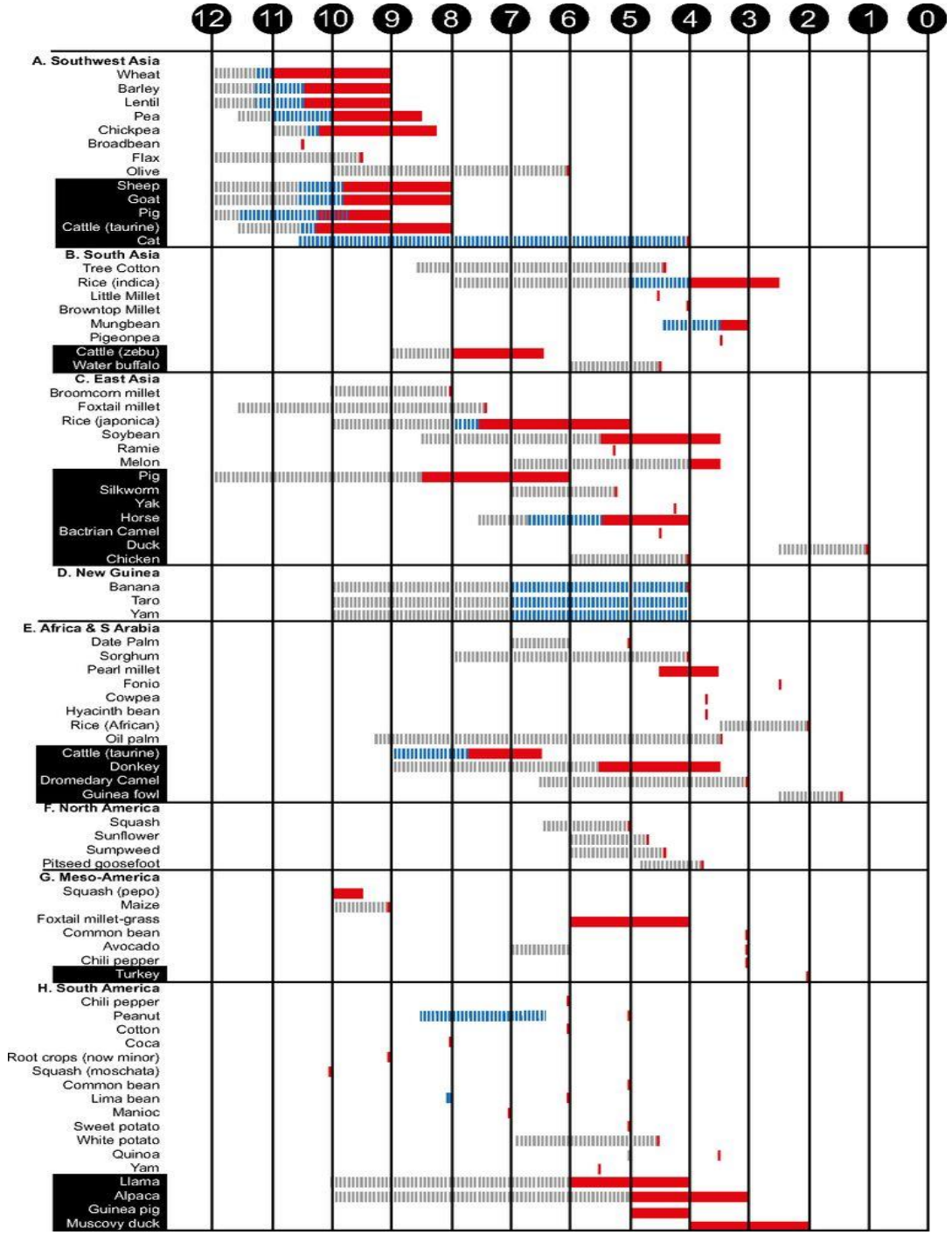
Lack of animal domesticates
No draught animals for power
Agriculture entirely dependent on human muscle power
No labour surpluses

