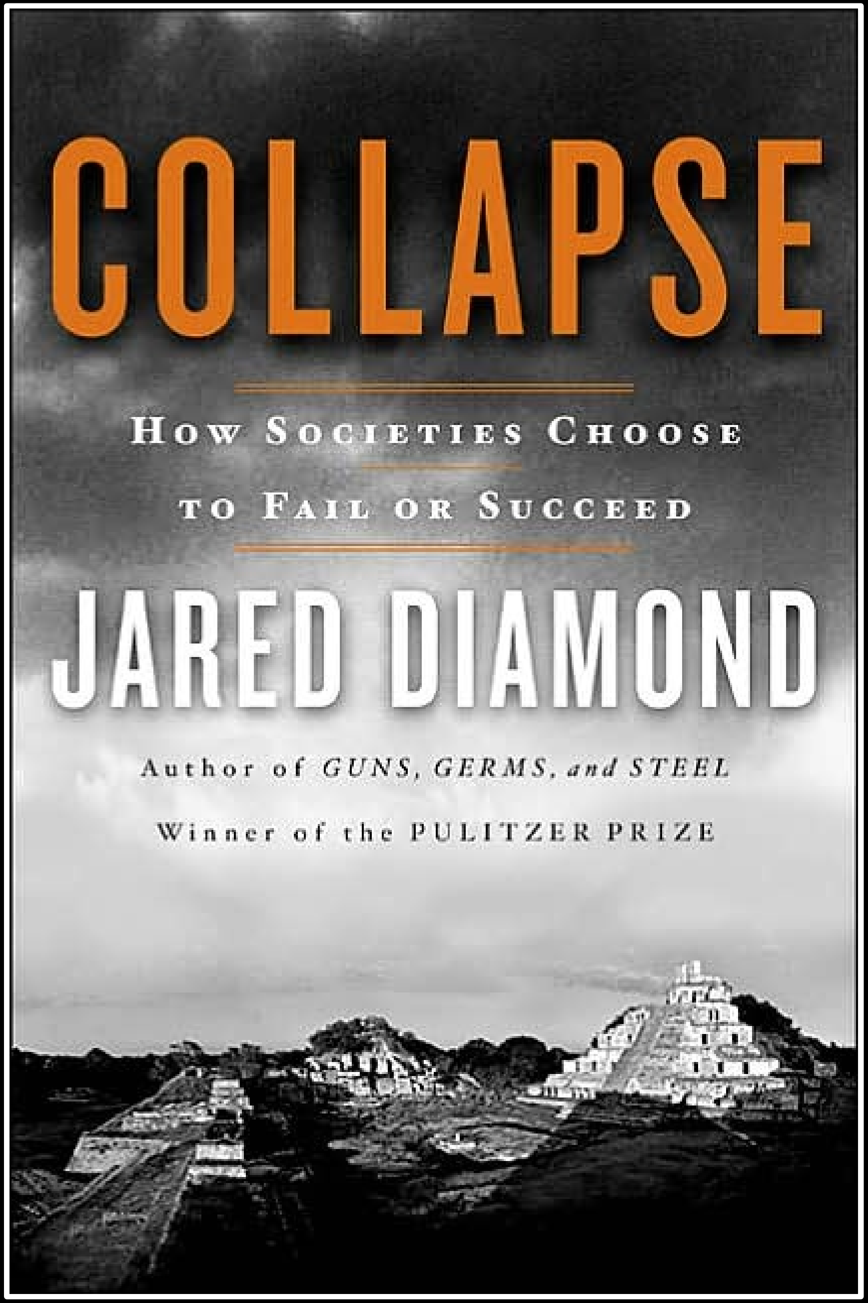
Simulating "Collapse"

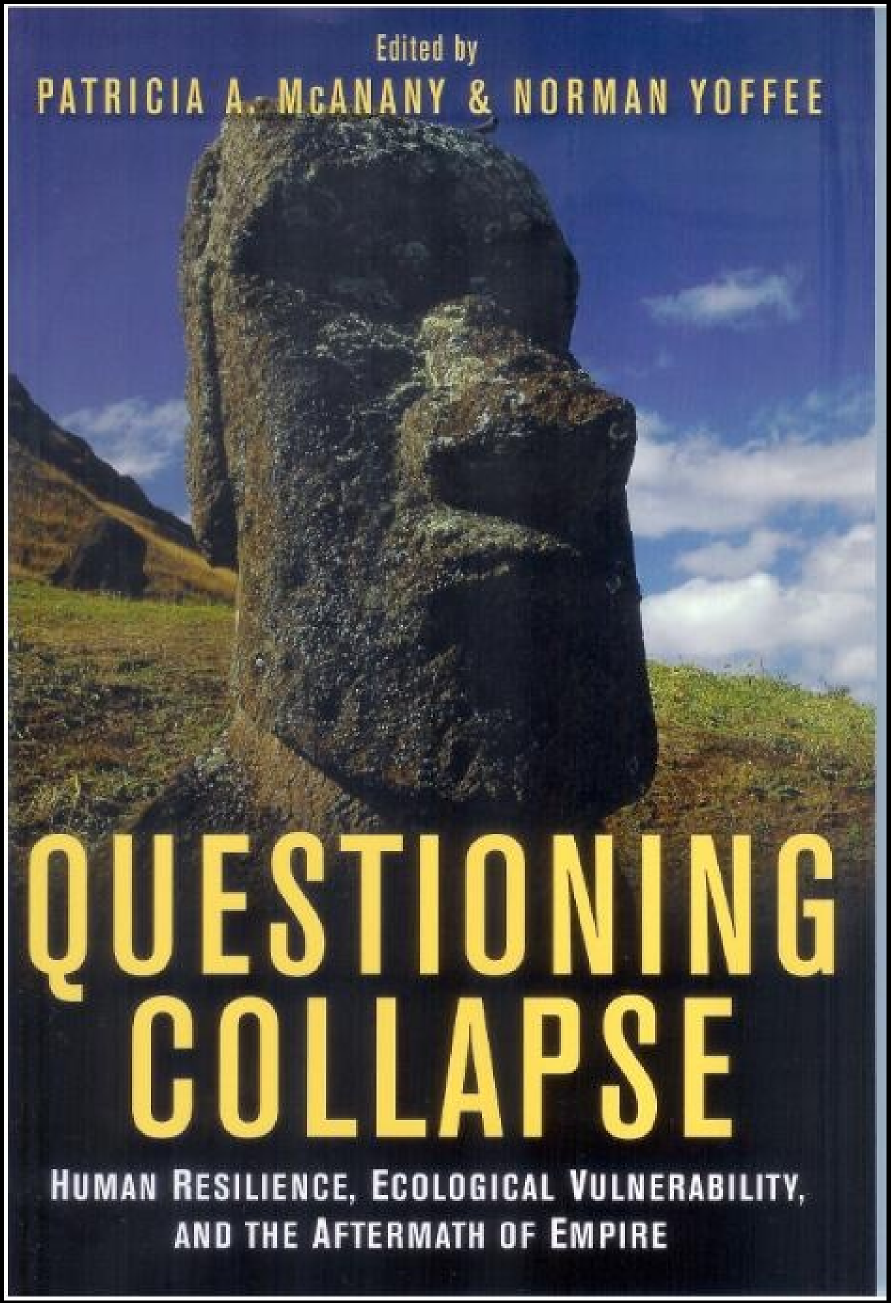
A computational modeling approach to understanding adaptive reorganization in low-level socio-natural systems

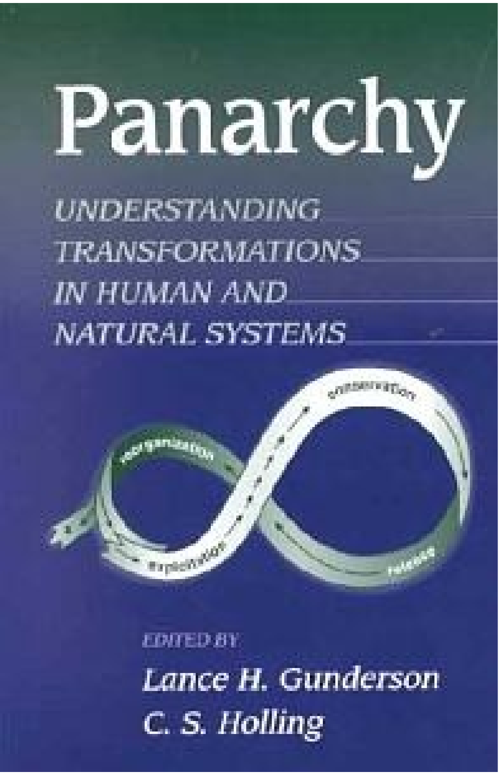
Isaac I.T. Ullah and C. Michael Barton

school of human evolution & social change
ARIZONA STATE UNIVERSITY

General Problem Domain



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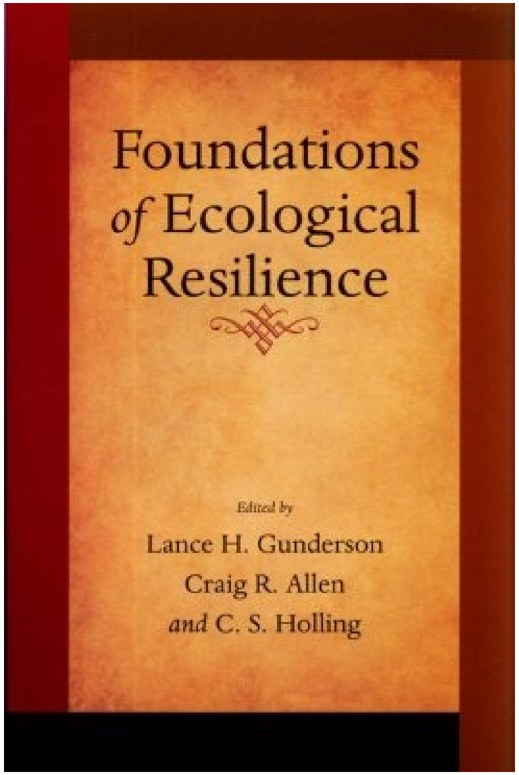
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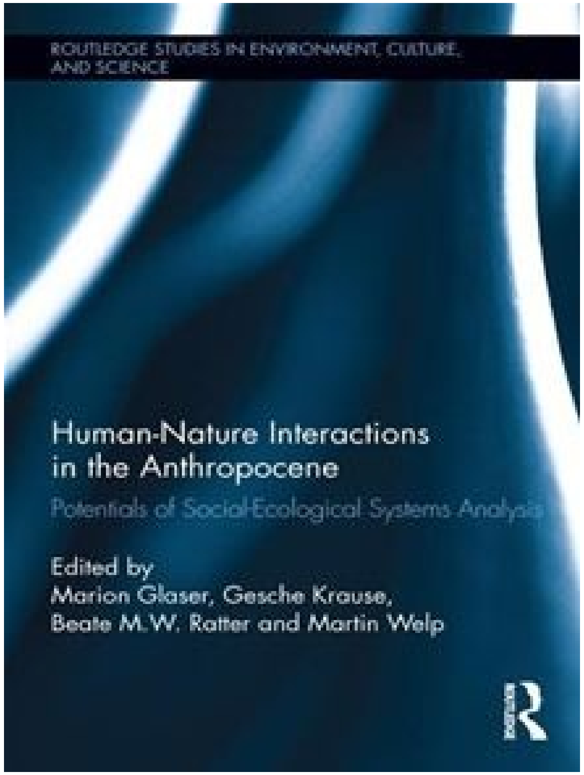
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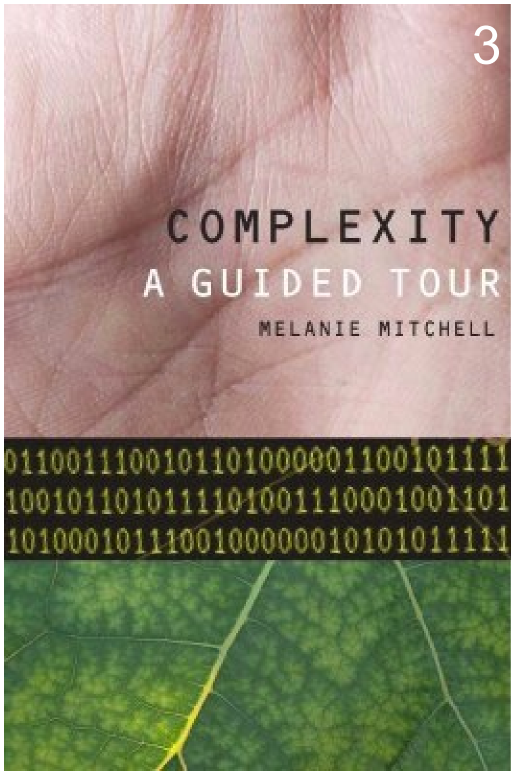
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A GUIDED TOUR
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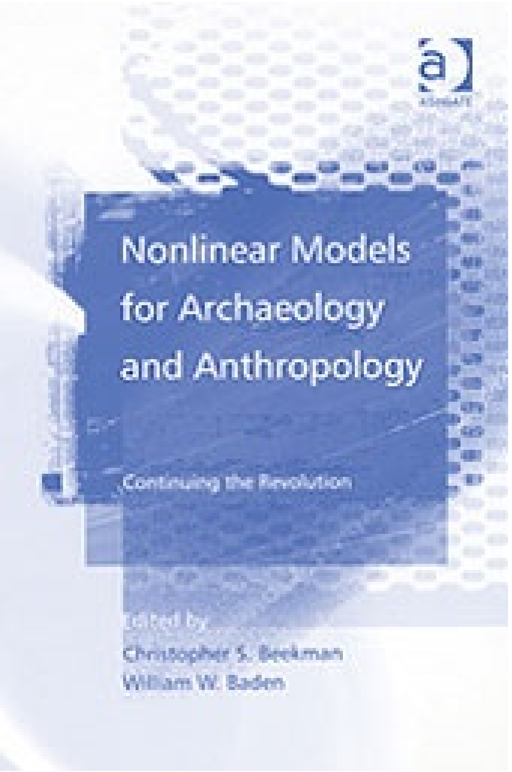
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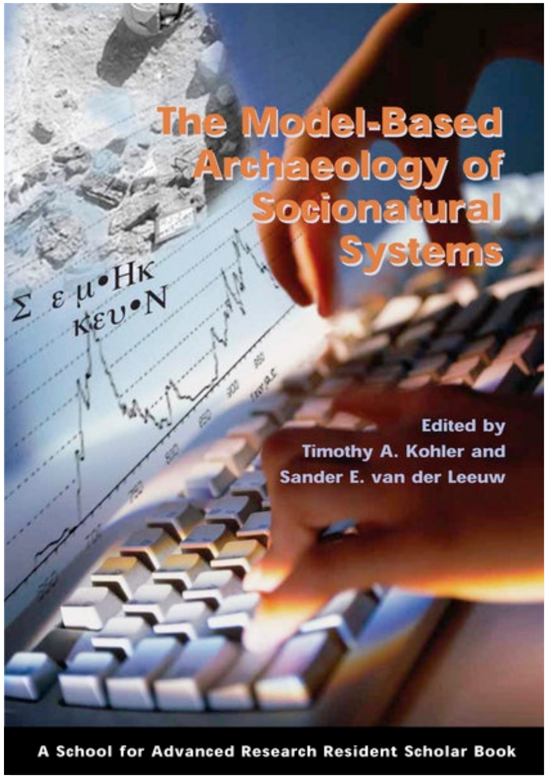
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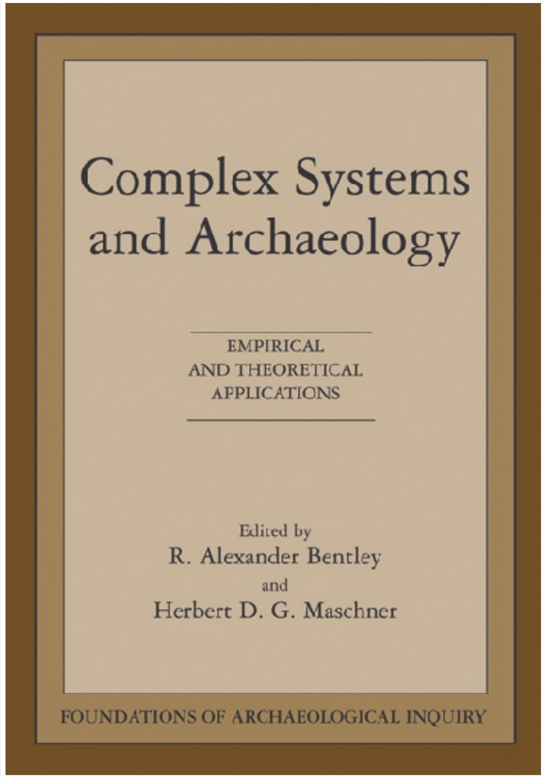
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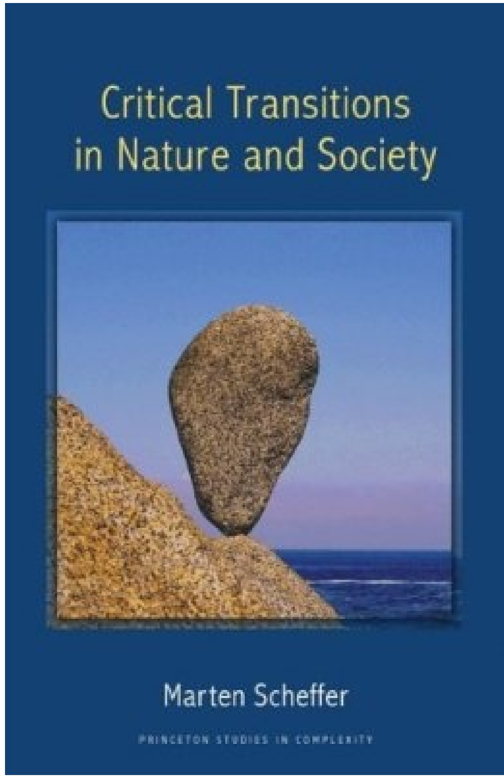
Critical Transitions in Nature and Society
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PRINCETON STUDIES IN COMPLEXITY

