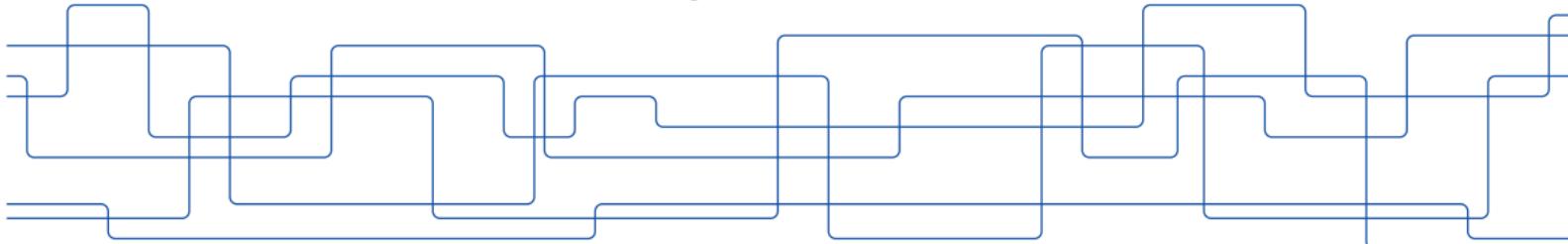




A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

En Rumsligt Explicit Agentbaserad Modell av Interaktionen mellan Människor och Resurser på Påskön

Peter Steiglechner, 29 June 2020



Outline

A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

Easter Island History

Traditional Approach: Dynamic System Modelling

New Approach: Agent-Based Modelling (ABM)