Parallel foraging and farming over last 7,000 years

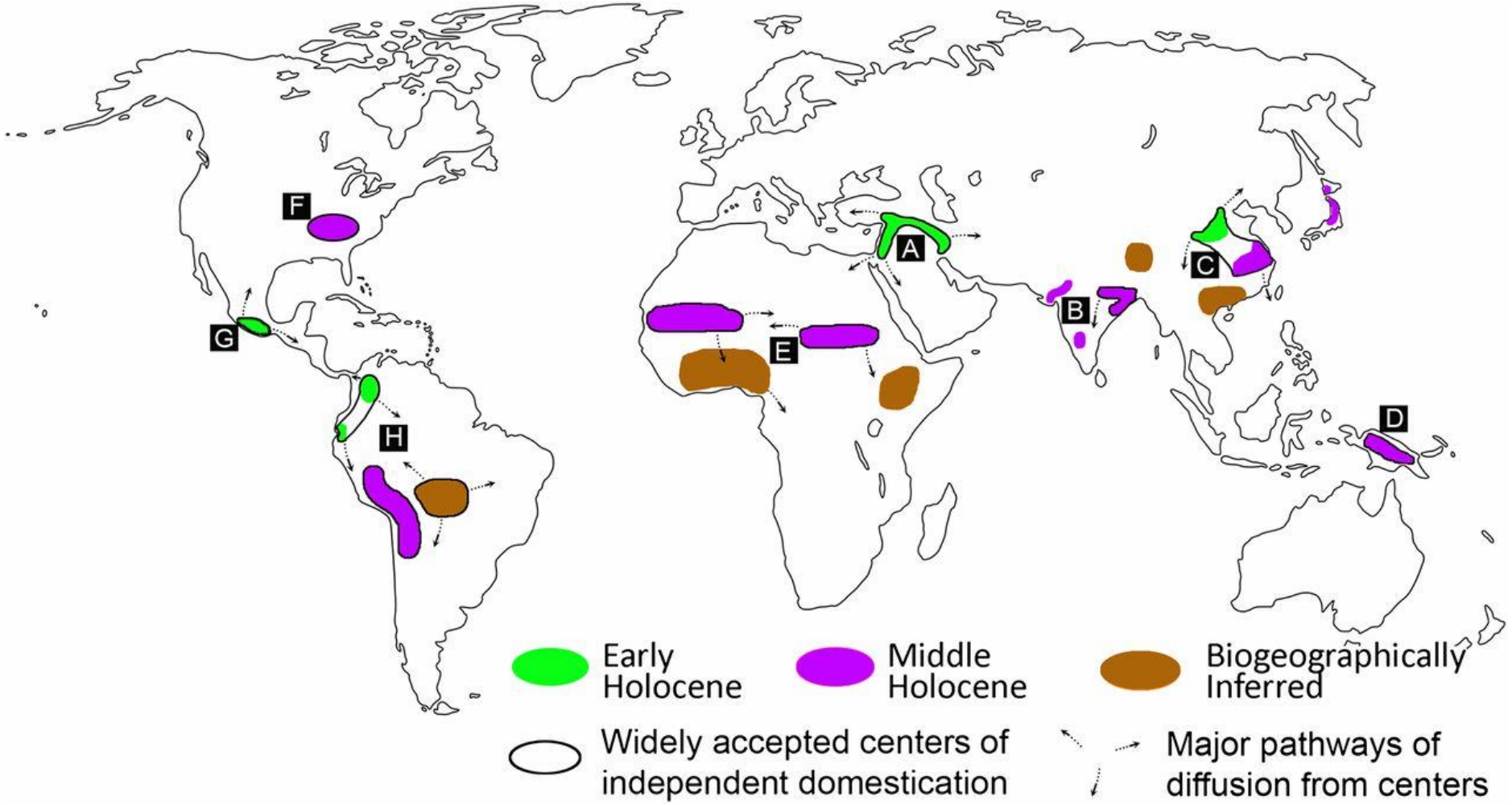
Never devloped advanced technologies – still using stone tools in 1960s
No metal