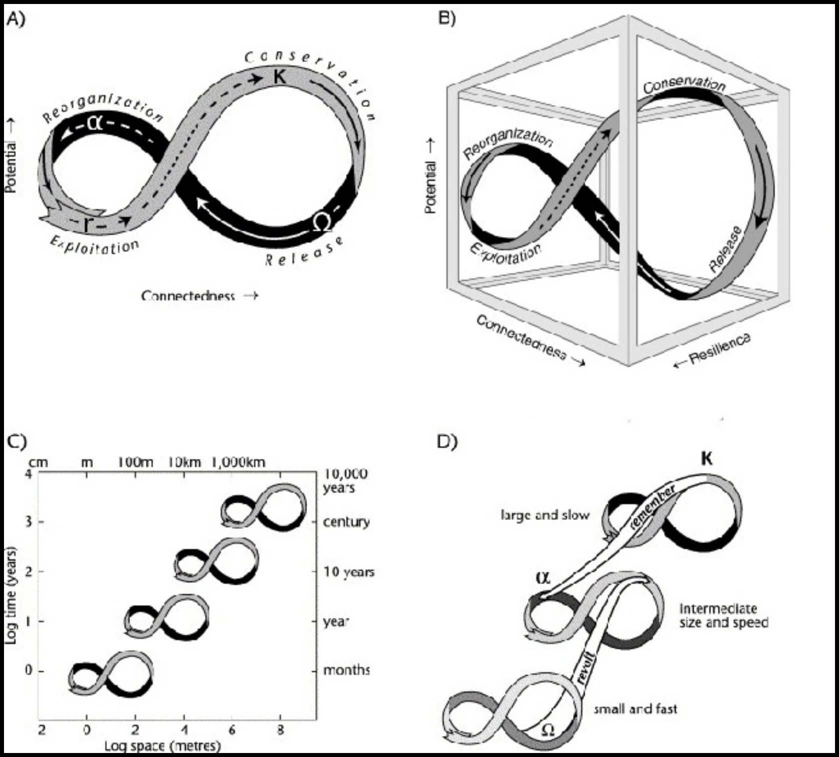
Main Research Goal

To better understand the complex human and natural dynamics <u>within</u> agropastoral subsistence systems and to see how these could lead to long-term stability, perpetual or increasing change, or to critical transitions.

Agropastoral Villages as “Regional Social-Ecological Systems”

Ideas Borrowed from Classic Resilience Theory:

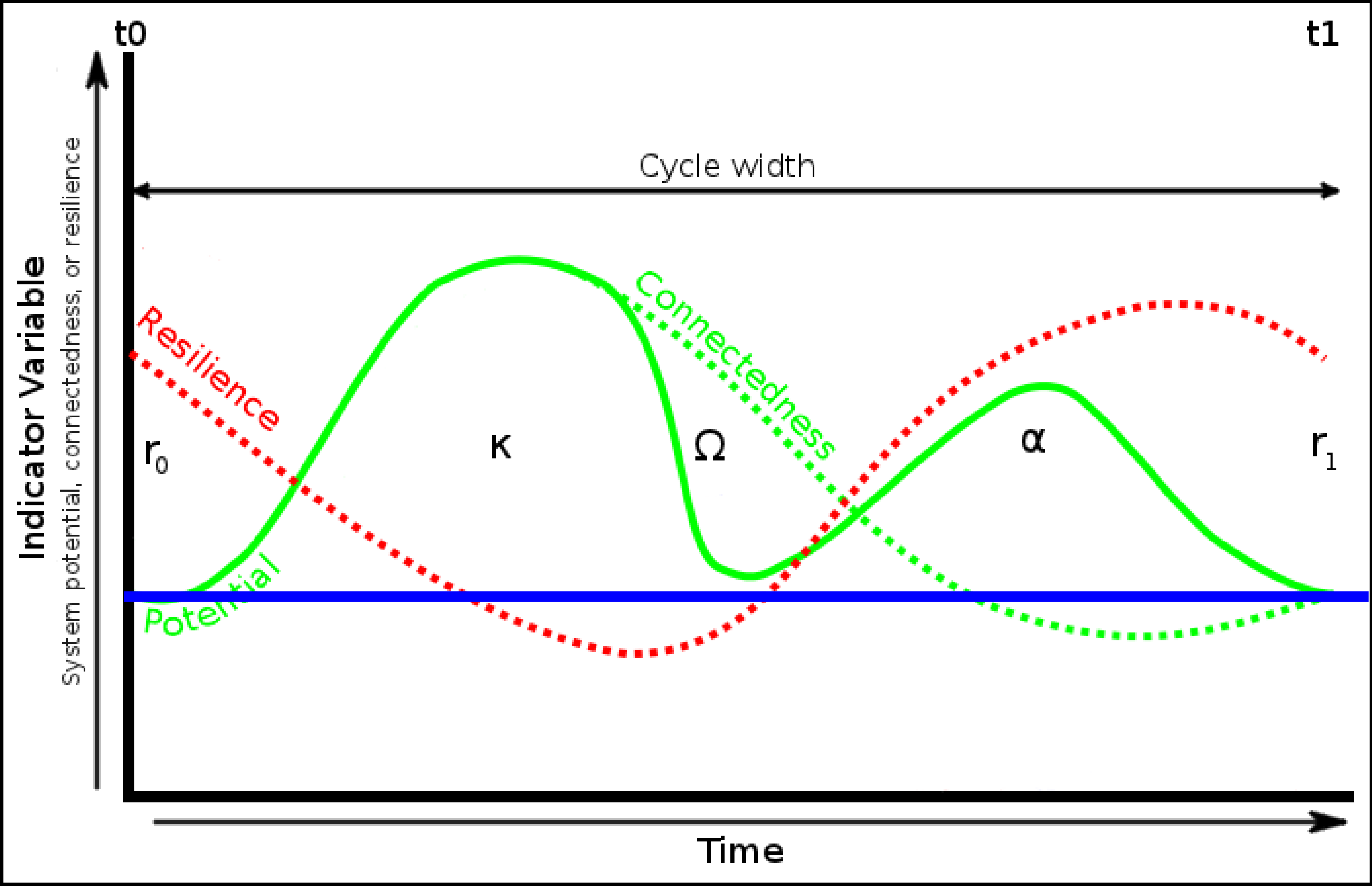
- Nested hierarchy (panarchy) of adaptive phenomena: Individual > household > village > regional village network
- Temporal and spatial scales increase with each level, intra- and inter-scale connections at and between levels
- Social system is connected to a particular landscape, with the legacy of history



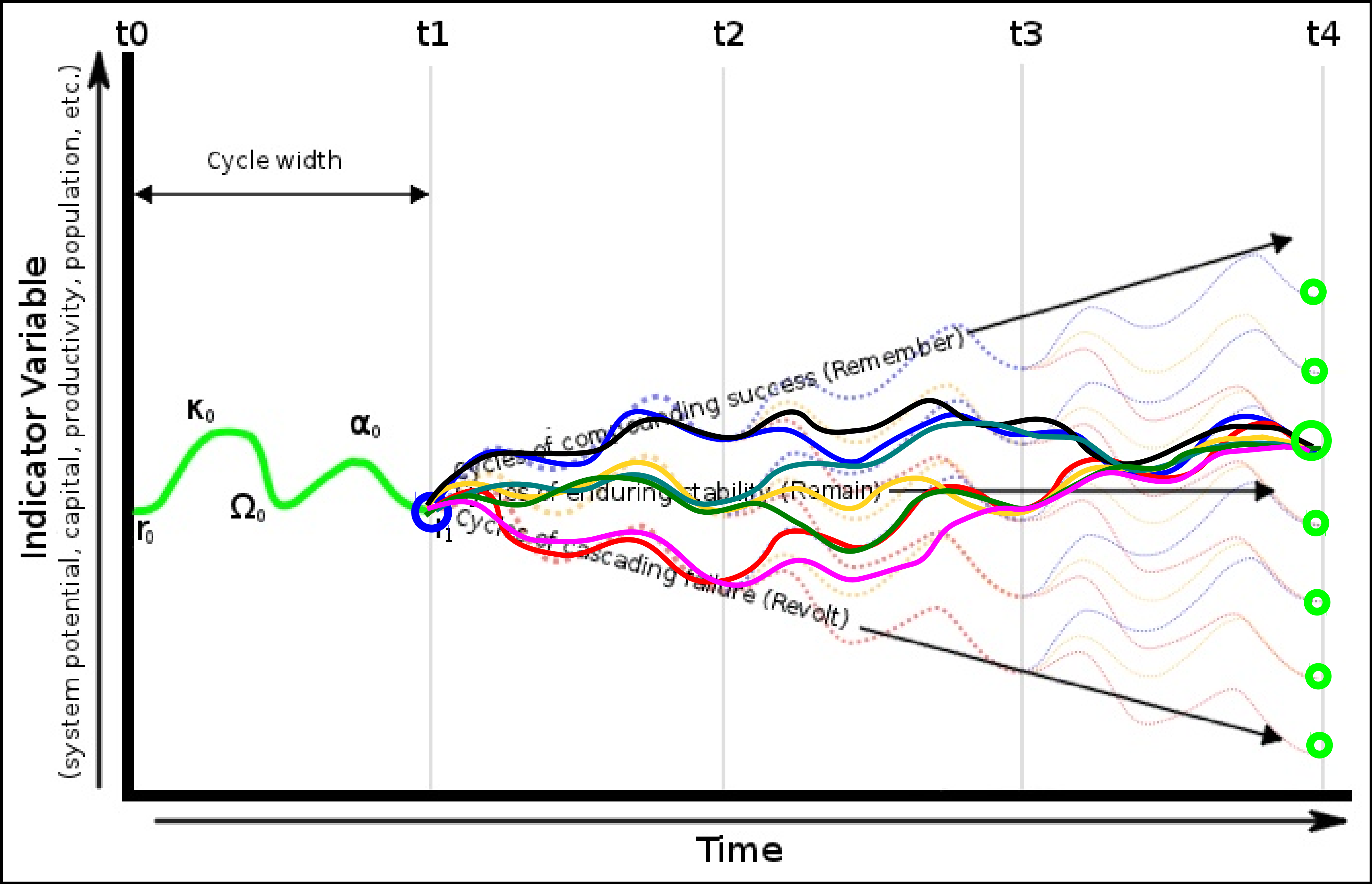
Informs the relationship of system potential, connectedness, and resilience <u>over time</u>

Informs ideas about <u>how the system will respond to stress/pressure</u> (e.g., resiliency, path dependency, rigidity traps, critical transition, etc.)