The Easter Island ABM

Results and Discussion

Outline

A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

Easter Island History

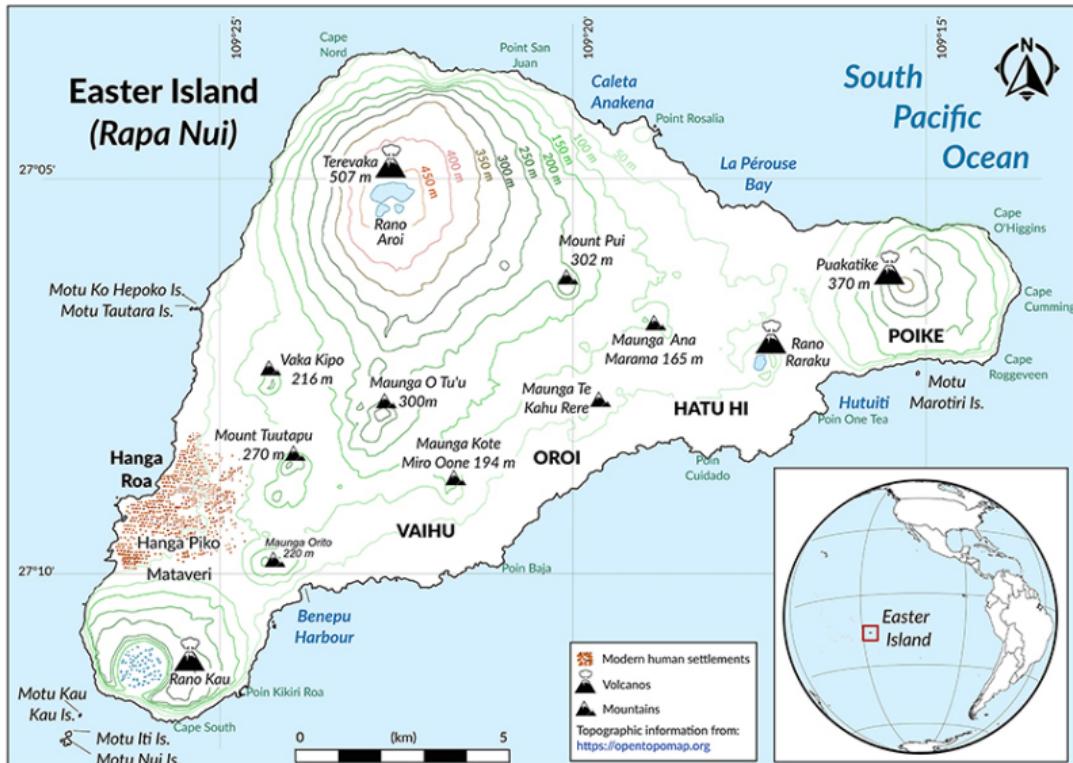
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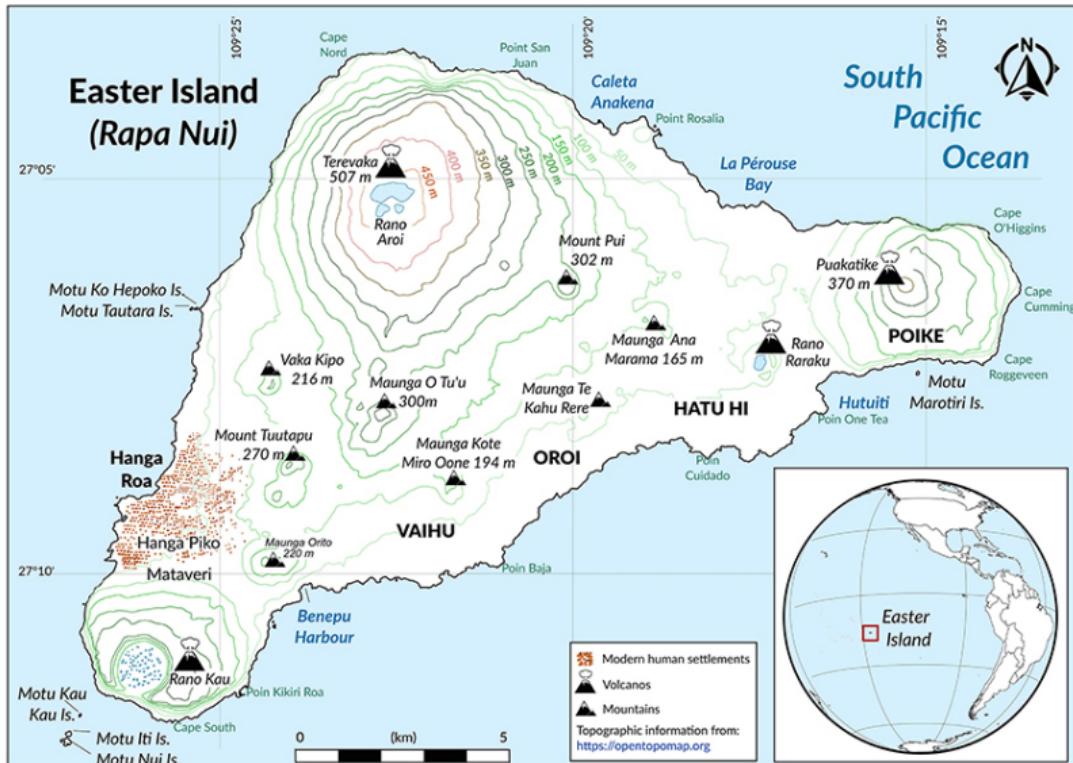
Results and Discussion

Easter Island Mystery

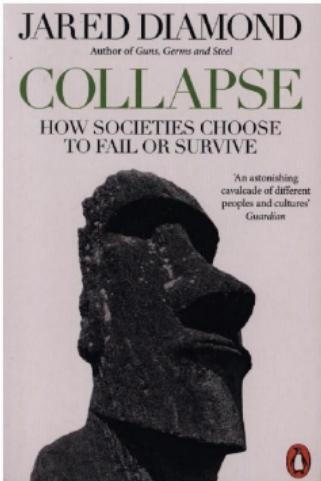


Merico (2017)

Easter Island Mystery



Merico (2017)



Diamond (2011)

Facts of Easter Island History



Palm Forest



Deforestation



Pacific Rats



Agriculture



Moai Statues



European Contact



Palm Forest

Artistic Rendering, Rull (2020)