Farming did not lead to rapid development of more advanced civilisations

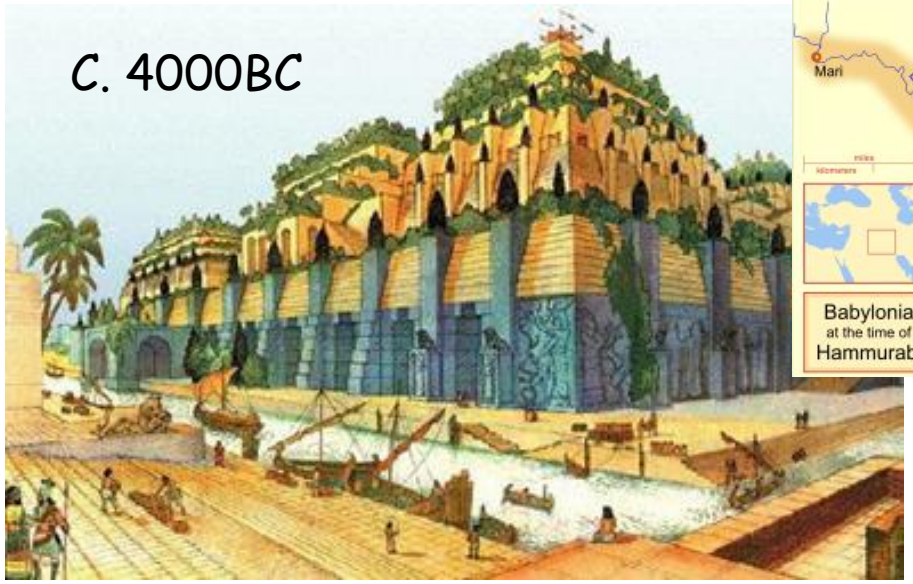


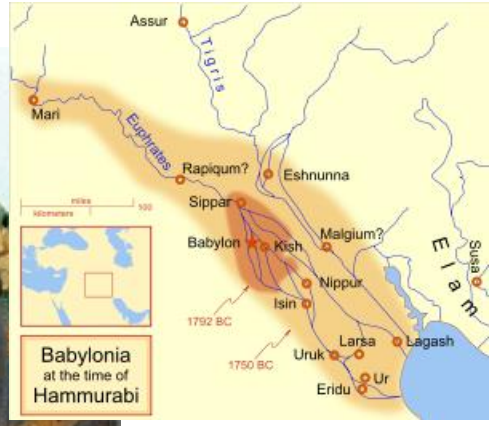


Larson et al. (2014)



Larson et al. (2014)