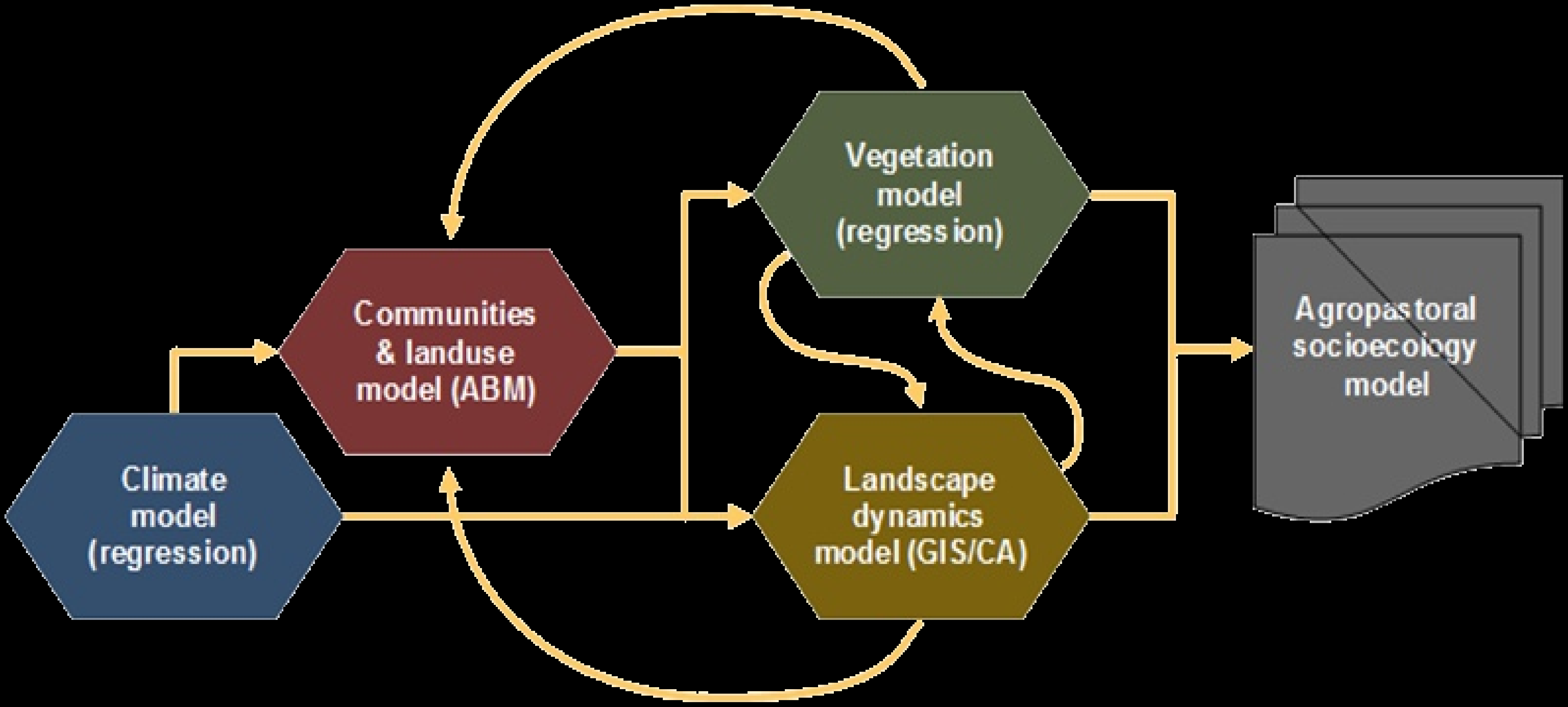
Temporalizing the Adaptive Cycle

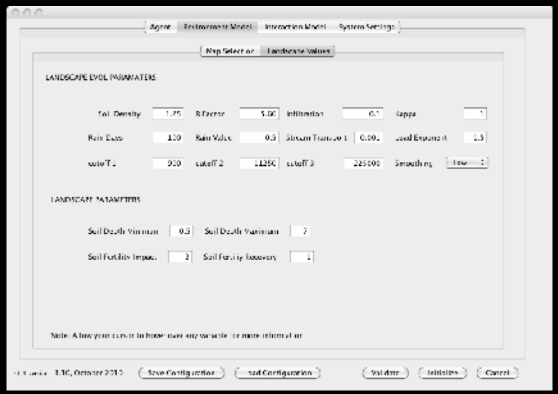


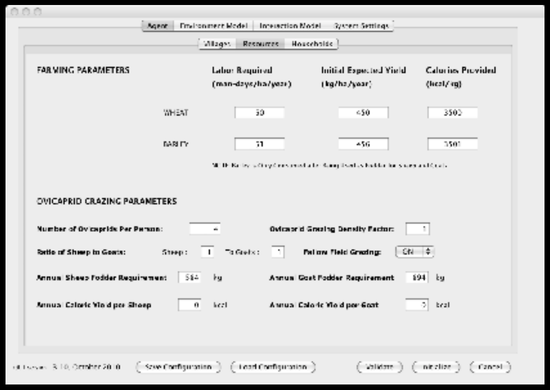
Connection to Complexity Theory

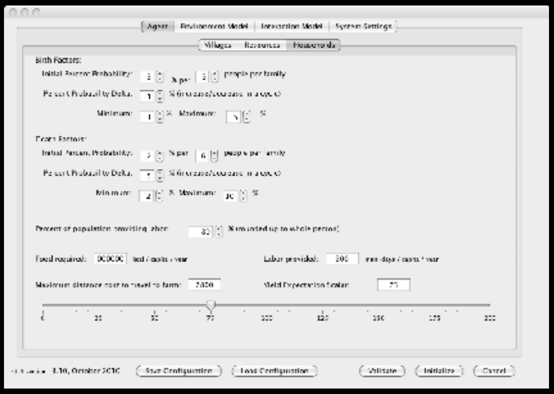


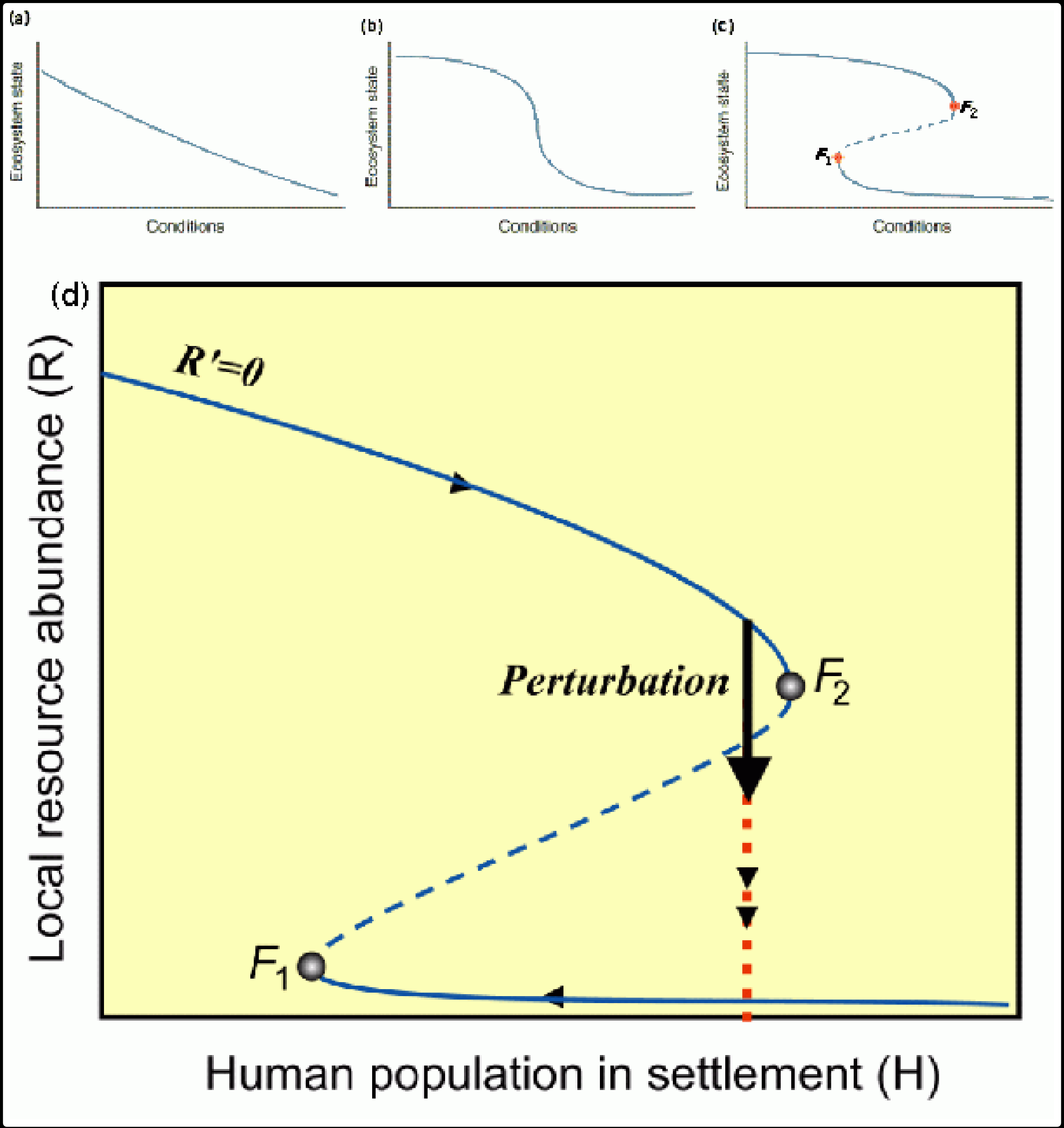
The MedLanD Modeling Laboratory











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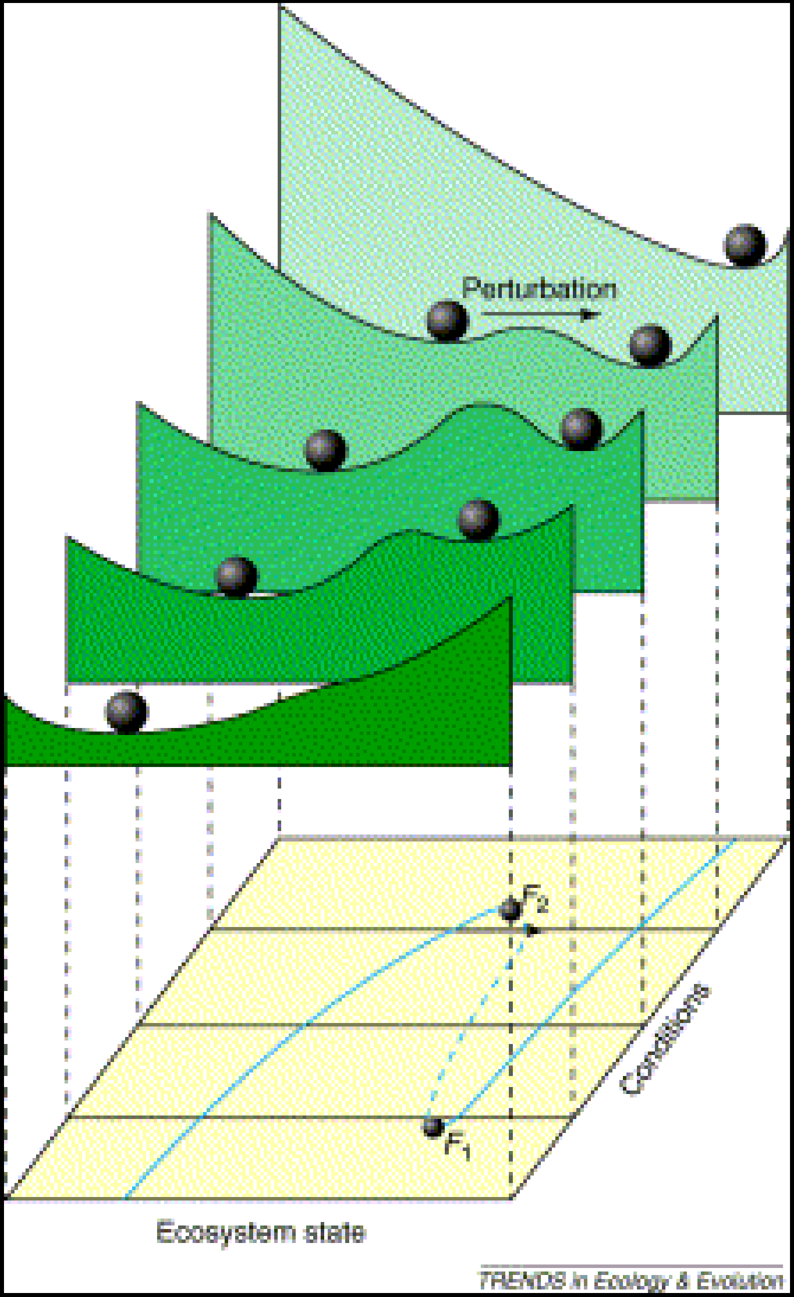
Attractors and Repellors



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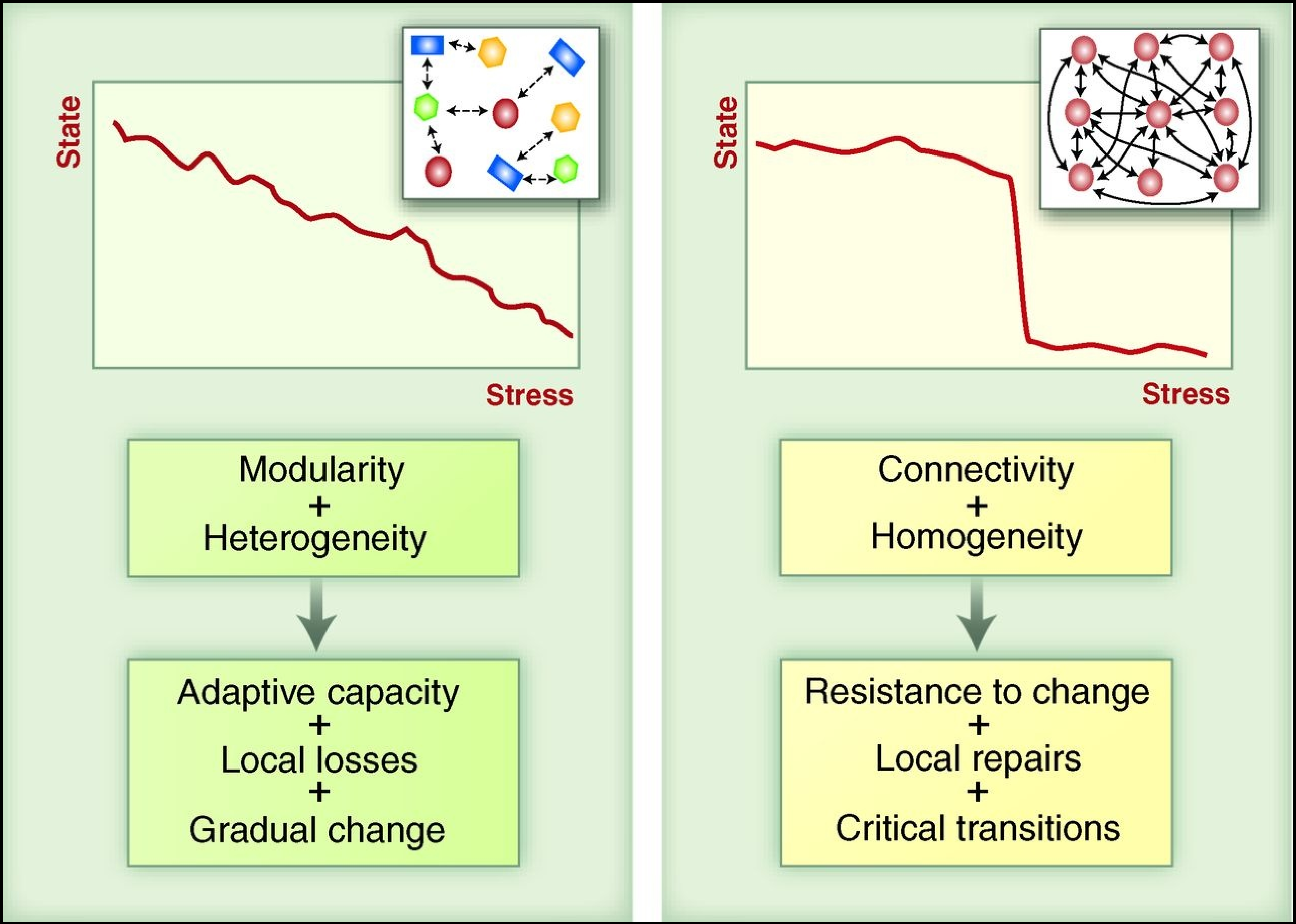

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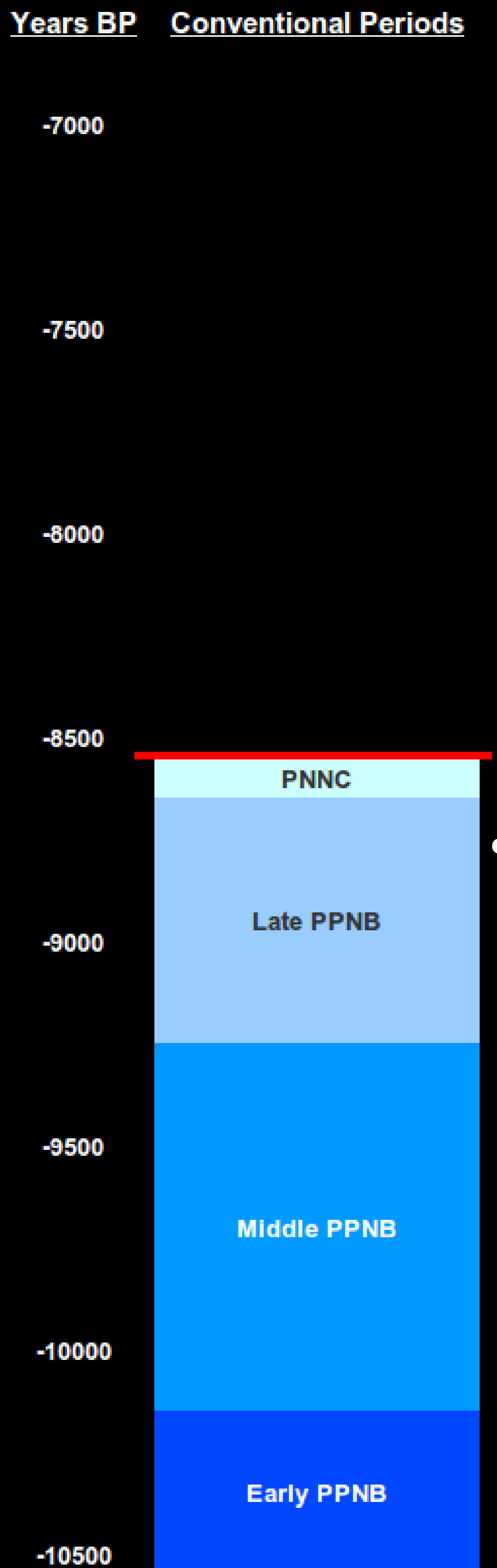
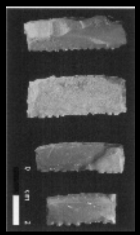
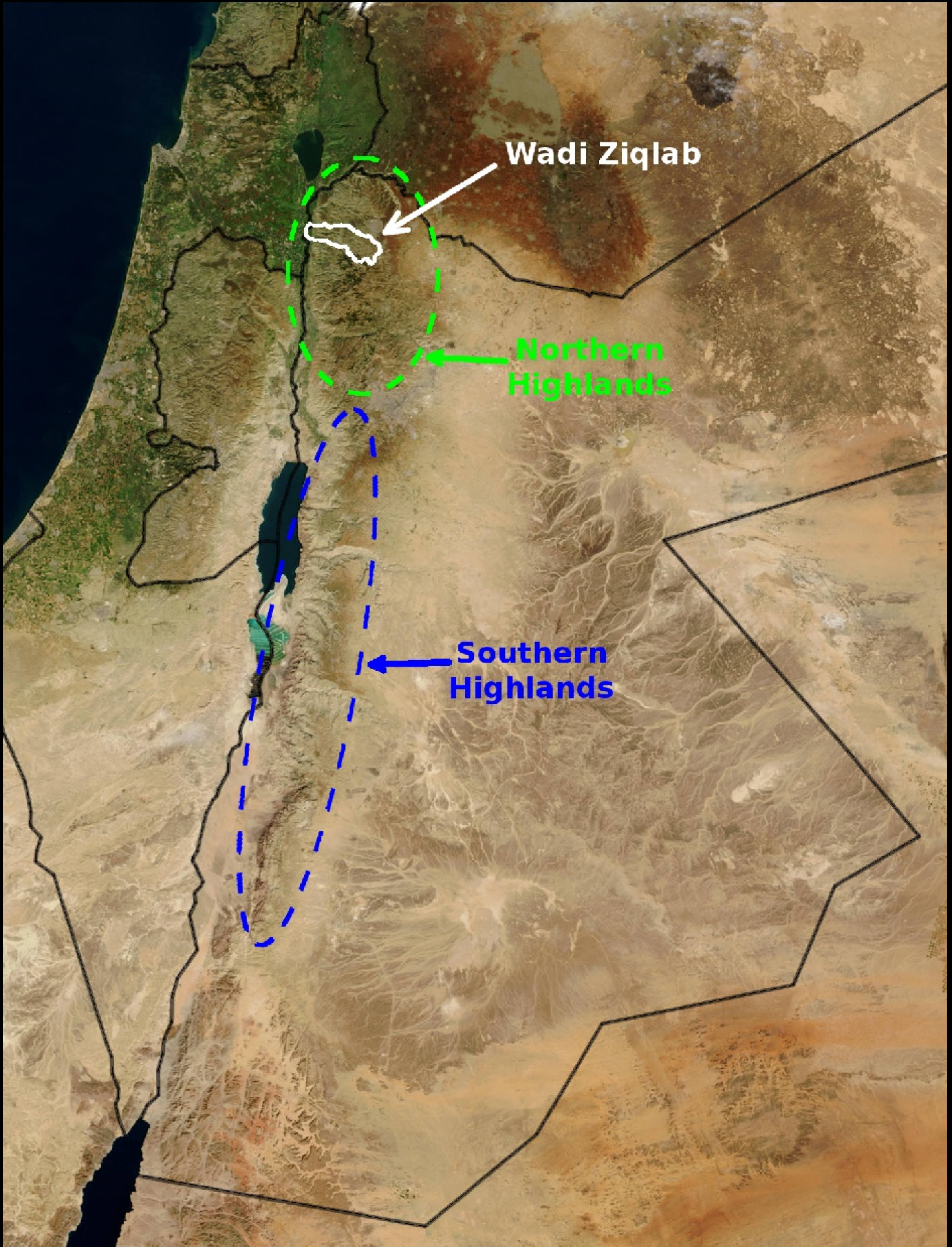


Late Neolithic (c. 8500 – 7000 B.P.)