Facts of Easter Island History



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Deforestation

Modern Day Image en.wikipedia.org/wiki/Easter_Island



Facts of Easter Island History



Palm Forest



Deforestation



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Moai Statues

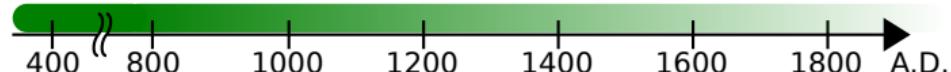


European Contact



Pacific Rats

de.wikipedia.org/wiki/Pazifische_Ratte



Facts of Easter Island History



Palm Forest



Deforestation



Pacific Rats



Agriculture



Moai Statues



European Contact



Agriculture

Hunt and Lipo (2009)



Facts of Easter Island History



Palm Forest



Deforestation



Pacific Rats



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Moai Statues



European Contact



Moai Statues

<https://nl.wikipedia.org/wiki/Moai>



Facts of Easter Island History



Palm Forest



Deforestation



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Moai Statues



European Contact

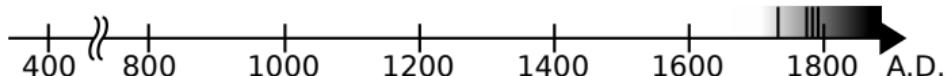


European Contact

Observations:

- ▶ Advanced civilisation
- ▶ Initially dense forest
- ▶ Barren island
- ▶ Declining population number
- ▶ Moai lying on the ground

www.nytimes.com/2017/10/12/science/easter-island-dna-south-america.html



The Mystery – Two Major Narratives

Ecocidal View

Brander and Taylor (1998), Diamond (2011), Bahn and Flenley (2017)

- Early arrival,
- Population grows slowly exponentially,
- Intensification of agriculture and deforestation,
- Population reaches $6k$ to $20k$ people in 17th century,
- Overexploitation of resources and conflict (Malthusian catastrophe),
- 'Collapse' prior to European contact

Genocidal View

Peiser (2005), Hunt (2007), Basener et al. (2008)

- Late arrival,
- Population grows quickly and then remains constant at $4k$ people,
- Rats cause deforestation,
- Humans resilient,
- European contact triggers decline due to slave trades and diseases



Population dynamics?

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Mathematical Modelling of Human-Resource Interaction

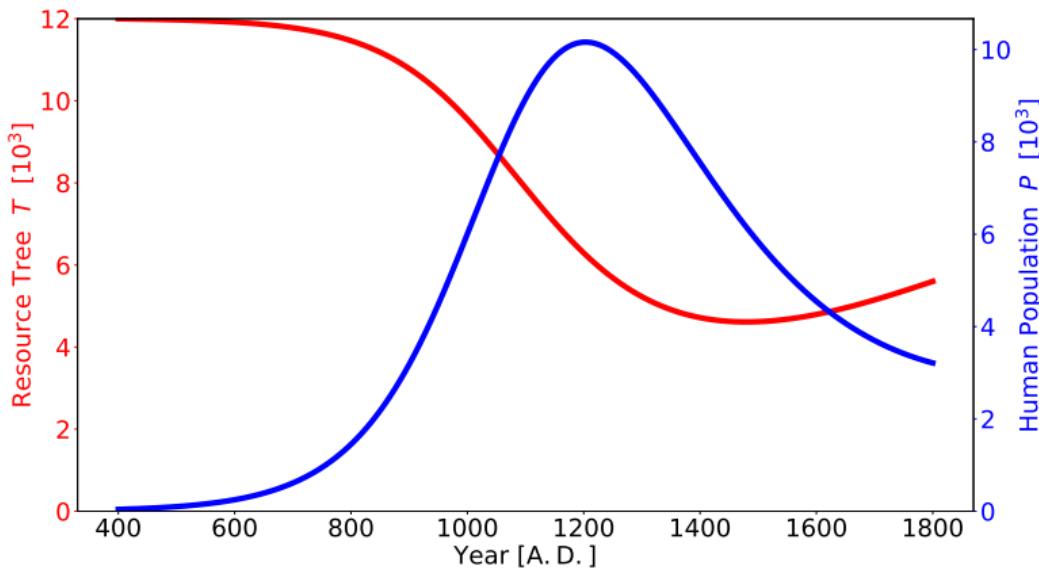
- ▶ Macroscopic variables:
 - ▶ Resource stock (palm trees): T
 - ▶ Human population size: P
- Human-resource interactions (Lotka-Volterra predator-prey type)
- ▶ So far: Dynamics described by ordinary differential equations (ODEs)