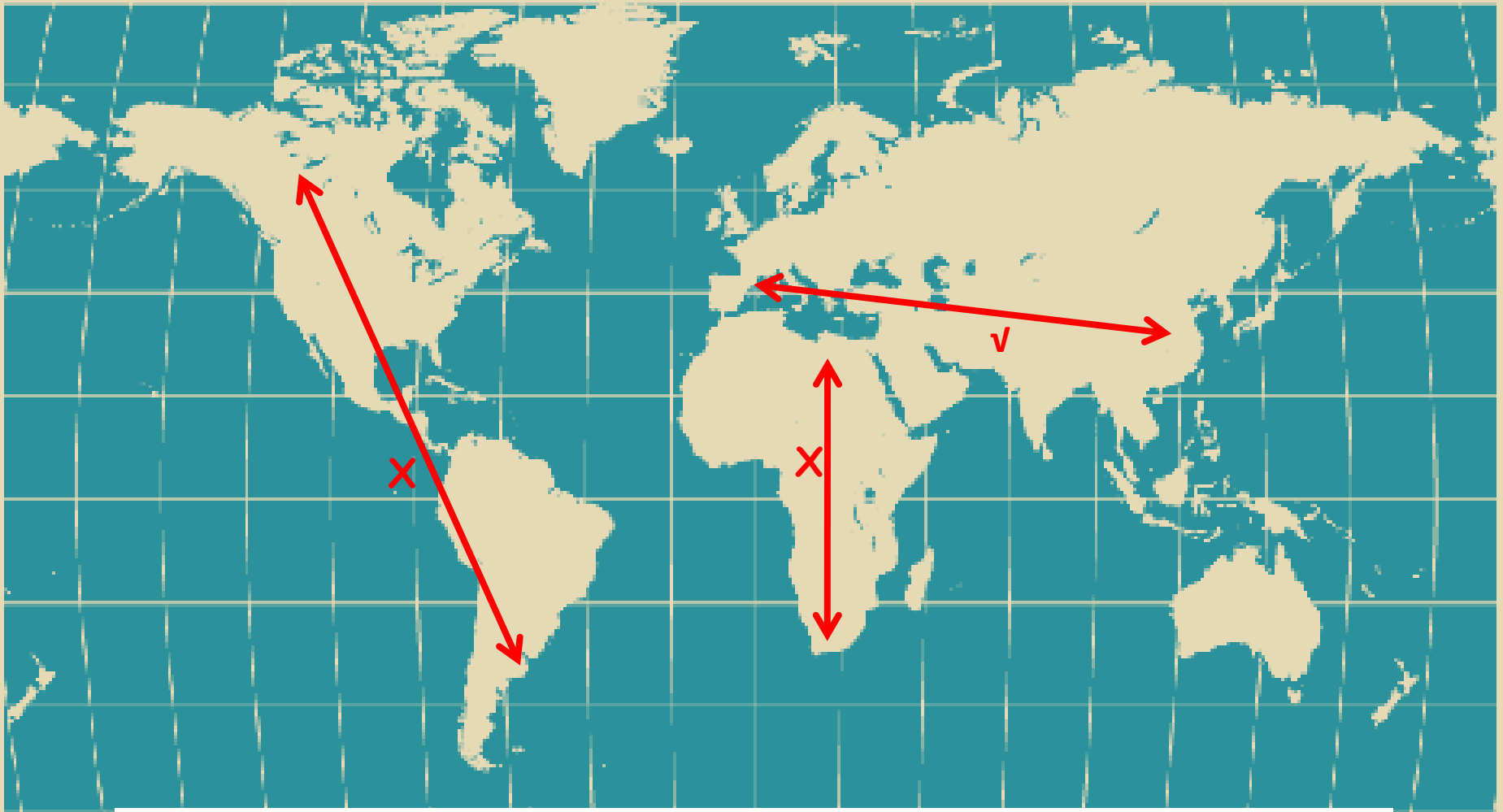




- Inca empire in the Andes
- Mayans in Mesoamerica
- Babylon in the fertile Crescent

Consequences of Domestication I

- Investment in infrastructure, architecture and more permanent material culture
- Crop processing technology and labour requirements
- Larger community sizes
- Specialization of roles such as craft production
- Land ownership and the development of differential wealth accumulation
- Stratification in societies
- Population growth



east-west vs north-south axes

- Mexican wheels and writing never reached the Andes and vice versa, llamas ad potatoes never made it to Mexico.

Consequences of Domestication II – Impacts on Human Societies

- Differences in biogeographic 'luck' and continental orientation / isolation became one of the main reasons why Eurasian peoples conquered Native American peoples, rather than the other way round.

- From c. 10,500 BP, food production was accompanied by human population explosion that has continued to the present day. Food could be produced much more densely and productively.