- Generally much less spectacular than the PPNB/C
- Widely dispersed in small hamlets of only about 20 people each, with fewer larger settlements of a few hundred people
- Stone tools made from non-standardized flakes, very little art, simple one-room houses, pottery invented, but most pots undecorated coarse-wares

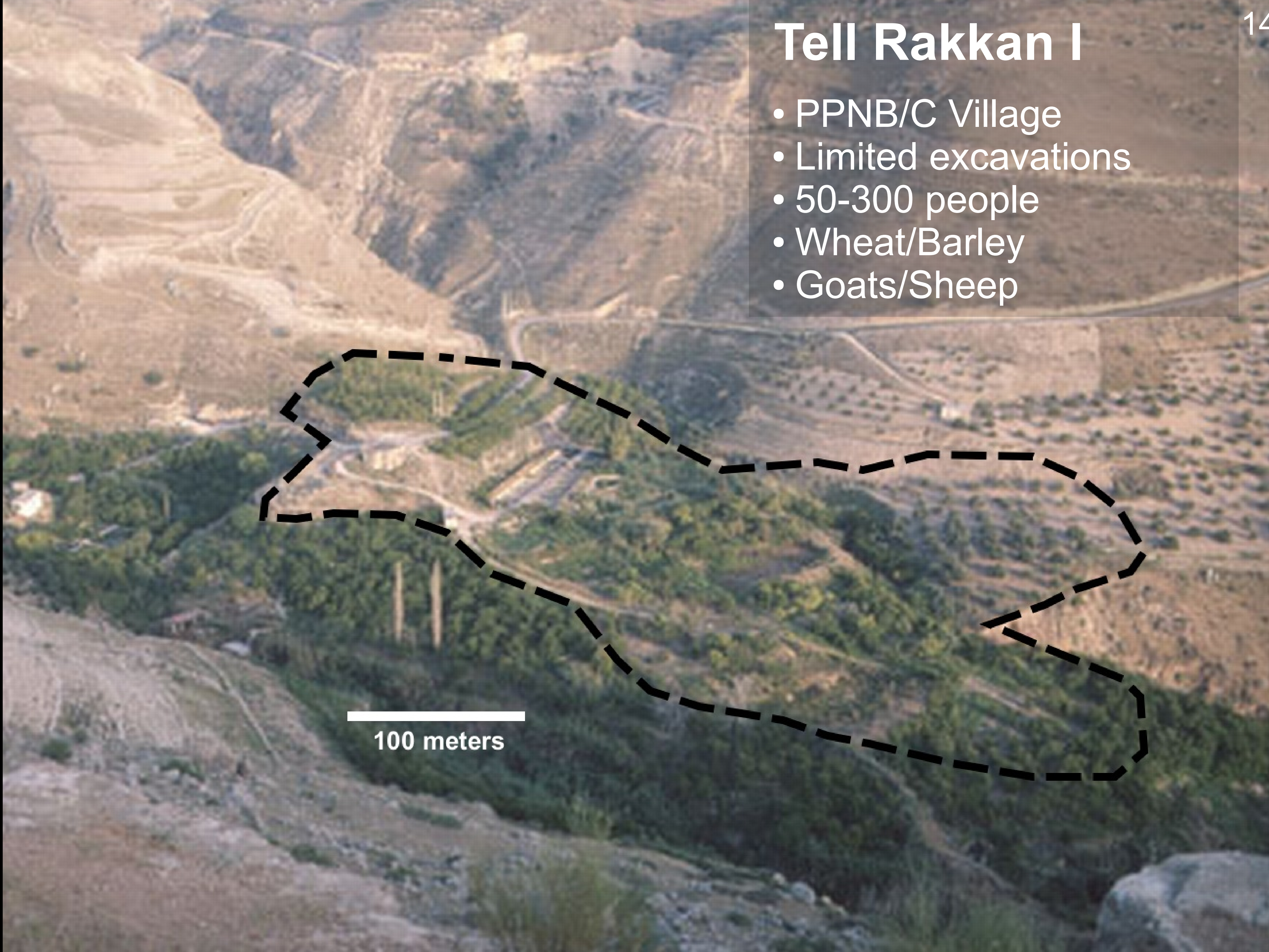


- **Late PPNB/C (c. 9250 – 8500 B.P.)**
  - High levels of settlement centralization, with dense habitation in a few large agglomerated towns, each containing up to 3000 people
  - Highly standardized blade-based stone tool technology, advanced knowledge of plaster-making, multistory dwellings with many rooms, large statuary, and spectacular art

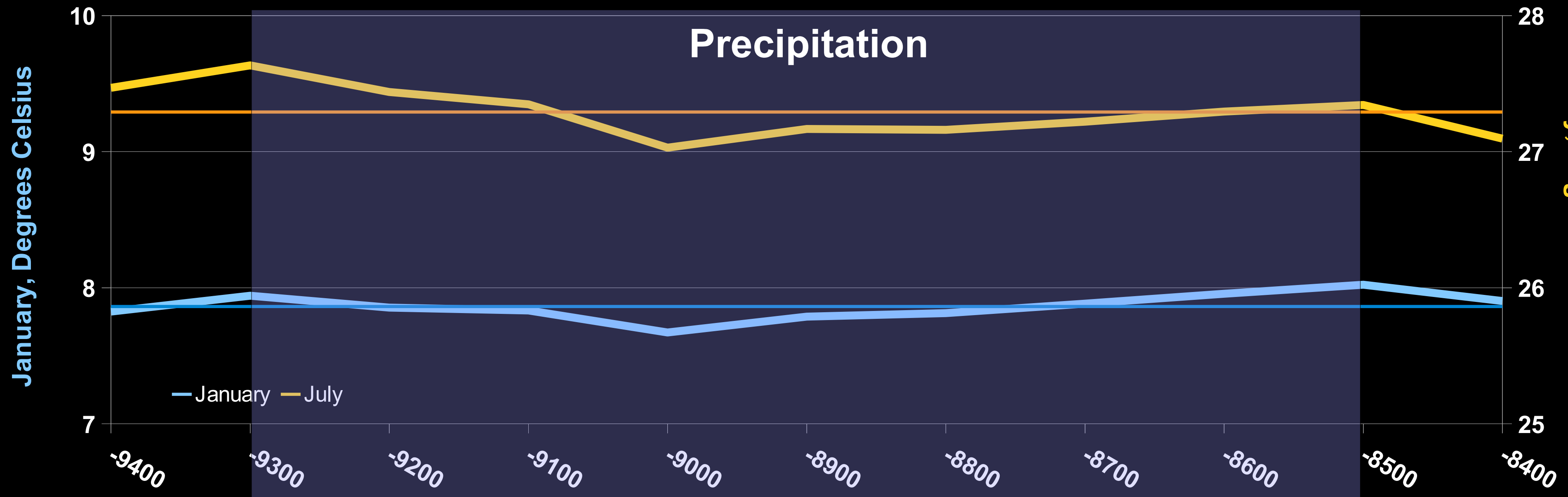

Wadi Ziqlab
Northern Highlands
Southern Highlands

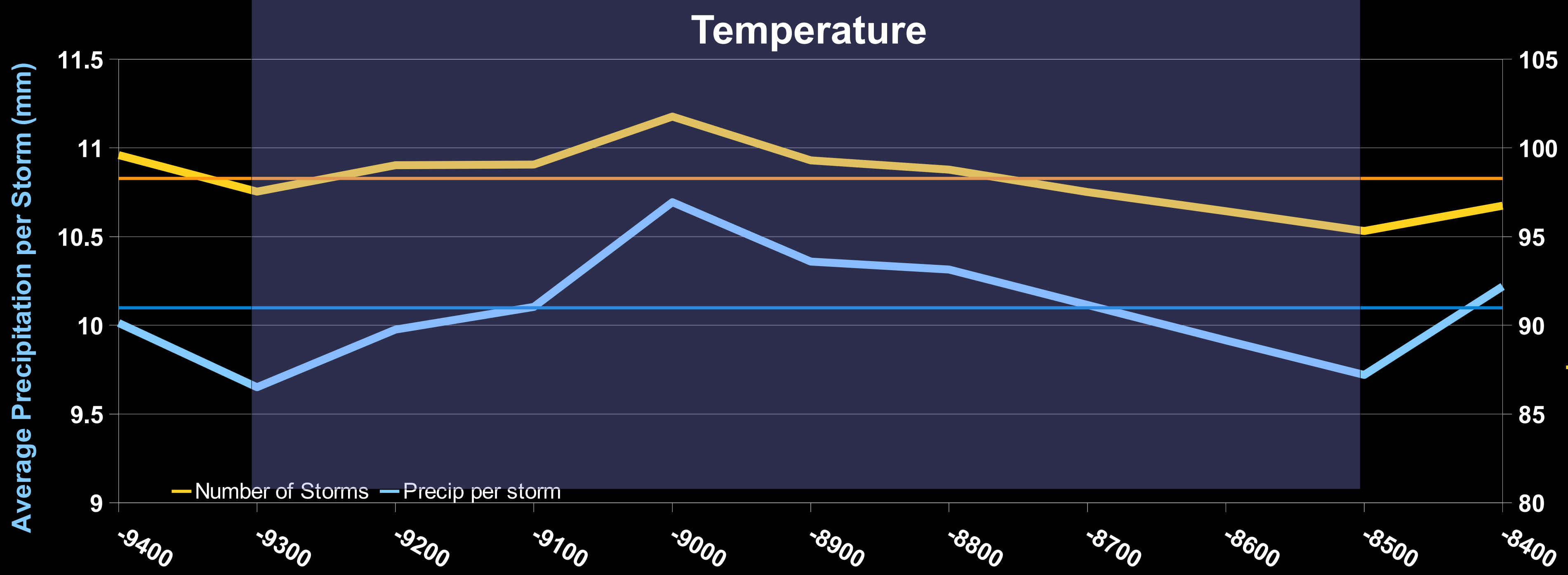
Tell Rakkan I

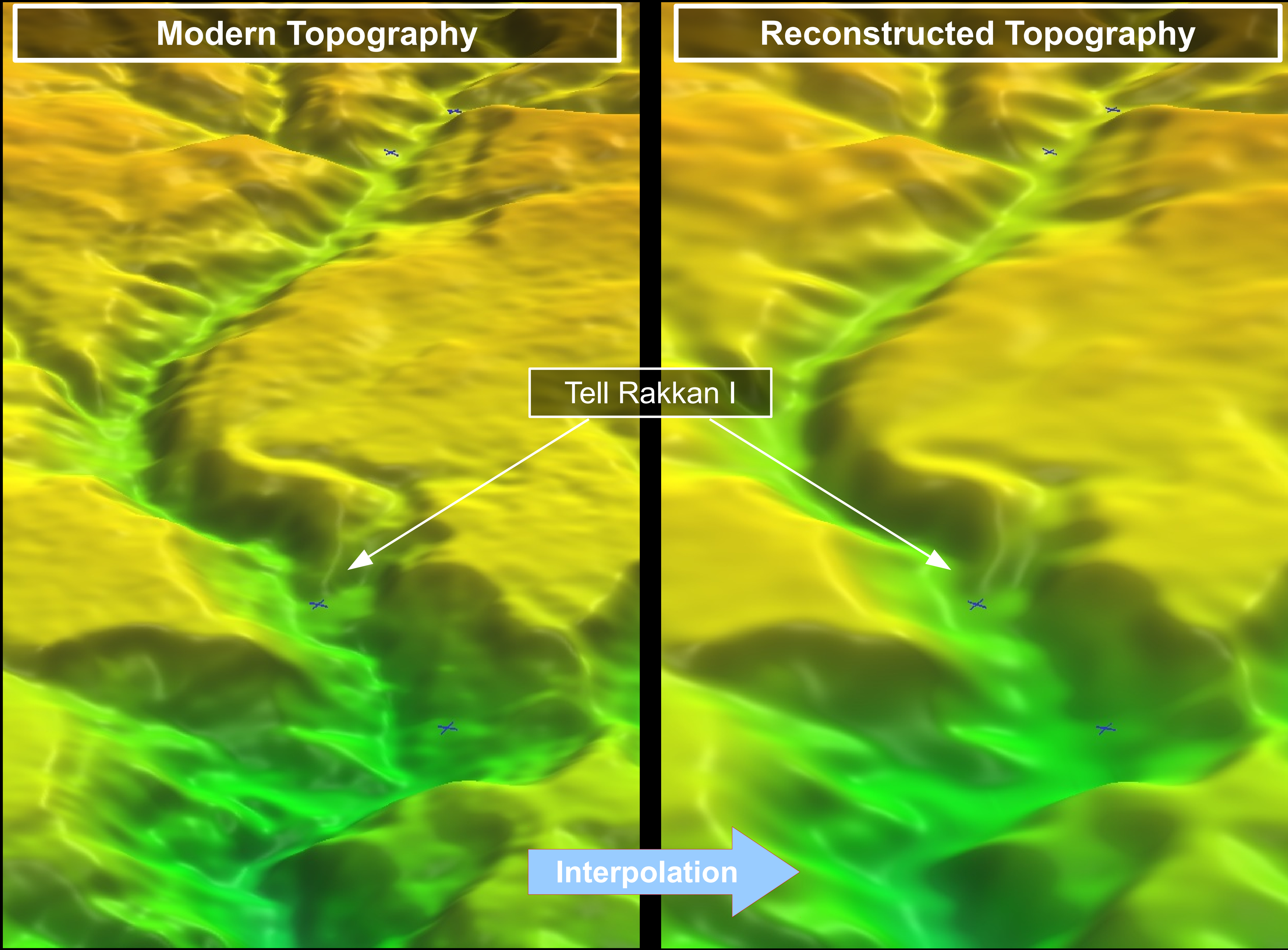
- PPNB/C Village
- Limited excavations
- 50-300 people
- Wheat/Barley
- Goats/Sheep