$$\begin{aligned}\frac{dP}{dt} &= r_P(T, P, H(P)) \cdot P \\ \frac{dT}{dt} &= r_T(T) \cdot T - H(P)\end{aligned}$$

with

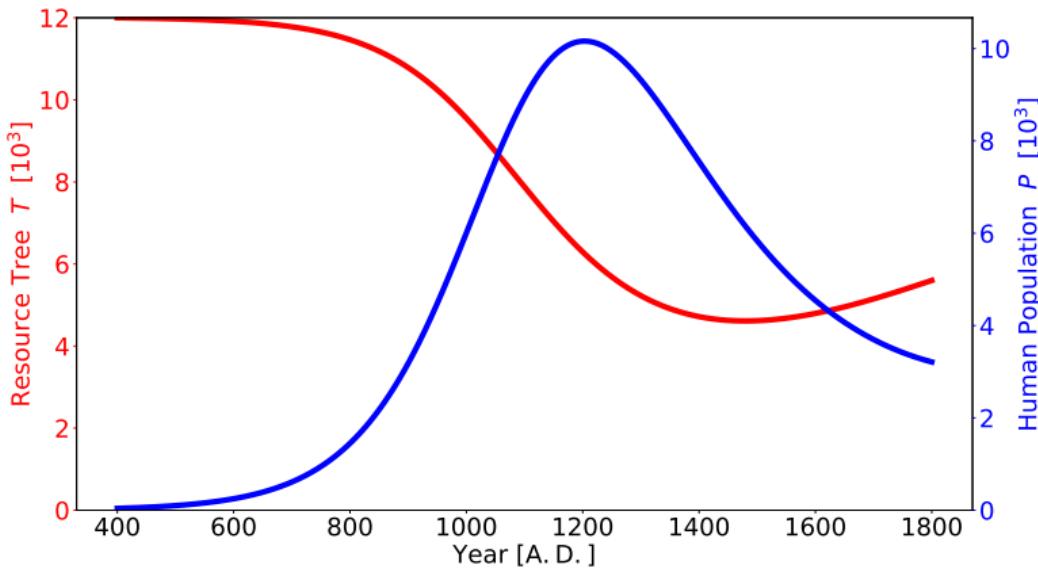
$$\begin{aligned}H(P) &= \text{harvest of population } P; \\ r_{T,P} &= \text{functions for rates of growth}\end{aligned}$$

The first model on Easter Island: Brander and Taylor (1998)



Model by Brander and
Taylor (1998)

The first model on Easter Island: Brander and Taylor (1998)

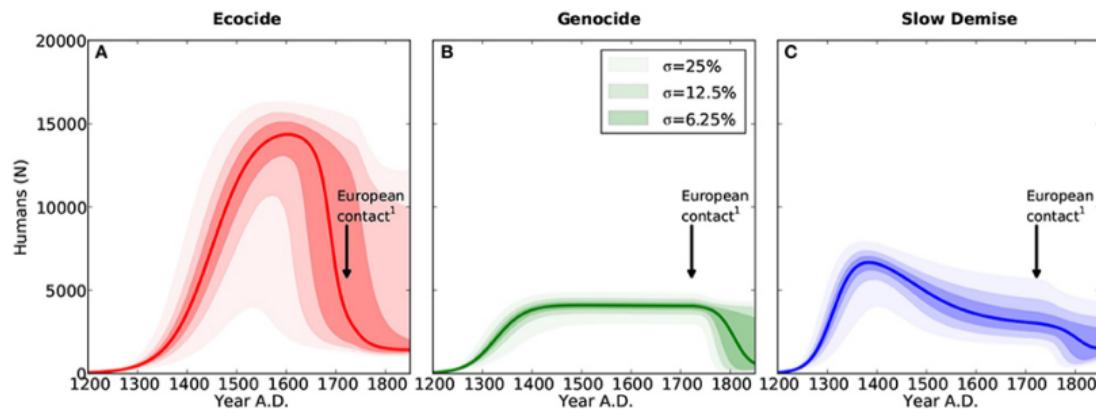


Model by Brander and Taylor (1998)