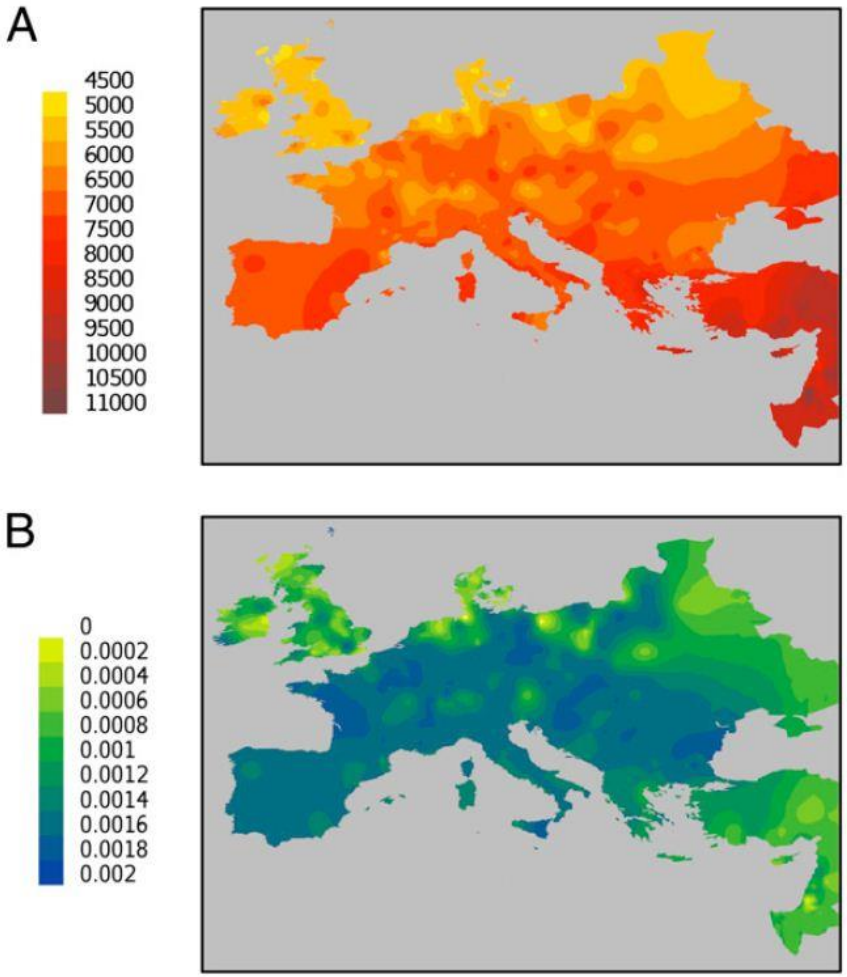
- Food production also led to an explosion of technology, full time craftspeople and inventors, kings, beaurocrats, and soldiers prompting social stratification, political centralization and standing armies.

- All these advantages are what enabled farmers to eventually displace hunter-gatherers.