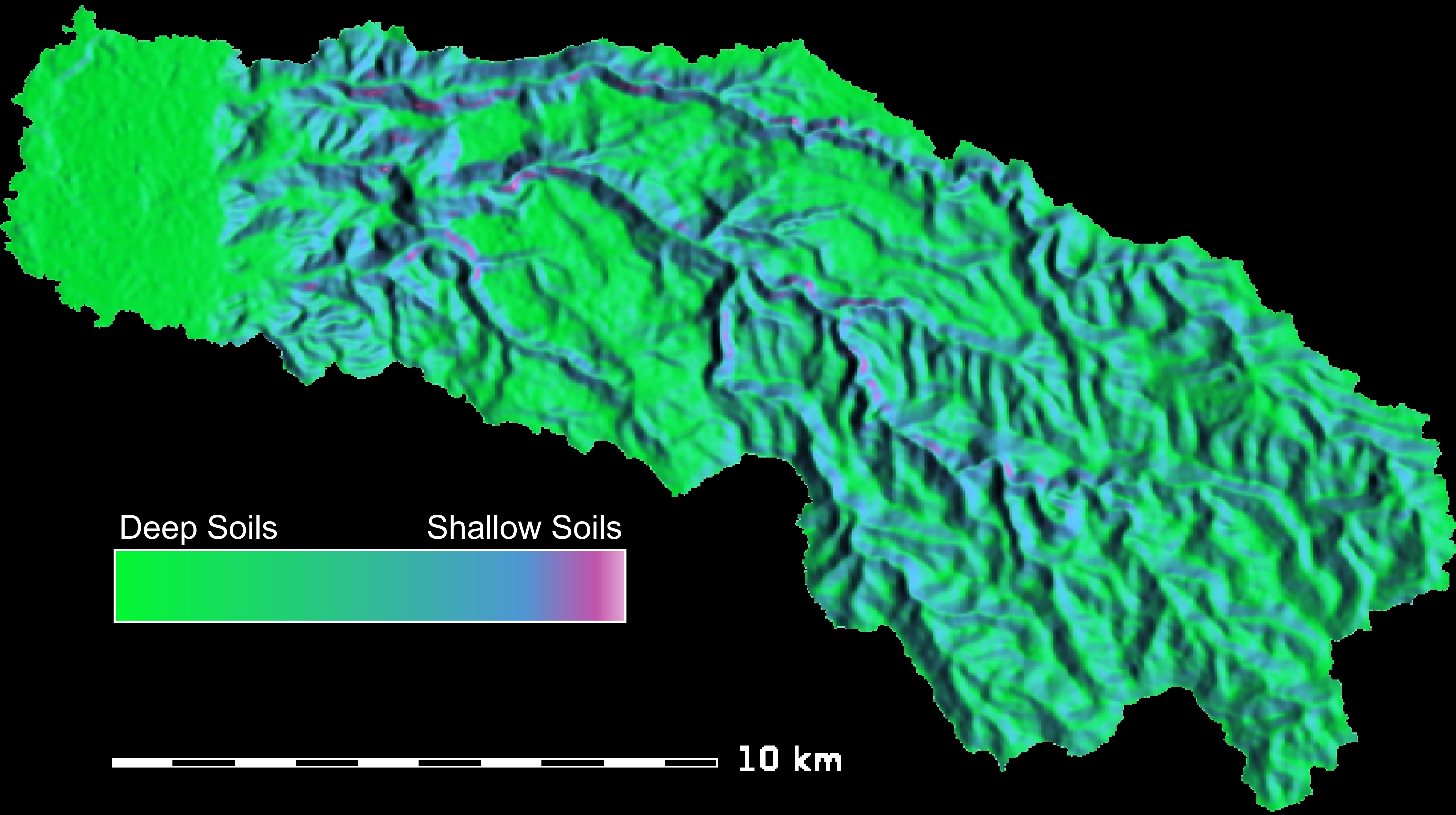
Reconstructing LPPNB Climate



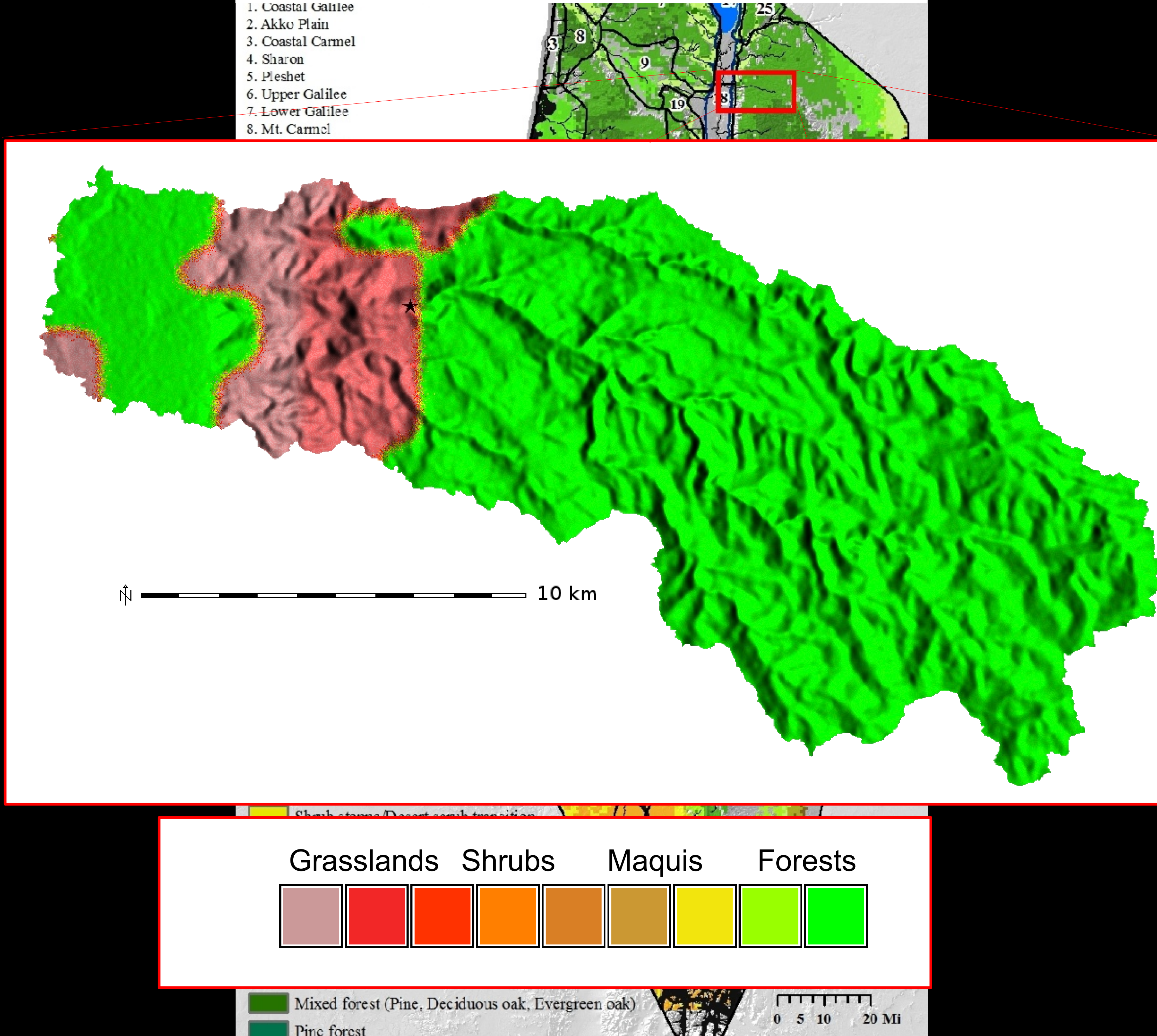



Modern Topography
Reconstructed Topography
Tell Rakkan I
Interpolation

Reconstructed Soil Properties



Climax vegetation – PPNB/C period



Agropastoral Economic Data

Data type	Data		Source
Pastoral product yields	*Baladi Goat*	*Awassi Sheep*	
Milk output (kg/yr):	200	60	Degen, 2007
Milk energy (kcal/kg):	753.6	1005.6	Mavrogenis and Papachristoforou, 1988
Percent milk not suckled:	66.00%	66.00%	Nablusi et al., 1993; Epstein, 1982
Percent milch animals:	36.00%	20.00%	Nyerges, 1980
Milk yields (kcal/yr):	99475.2	39821.76	Calculated from the above
Meat output (kg/animal):	10.09	14.88	Sen et al., 2004
Meat energy (kcal/kg):	1090	2300	USDA, 2011
Percent meat animals:	25.00%	25.00%	Nyerges, 1980
Meat yields (kcal/yr):	10998.1	34224	Calculated from the above
Goat:Sheep Ratio:	2	1	Ullah, 2011
Average yield (kcal/yr/animal):	38560.597	16520.352	Calculated from the above
Herd animal attributes	*Baladi Goat*	*Awassi Sheep*	
Body weight (kg):	40	70	Wilson, 1982; Epstein 1982; Degen, 2007
Fodder requirement (kg/yr/head):	584	894.25	Stuth and Sheffield 1991
Percent diet from barley fodder:	10.00%	10.00%	Thomson et al., 1986
Wild fodder need (kg/yr/head):	525.6	804.825	Calculated from the above
Barley need (kg/yr/head):	42.05	71.54	Calculated from the above
Agricultural Product Yields	*Barley*	*Wheat*	
Energy yield (kcal/kg):	3000	3540	Smith, 2006; Fairbairn et al., 1999
Maximum possible yields (kg/ha):	2500	3500	Pswarayi et al., 2008; Araus et al., 1998, 2001
Seed reserve:	15.00%	15.00%	Hillman, 1973
Required labor (man days/ha/yr):	50	50	Dabasi-Scheng, 1978
Wood gathering			
Wood need (kg/person):	2000		Karanth, 2006
Gathering intensity (kg/m2):	0.08		Karanth, 2006
Labor and planning			
Maximum farming distance (hrs):	3		Estimated from McCall 1985
Maximum grazing distance (hrs):	8		Ullah, 2011
Farm yield expectation scalar:	75.00%		Estimated from Grisley and Kellogg, 1983
Labor availability (man days/yr):	300		Estimated from McCall 1985
Wood gathering distance weight:	3		Estimated from Karanth, 2006; Hartter and Boston, 2007, 2008

Research Design

Create a series of "hypothesis generating" experiments

- Model discrete agropastoral subsistence systems
- Limit the number of dynamics to be investigated
- Repeat each experiment multiple times*
- Conduct a "control model"

Three Potential Neolithic Subsistence Systems

	1) Pastoralists	**2) Agropastoralists**	**3) Agriculturalists**
Agro/pastoral ratio:	20/80	50/50	80/20
Ovicaprids per person:	26	17	7

Four Varieties of Landuse Decision-Making Mindsets

	1) Good-Hardworking	2) Good-Lazy
Herd stocking rate:	~0.15 animals/ha	~0.15 animals/ha
Farming fertility decline:	1.00%	1.00%
Farmplot preference:	None	Maquis or less

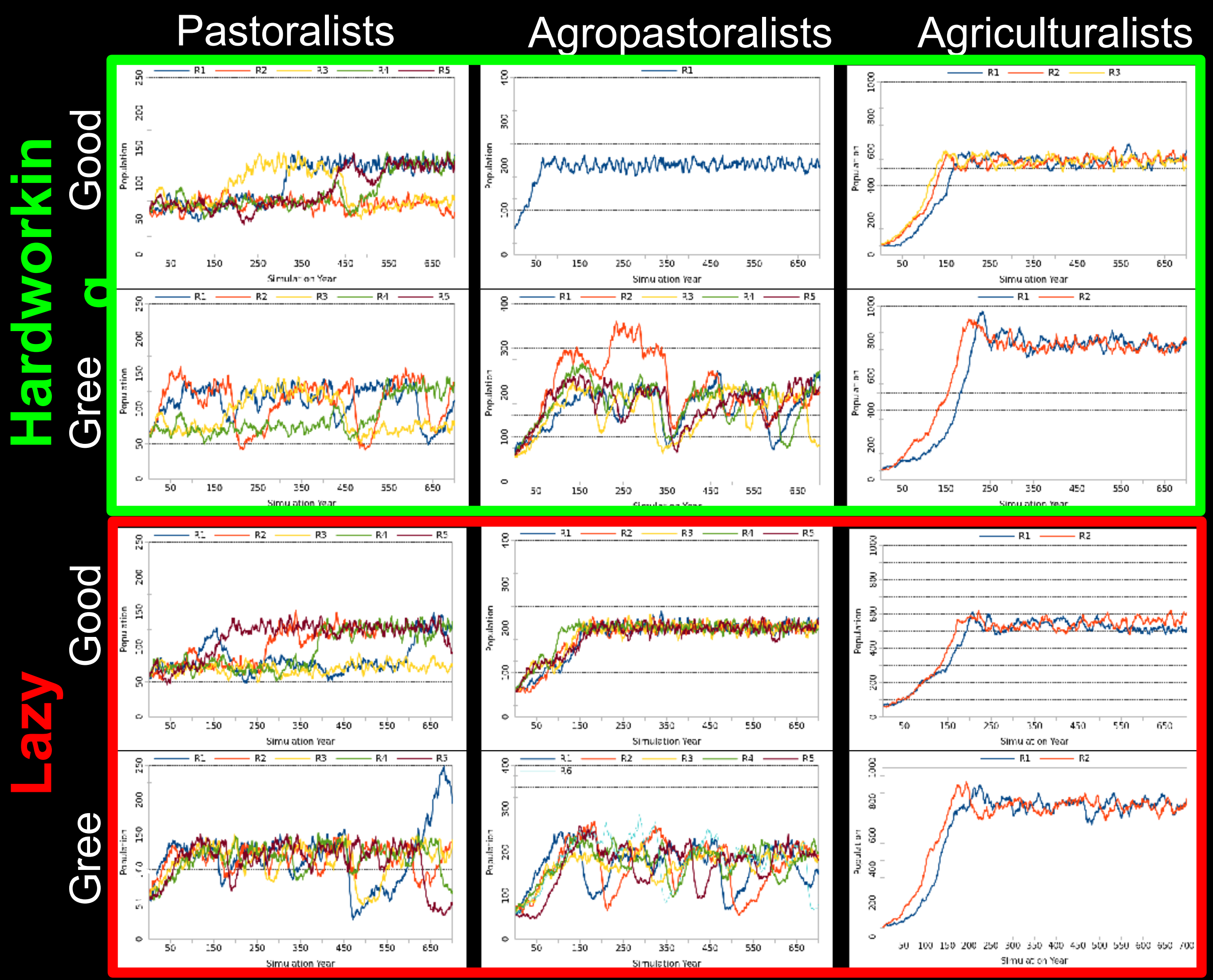
	3) Greedy-Hardworking	4) Greedy-Lazy
Herd stocking rate:	~0.3 animals/ha	~0.3 animals/ha
Farming fertility decline:	2.00%	2.00%
Farmplot preference:	None	Maquis or less

Research Results

Patterns in:

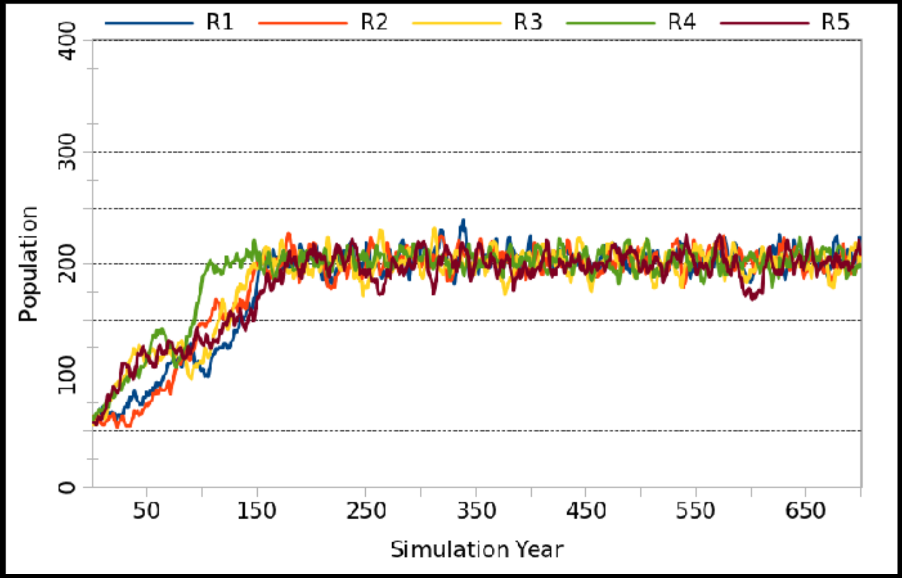
- Population Dynamics
- Vegetation Dynamics
- Soil Dynamics