- ▶ Extensions:
 - ▶ Socio-economic institutions (Good and Reuveny, 2006)
 - ▶ Second resource (D'Alessandro, 2007)
 - ▶ Rat population (Basener et al., 2008)
 - ▶ Disease model (Brandt and Merico, 2015)

Shortcomings of Dynamic System Models

► Uncertainty in Parameters

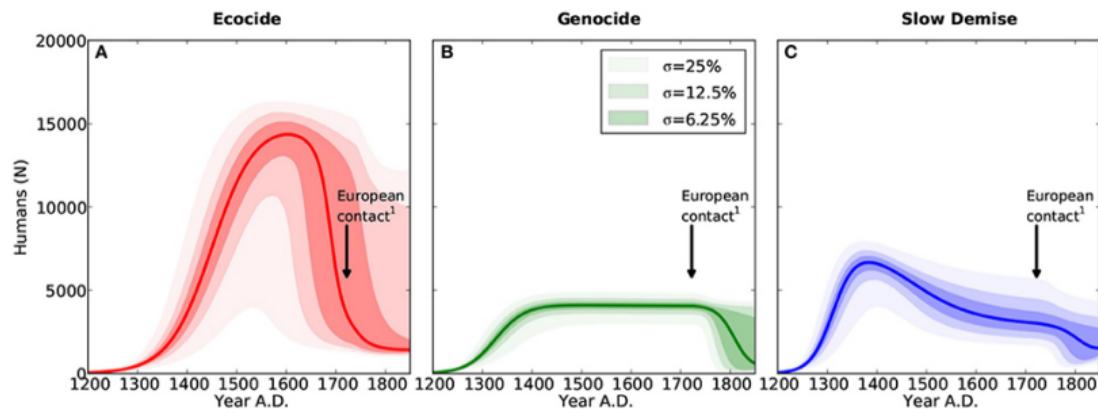


Model by
Brandt and
Merico (2015)

→ Macroscopic view does not give insight into plausibility of resulting trajectory

Shortcomings of Dynamic System Models

► Uncertainty in Parameters



Model by
Brandt and
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► Neglect ...

- Spatial constraints
- Irreducibility and heterogeneity
- Adaptation and emergent phenomena
- Stochasticity

More in e.g. Bookstaber (2017), Bonabeau (2002)

Outline

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Results and Discussion

What is Agent-Based Modeling (ABM)

Algorithm 1: General Structure

Initialise Environment

Initialise discrete Agents with specific traits in some location within the environment

for $t \in \{t_{\text{start}}, t_{\text{end}}\}$ **do**

for agent (*in asynchronous order*) **do**

Interaction between agent and environment based on rules and heuristics

Update agent according to autonomous decisions

Calculate aggregate variables of environment and agents

Advantages of ABM with respect to ODE models

Epstein and Axtell (1996), Bonabeau (2002) on Agent-Based Modelling:

"Perhaps one day people will interpret the question, 'Can you explain [an observed social phenomenon]?' as asking 'Can you grow it?'"