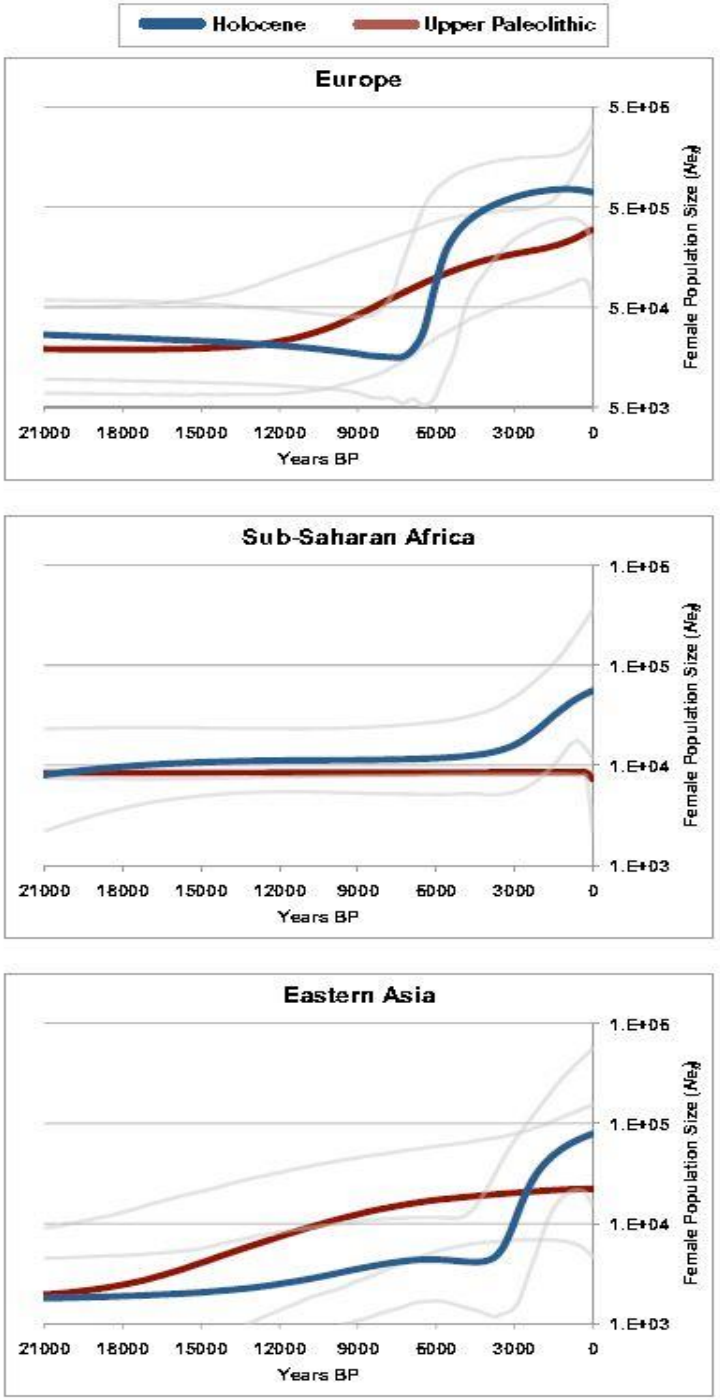
World Population Expansion

Time BP	Millions of people
12,000	1-10
2,000	170-400
220 (1780)	800-1,100
150 (1860)	1,100-1,400
70 (1940)	2,400-2,600
0 (2010)	6,900
+40 (2050)	9,100

Rapid global demographic expansions after the origins of agriculture: 5-fold increase in population growth



Gignoux et al (2011)



Consequences of Domestication III
The Evolution of Epidemic Infectious Diseases

The main killers of human beings since the advent of agriculture have been acute, highly infectious, epidemic diseases.

'Crowd diseases' could not have existed before the origins of agriculture, because they can sustain themselves only in large dense populations that did not exist before agriculture.

Many diseases evolved from similar epidemic diseases of domestic animals:

- measles and tuberculosis arose from diseases of cattle
- influenza from pigs and chickens / ducks
- smallpox from either cattle or camels.

Crowd diseases became agents of conquest, because unexposed populations lacked any immunity. All but one of our large domestic mammals were Eurasian species, evolution of crowd diseases was concentrated in Eurasia, and these diseases became some of the most important agents by which Eurasian colonists expanding overseas killed indigenous peoples of the Americas, Australia, the Pacific and southern Africa.

Consequences of Domestication IV

Demographic, technological, political and military advantages – the first farmers got the first metal tools, writing, empires and professional armies.

Many of our deadliest infectious diseases
- require dense human populations to thrive
- often involved switches from domesticated livestock to humans.

These advantages - *guns, germs and steel* - the agents of conquest

The history of the last 10,000 years consists of tales of hunter-gatherer societies being driven out, infected, conquered or exterminated by farming societies in every area of the world suitable for farming.