Patterns in Population Dynamics

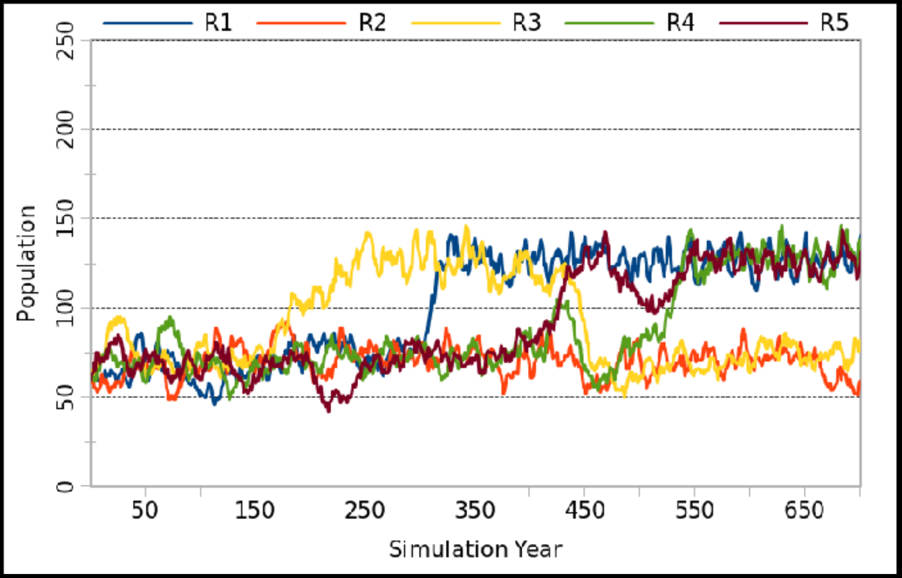


Demographic Stability

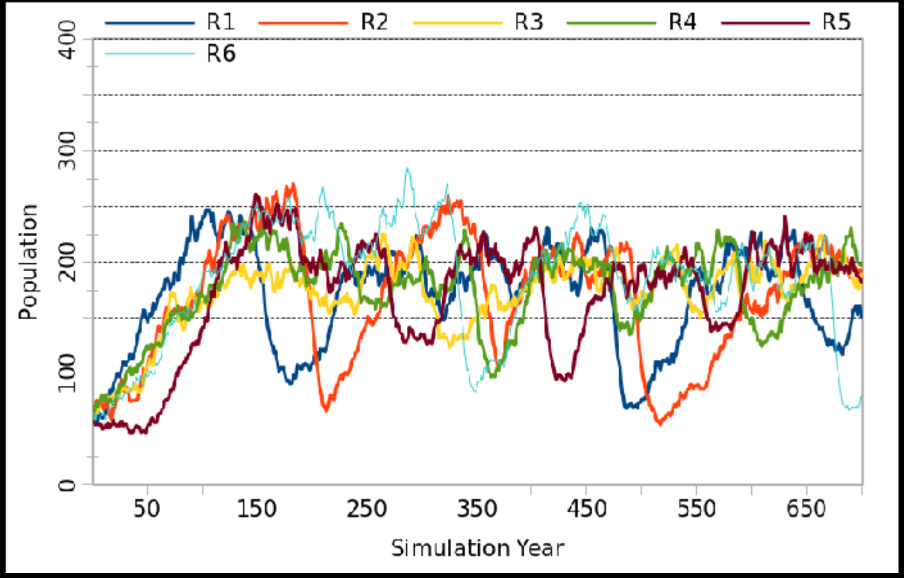
1) Metastable



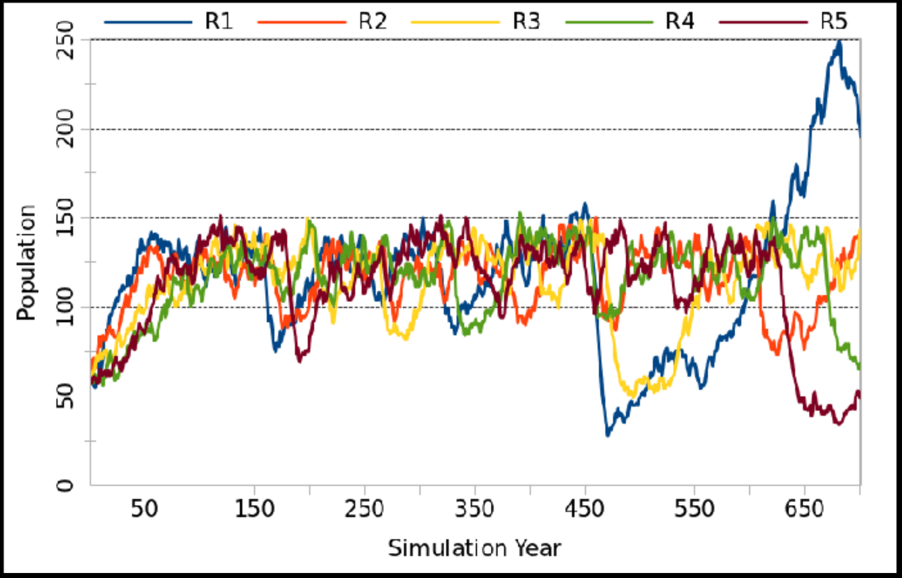
2) Multi-stable



3) Unstable



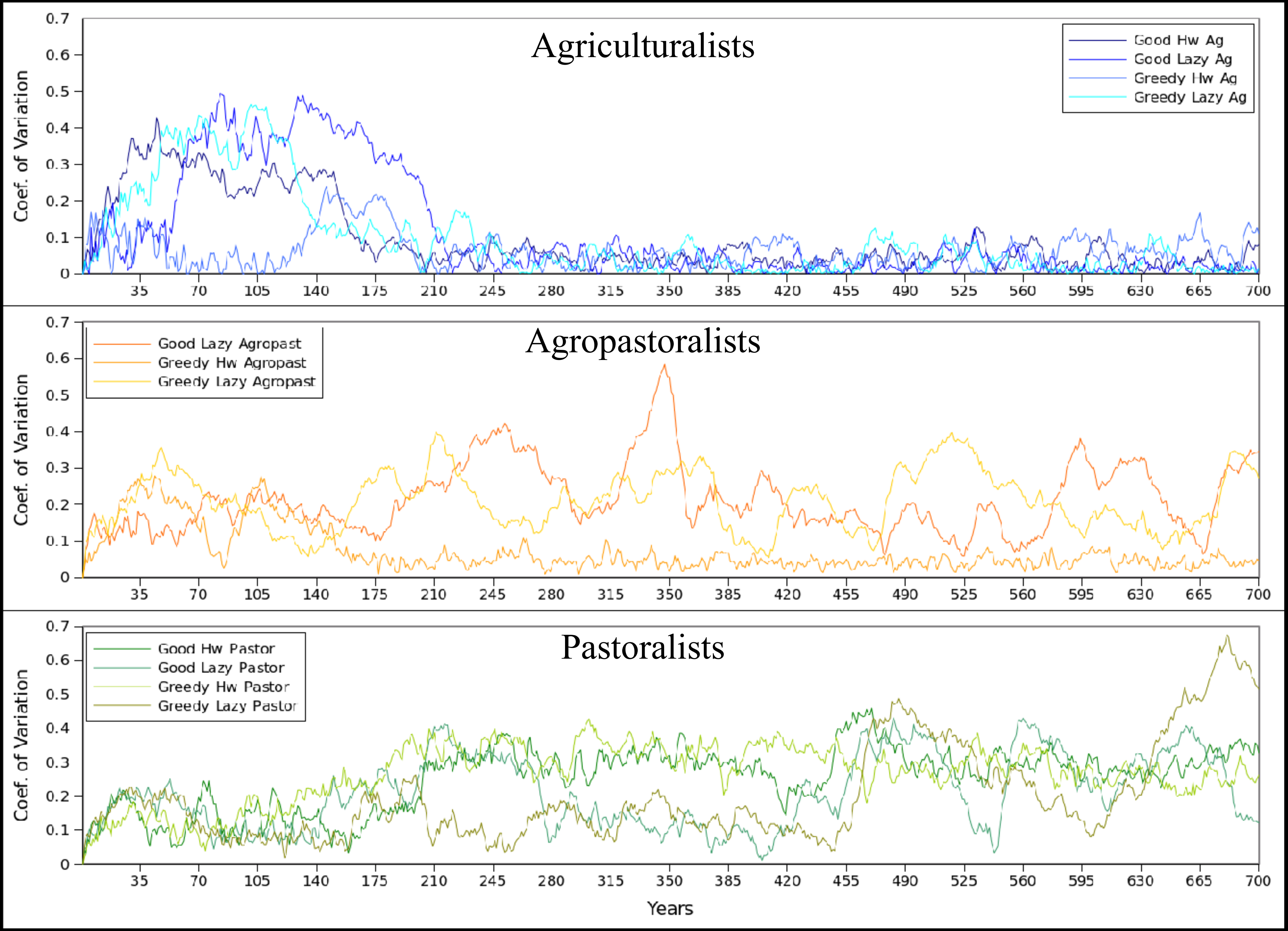
4) Stable trending to Unstable



Subsistence and Demographic Stability

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hardworking	*Good*	Multi-stable	Metastable	Metastable
	Greedy	Multi-stable	Trending to Unstable	Metastable
Lazy	*Good*	Multi-stable	Metastable	Metastable
	Greedy	Trending to Unstable	Unstable	Metastable

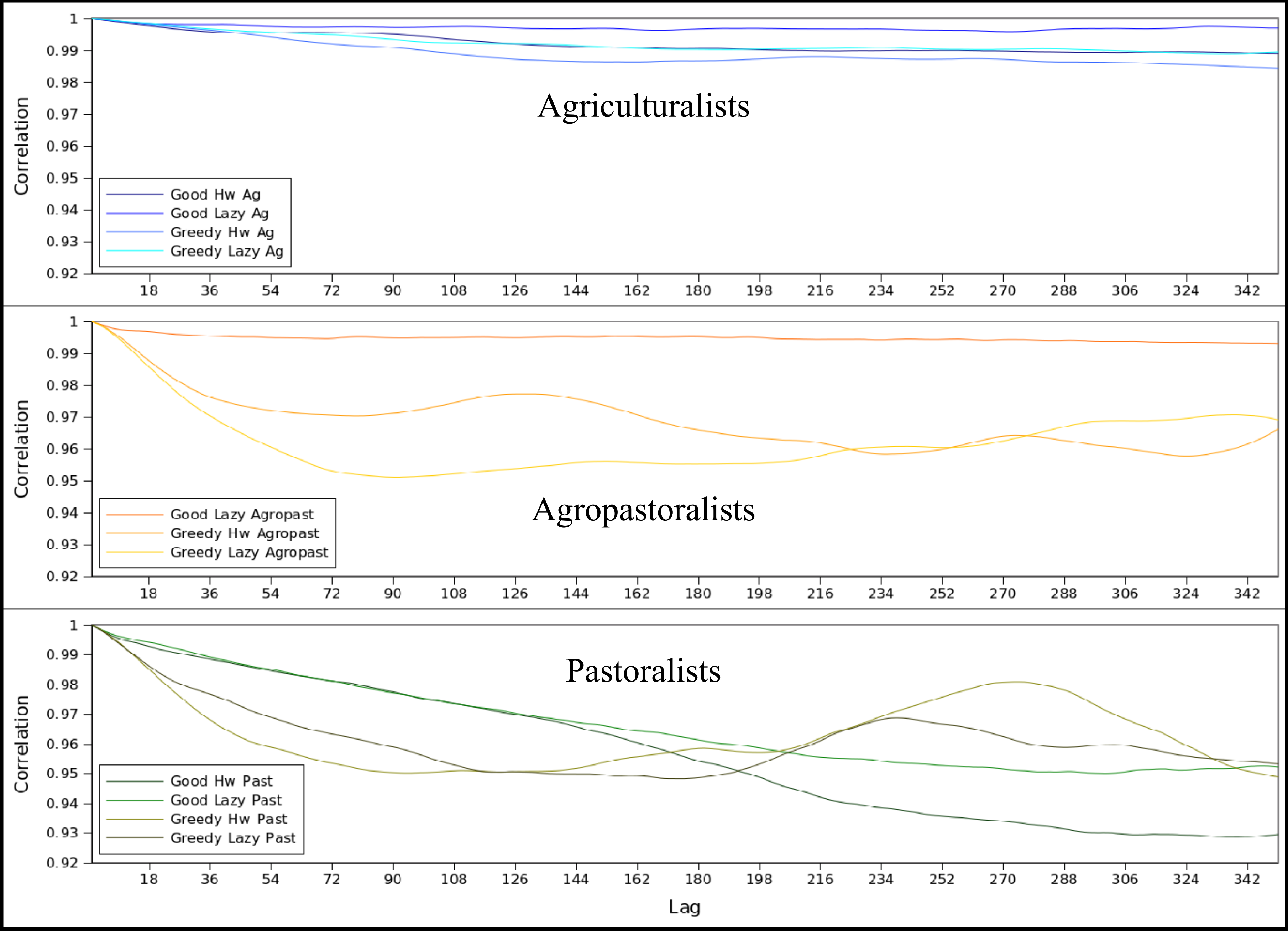
Inter-Run Variation Over Time



Subsistence and Inter-Run Variation

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hardworking	*Good*	Diverging	–	Converging
	Greedy	Diverging	Converging and Diverging	Converging
Lazy	*Good*	Diverging	Converging and Diverging	Converging
	Greedy	Diverging	Converging	Converging

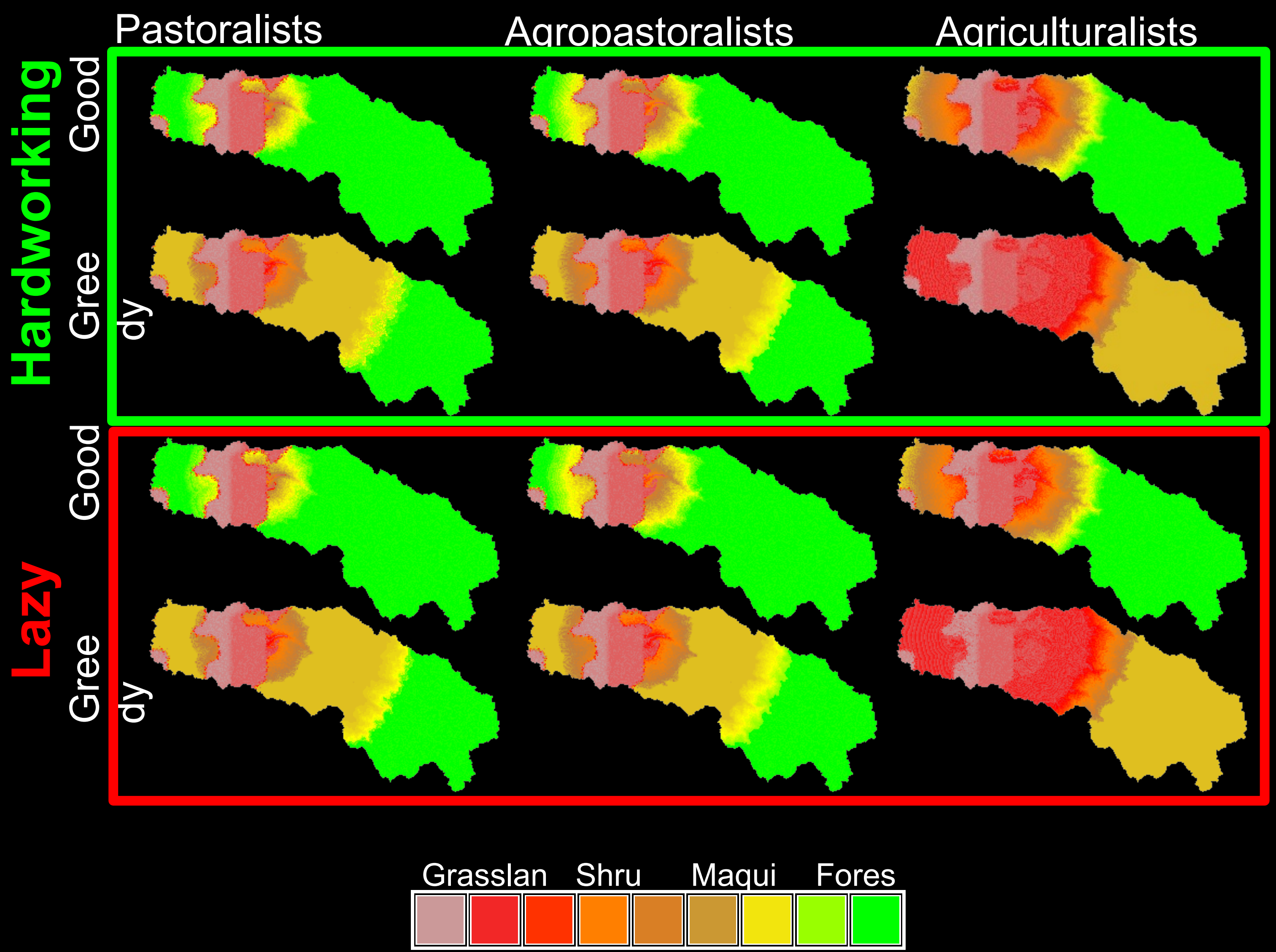
Cyclicity (Inter-Run Lag-Correlation)



Subsistence and Cyclicity

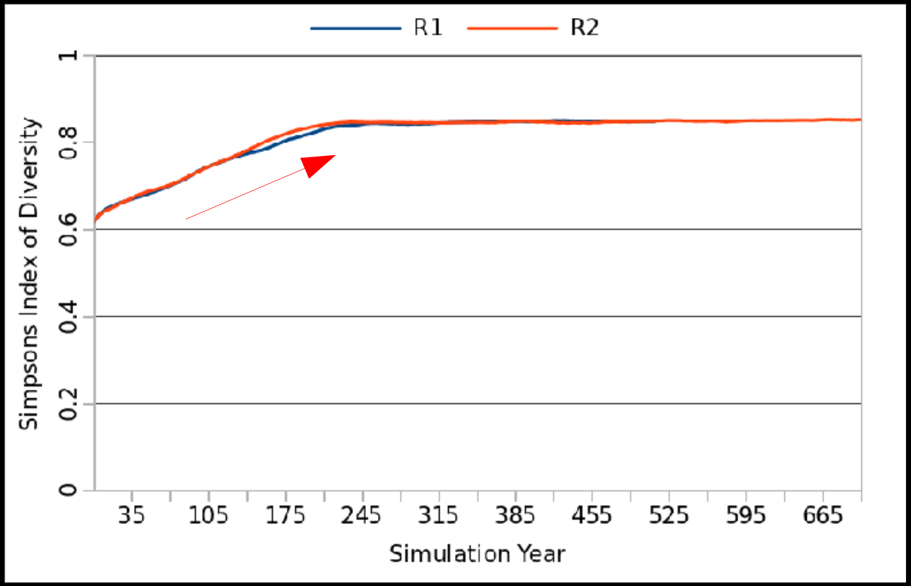
		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hardworking	*Good*	350 (?)	None (long-term?)	None (long-term?)
	Greedy	**180, 275**	**130**, **275**	None (long-term?)
Lazy	*Good*	350 (?)	None (long-term?)	None (long-term?)
	Greedy	**240**	**340**	None (long-term?)