From macroscopic, top-down description → to microscopic, bottom-up description

1. ABM allows for rules and heuristics to be

- ▶ non-linear, discontinuous
 - ▶ heterogeneous,
 - ▶ stochastic,
 - ▶ adaptive
- non-ergodicity & computational irreducibility

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3. Decisions include stochasticity

4. Natural implementation of heterogeneous space dependency

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Easter Island History

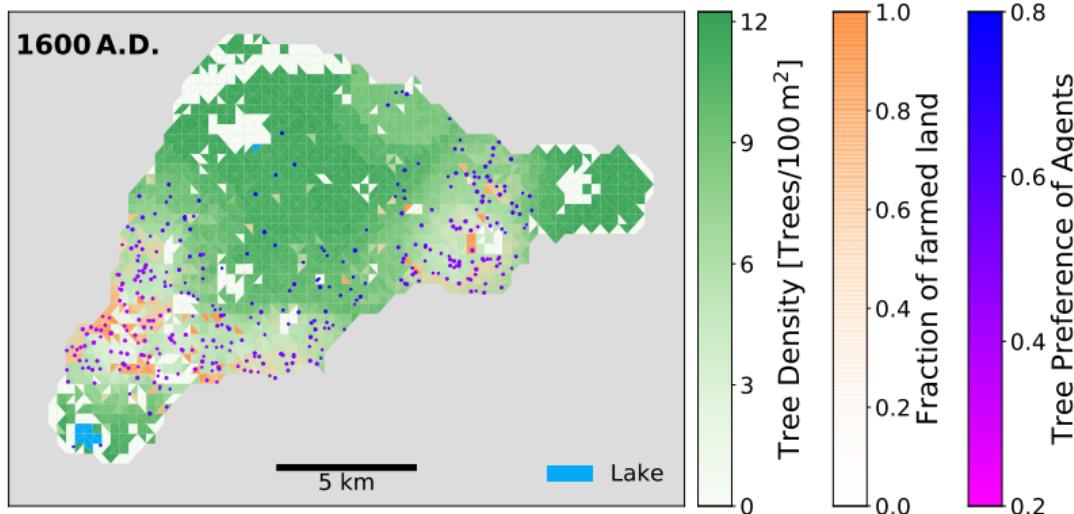
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The Easter Island ABM