Languages - human expansions and replacements, mean that 88% of all humans alive today speak a language belonging to one of a mere seven language families confined in the early Holocene to two small areas of Eurasia, the Fertile Crescent and parts of China.

Through that head start, the inhabitants of these two areas spread their languages and genes over much of the rest of the world.

Collision at Cajamarca 1532

Pizarro seizing the Inca of Peru, painting by Millais, 1845

<u>Pizarro</u>
Spanish conquistador

62 horse soldiers
106 foot soldiers
Unfamiliar mountainous terrain
Nearest Spanish reinforcements 1500km away in Panama

Horses
Guns
Swords & armour (metal)
European maritime technology
Writing

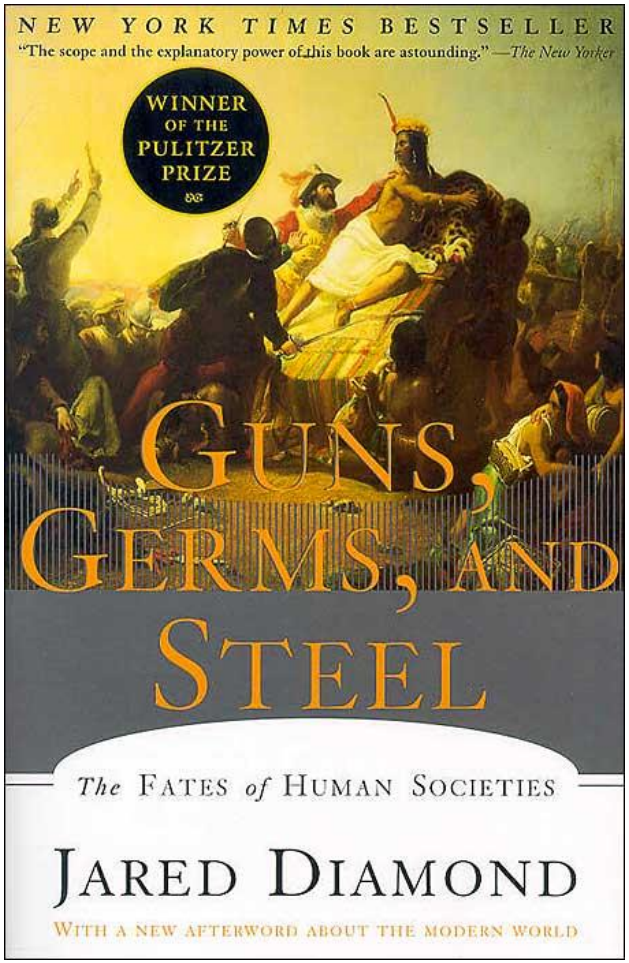
vs

<u>Atahuallpa</u>
Inca Emperor, monarch of the largest and most advanced state in the New World

80,000 Inca warriers
In the heart of his own empire of millions of subjects

No horses, no guns, no swords, just clubs and arrows

No writing
No wheels



http://topdocumentaryfilms.com/guns-germs-and-steel/

Questions for next week:

What are the benefits and risks associated with genetically modified crops?

Is genetic modification changing the relationship between plants and people in fundamental ways?

What will we be eating in 30 years from now?

BIO235 Course Assessment

Course Assignment = 50%

Exam = 50%

Exam will be on Tuesday 18th Dec 10:15-11:45 = 1.5 hrs

Mix of short answer questions and short essay questions covering the whole course

All of them will be easy & straightforward!

BIO 235 Plants and People - Evolution and Domestication of Crops

Student Course Evaluation (LVB)

- Link to survey: https://qmsl.uzh.ch/en/AMNWA

- Survey period: Nov 19 – Dec 9, 2018 (Reminder: Dec 3)

- Number of participants, who receive the access data automatically: 26 participants