Patterns in Vegetation Dynamics

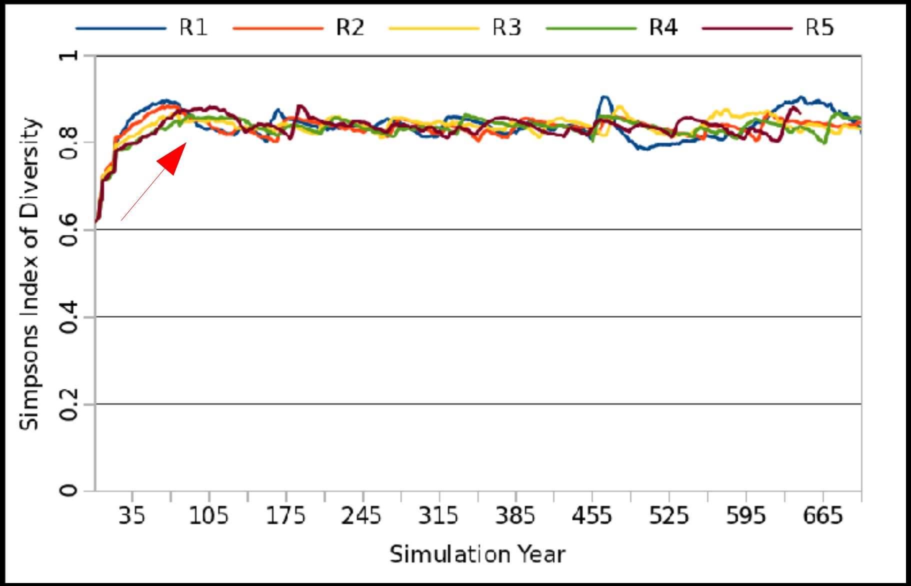


<u>Any</u> Human Activity *Increases* Biodiversity

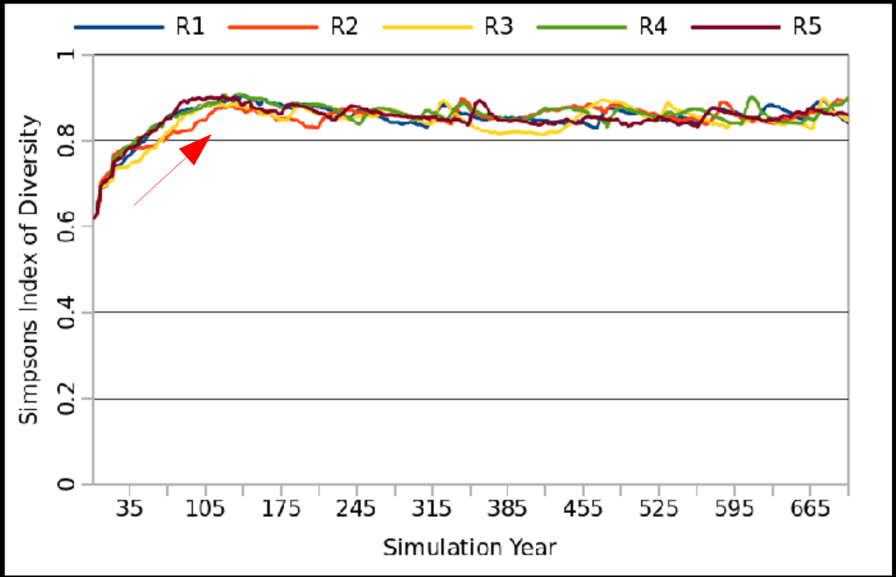
Agriculture



Pastoralism

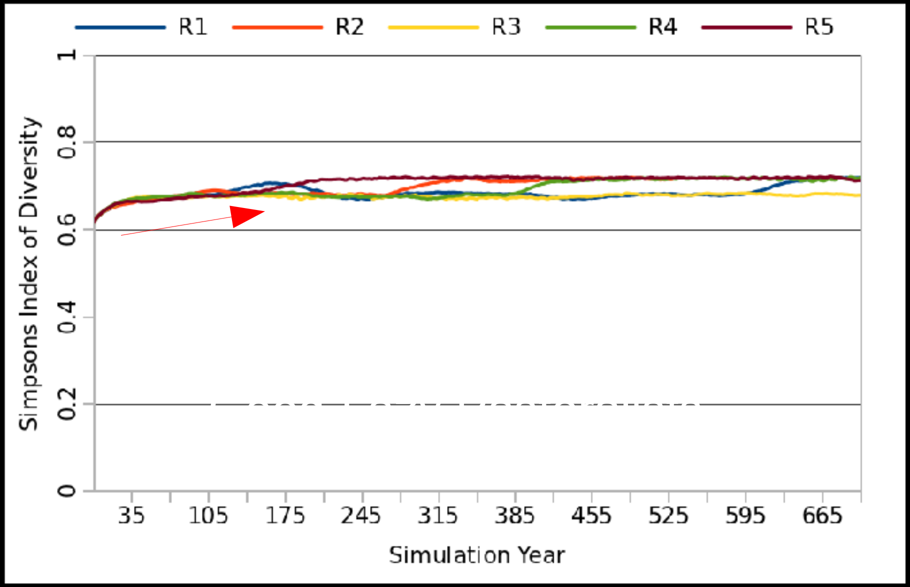


Agropastoralism

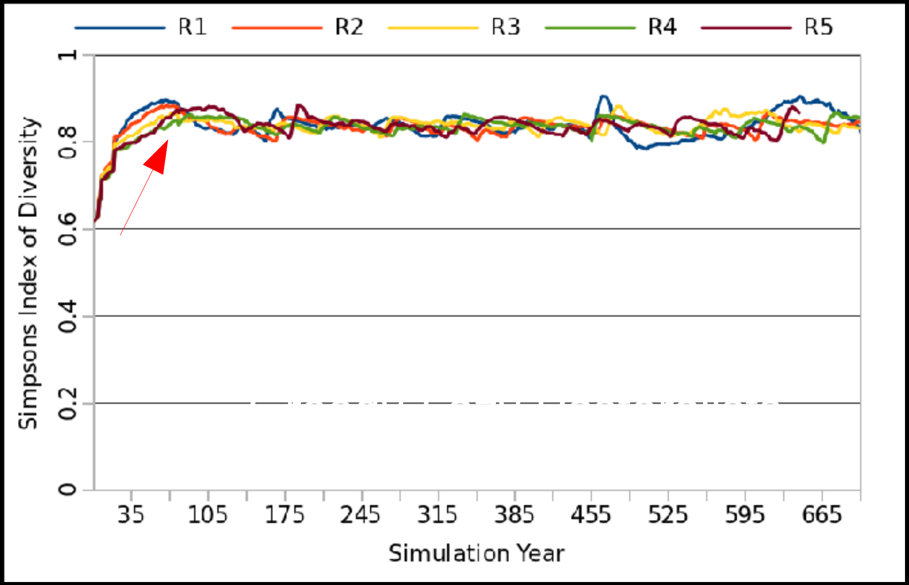


Being “Greedy” *Increases* Biodiversity for pastoralism and agropastoralism...