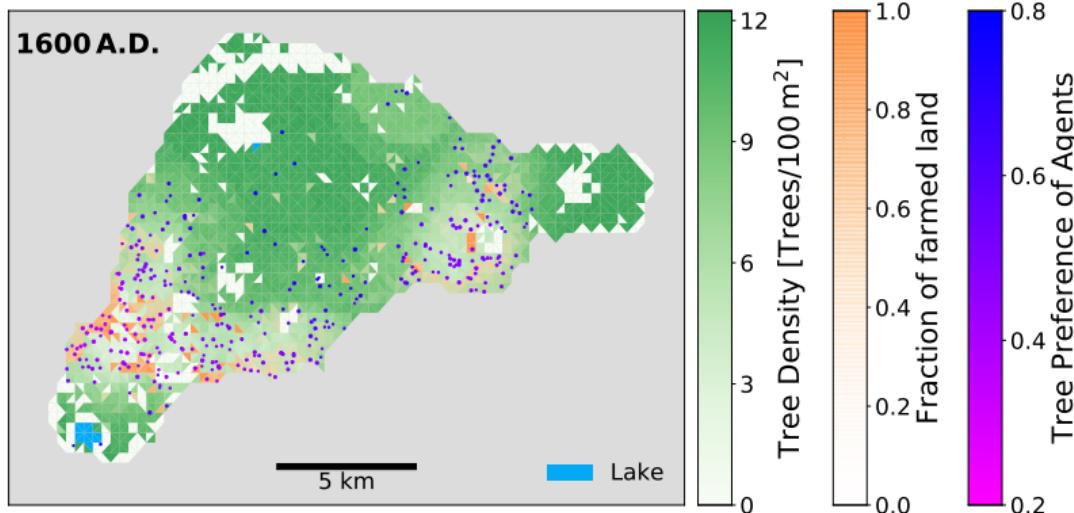
Results and Discussion

Easter Island ABM – Overview



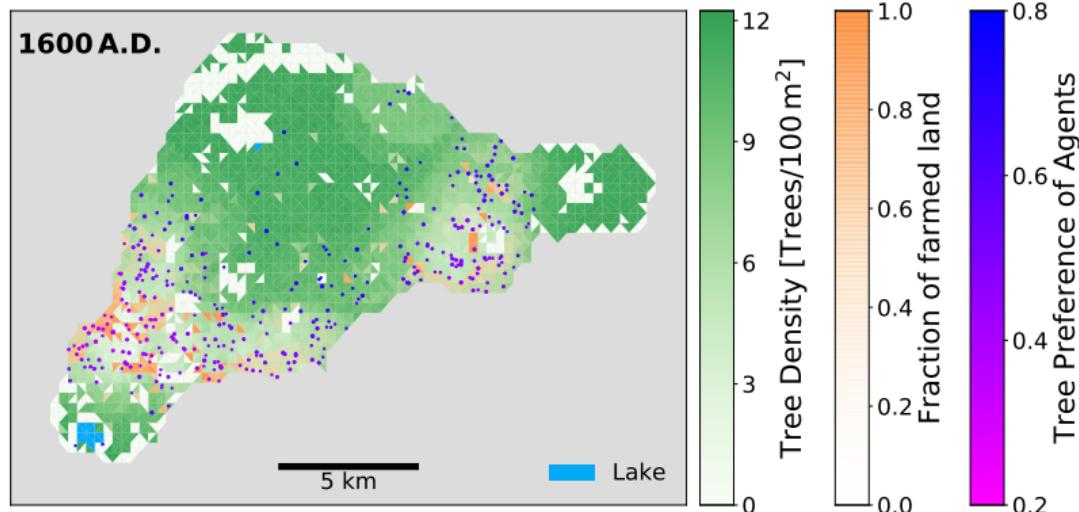
Easter Island ABM – Overview

- Agents (dots) are households of a few dozen (ca. up to 40) individuals.



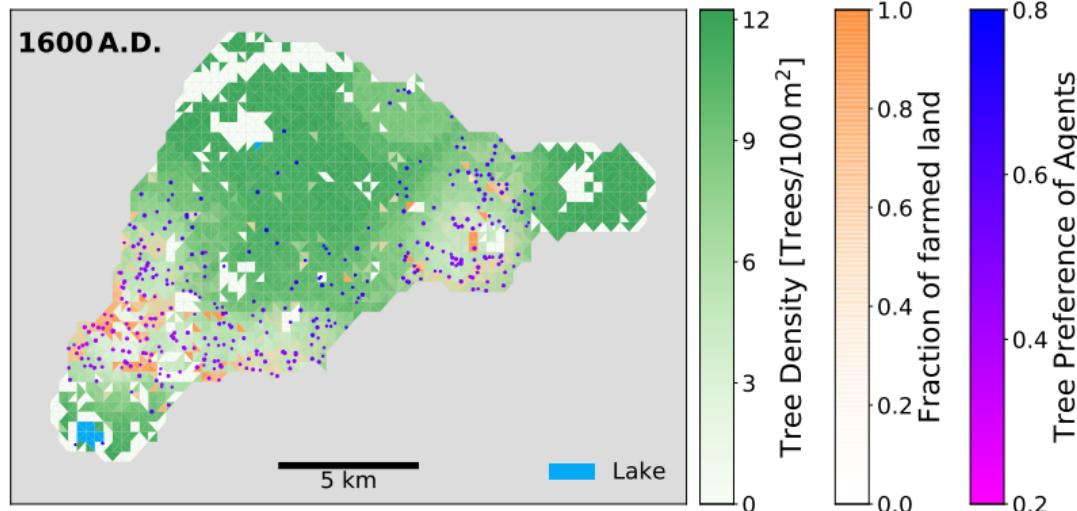
Easter Island ABM – Overview

- ▶ Agents (dots) are households of a few dozen (ca. up to 40) individuals.
- ▶ Environment provides trees and farming products
- ▶ Agents harvest from local environment (cut trees and occupy farming sites)