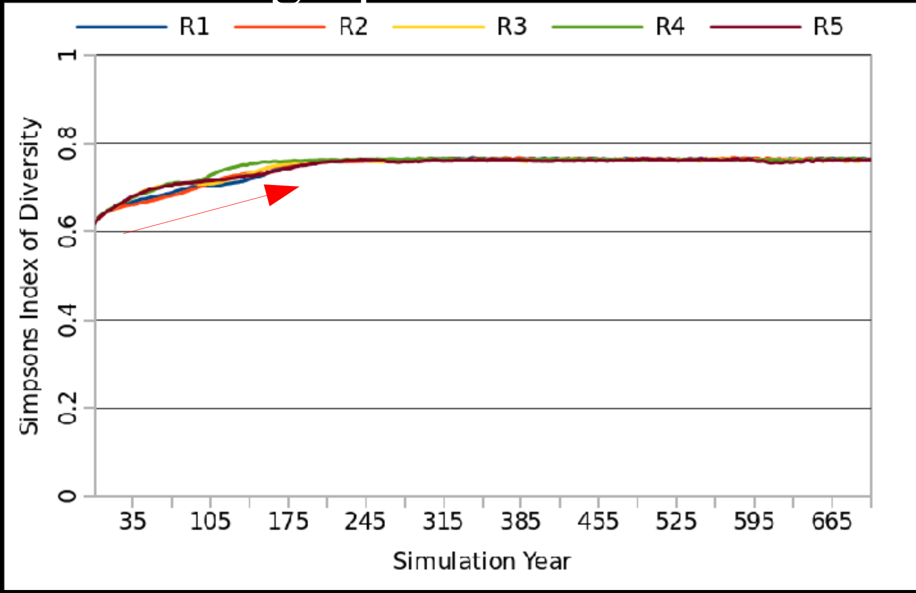
Good Pastoralism



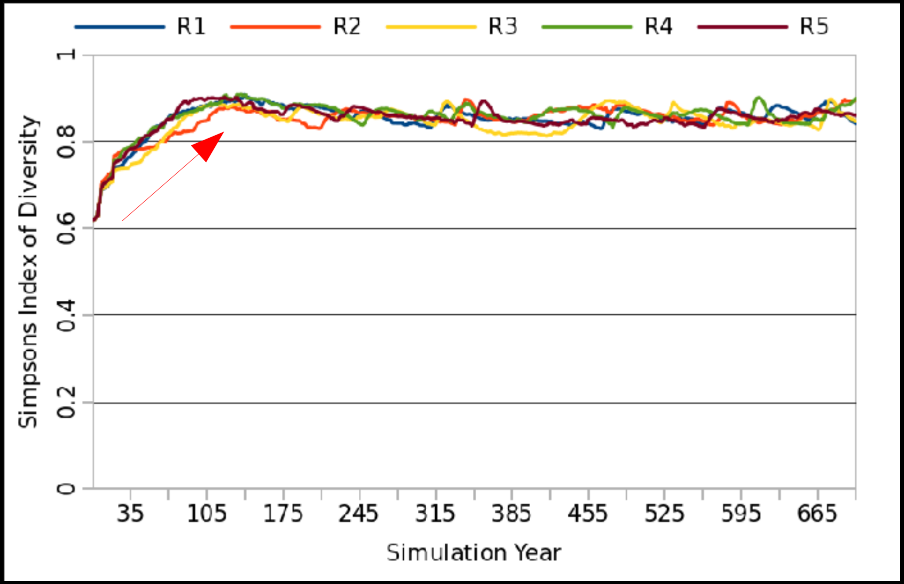
Greedy Pastoralism



Good Agropastoralism

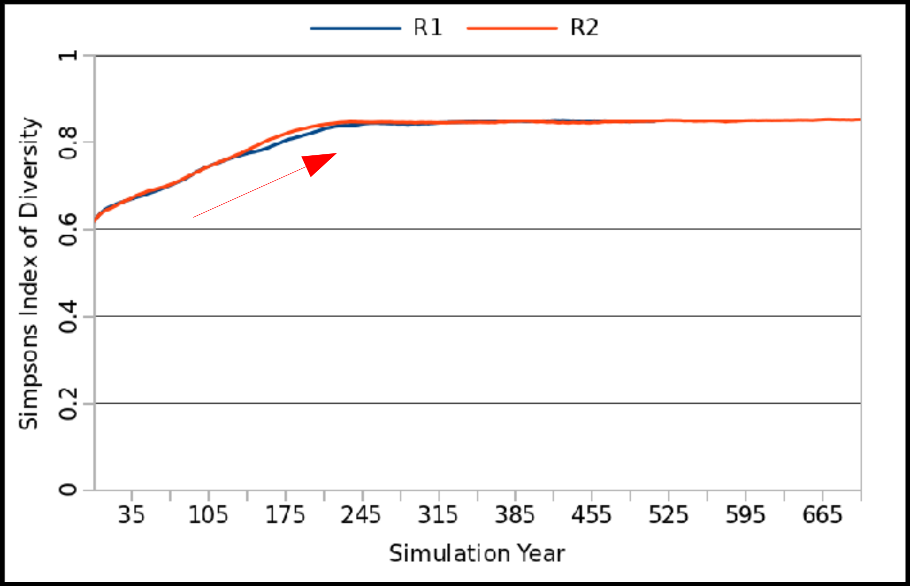


Greedy Agropastoralism

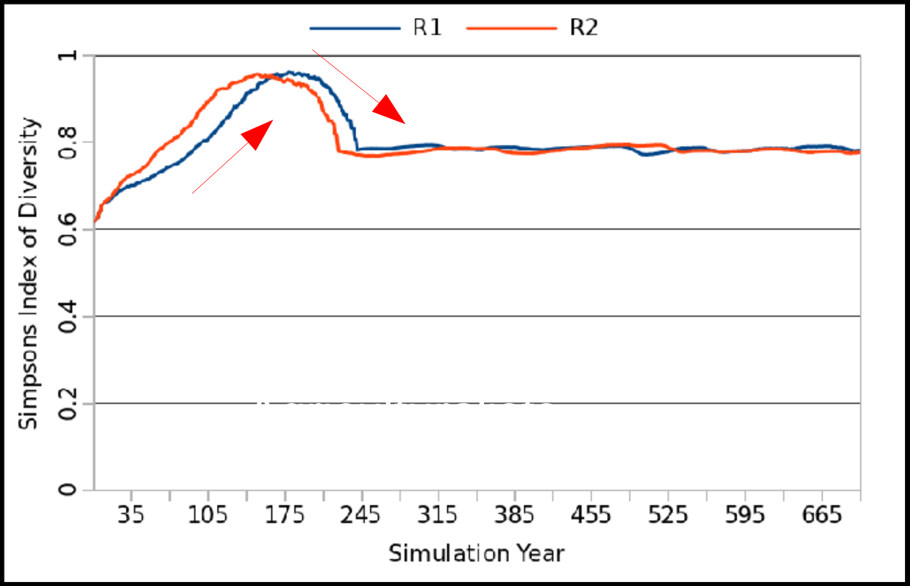


...but not for agriculture

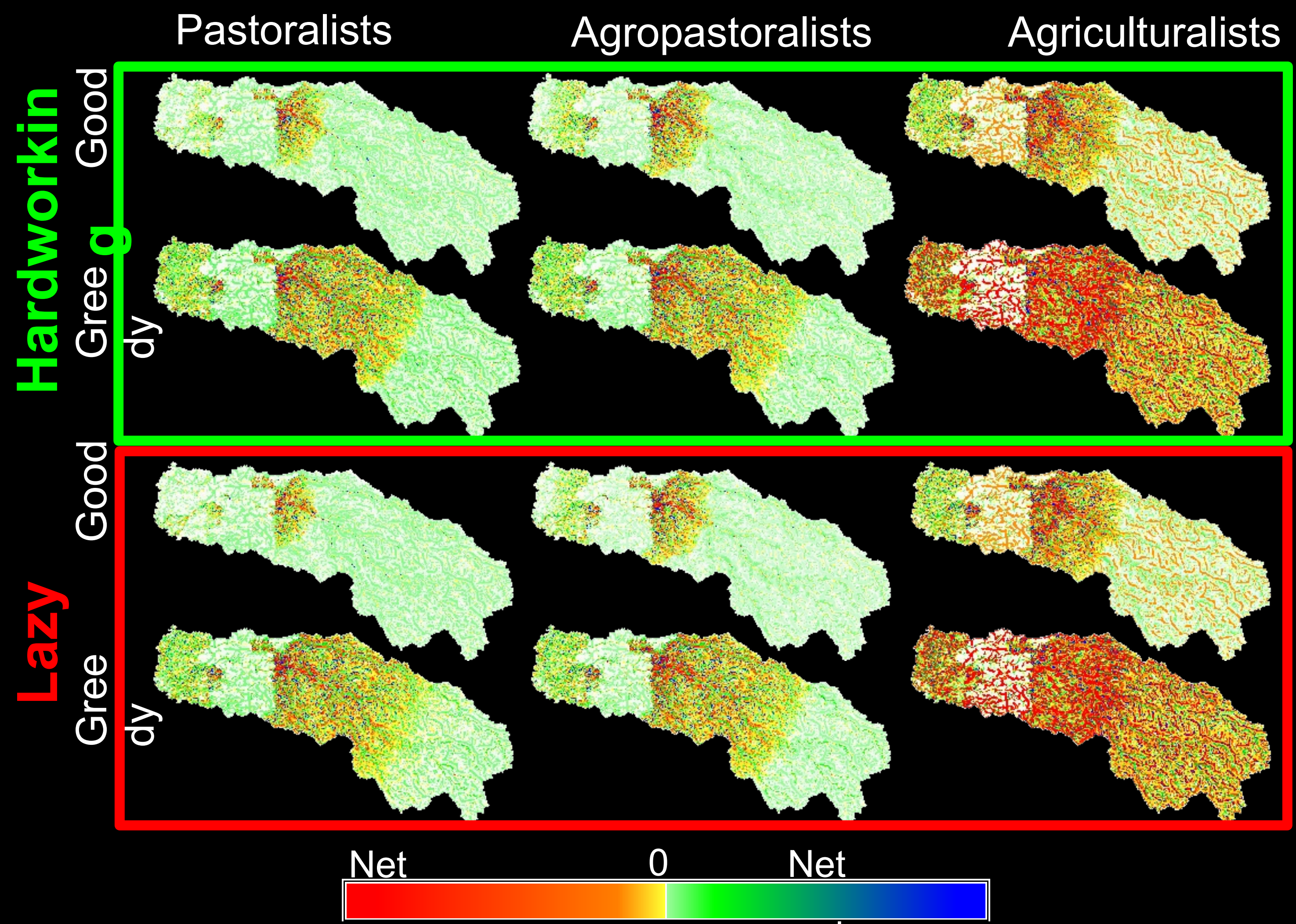
Good Agriculture



Greedy Agriculture



Patterns in Soil Dynamics



In General:

Agriculture leads to *more* erosion than would naturally occur
Pastoralism leads to *less* erosion than would naturally occur
Agropastoralism can produce *more* or produce *less*

Change in Sediment Balance due to Human Landuse (m^3)

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hard-working	*Good*	2020	362	-15376
	Greedy	2972	-628	-160590
Lazy	*Good*	2514	170	-14535
	Greedy	1256	-1395	-154406

Also:

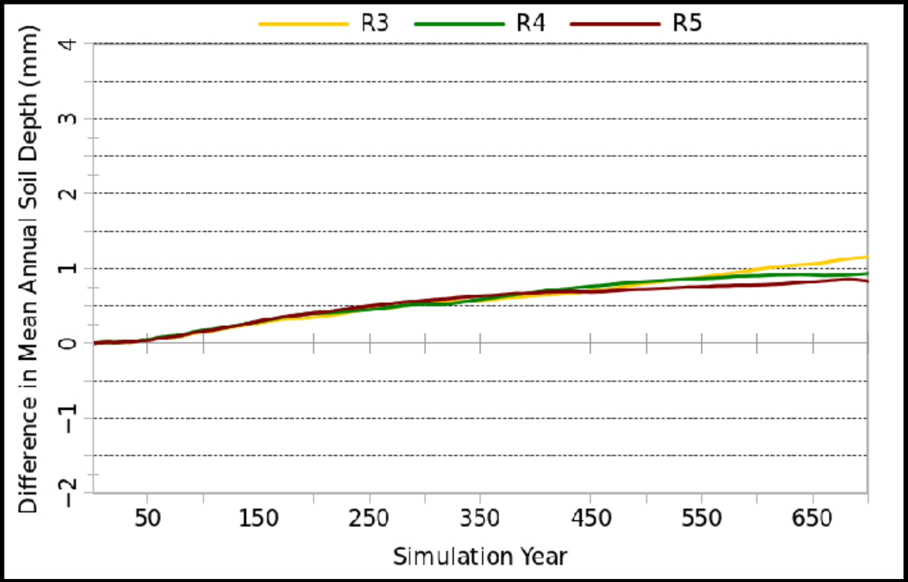
Being Greedy *tends* to result in relatively more erosion (but not always)

Change in Sediment Balance due to Human Landuse (m^3)

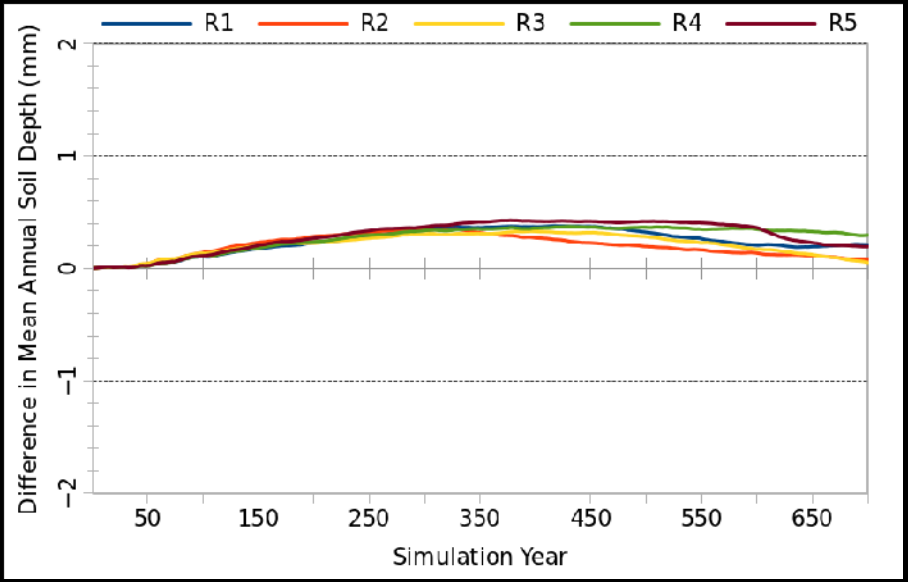
		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hard-working	*Good*	2020	362	-15376
	Greedy	2972	-628	-160590
Lazy	*Good*	2514	170	-14535
	Greedy	1256	-1395	-154406

Four types of temporal change in sediment depths

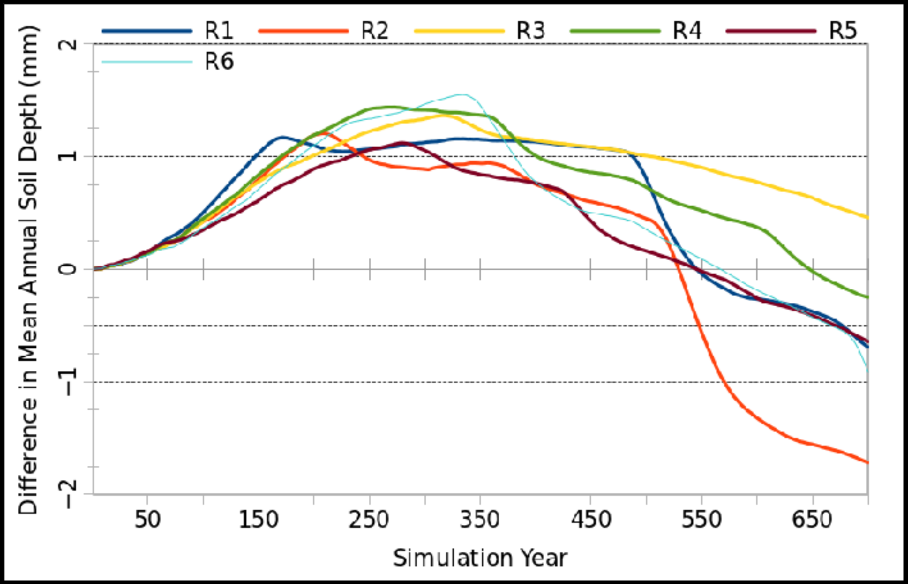
1) Increasing



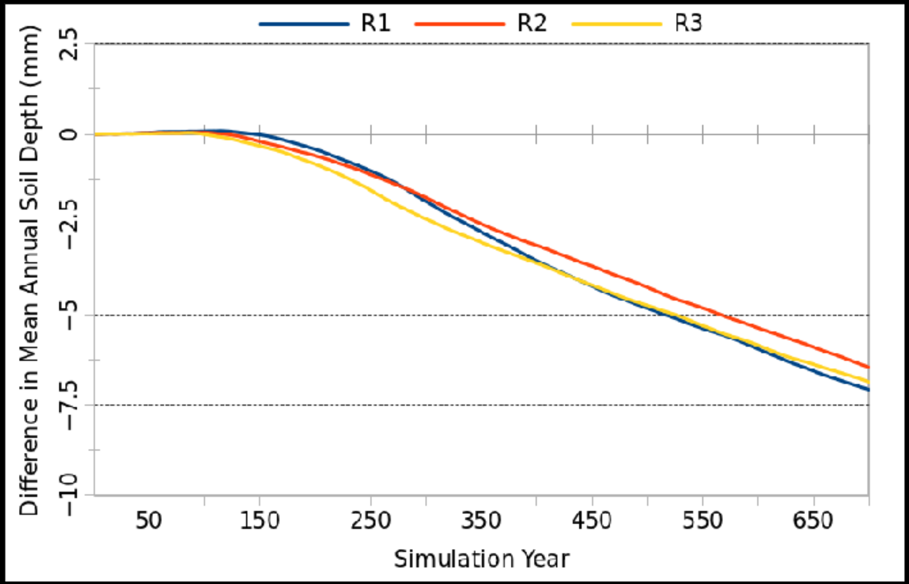
2) Increasing-Stable



3) Increasing-Decreasing



4) Decreasing



Subsistence and Soil Depth

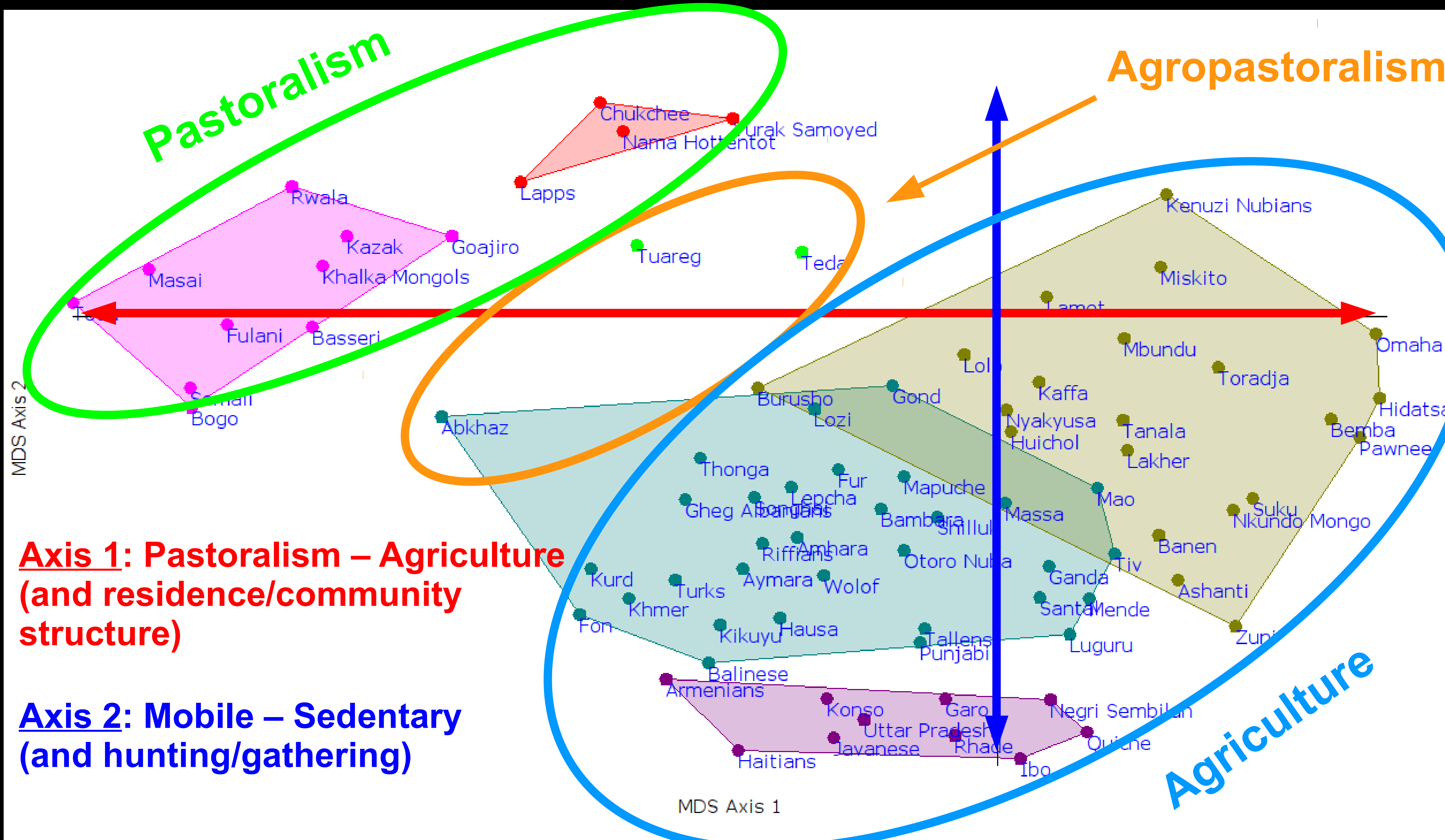
		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hardworking	*Good*	Increasing	Increasing-Stable	Decreasing
	Greedy	Increasing-Stable	Increasing-Decreasing	Decreasing
Lazy	*Good*	Increasing	Increasing-Stable	Decreasing
	Greedy	Increasing-Stable	Increasing-Decreasing	Decreasing

Larger Lessons

Lesson 1: Alternative stable states *do* seem to exist in human subsistence

- Agriculture and Pastoralism may be alternative stable states (i.e., they are “attractors”)
- Agropastoralism may be inherently unstable (i.e., it is a “repellor”)

Alternative Stable States of Human Subsistence Systems



79 societies; 52 subsistence, mobility, economic, and demographic variables

Larger Lessons

Lesson 2: Stability does not mean invulnerability

- Agriculture may be “stable”, but it also seems to be most at-risk for a large critical transition
- It may be especially at risk from external pressures, like climate change

General Resilience Trends For Each Experiment

System Potential

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hard-working	*Good*	Low	Medium	Medium-High
	Greedy	Low	Medium	High
Lazy	*Good*	Low	Medium	Medium-High
	Greedy	Low	Medium	High

System Resilience

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hard-working	*Good*	High	Low	Low
	Greedy	High	High	Low
Lazy	*Good*	High	Low	Low
	Greedy	High	High	Low

System Connectedness

		Pastoralists	*Agropastoralists*	*Agriculturalists*
Hard-working	*Good*	Low	Medium	High
	Greedy	Medium-Low	Medium-Low	High
Lazy	*Good*	Low	Medium	High
	Greedy	Medium-Low	Medium-Low	High

Larger Lessons

Lesson 3: Small differences in subsistence mindset can lead to widely different outcomes

- Some things only apparent over the long term
- Likely hard to predict the outcome of particular decisions

Future Research

- Expand research to other parts of the world
- Enable subsistence adaptation, and explore its effects
- Investigate the role of climate change in critical transitions

Thank you!

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