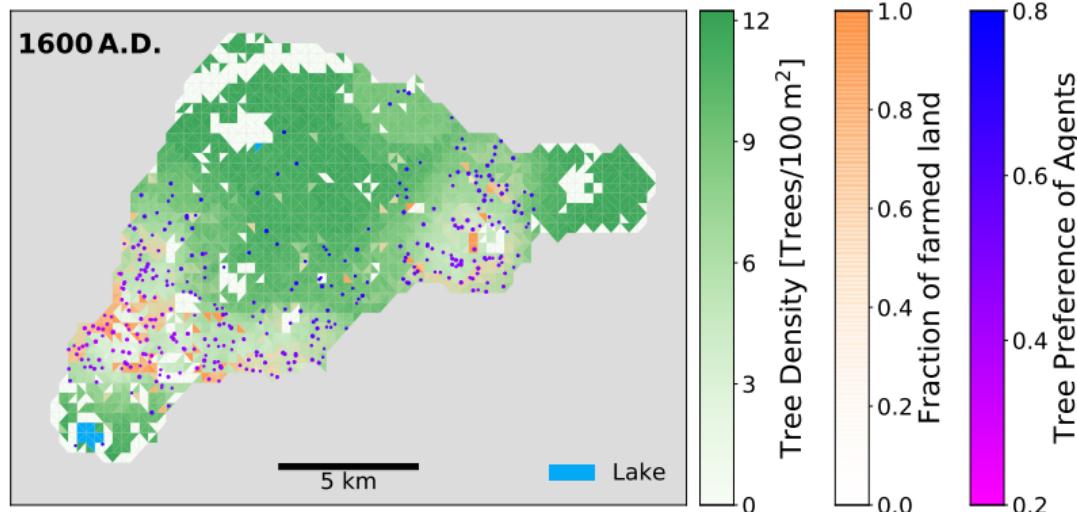
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If not successful, it decreases and the agent moves

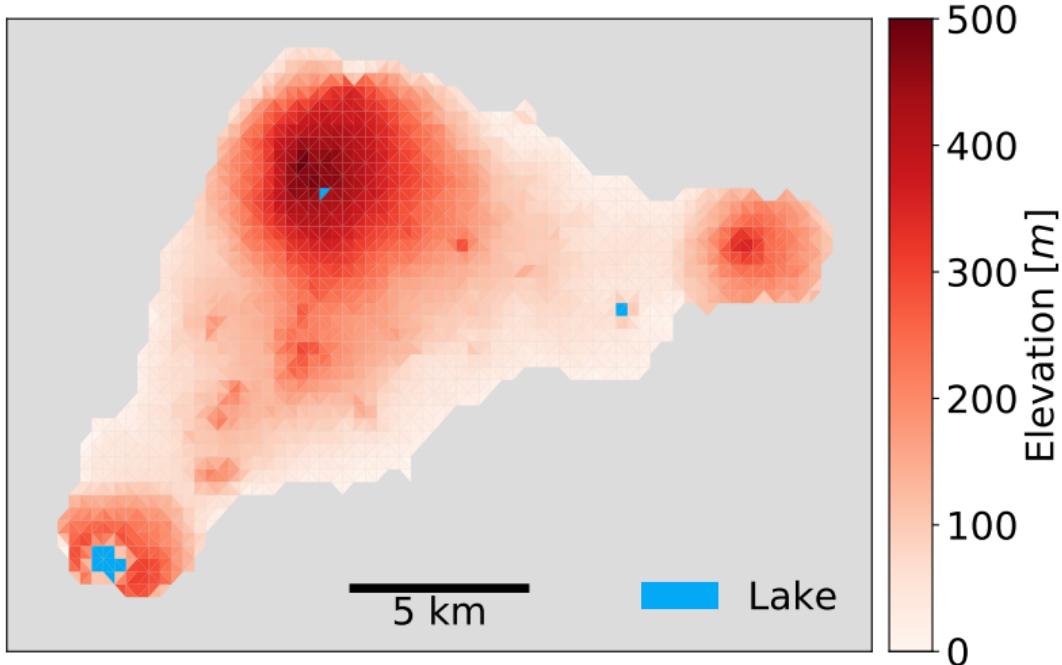


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- ▶ If successful, the agent's population grows (eventually producing more agents)
If not successful, it decreases and the agent moves
- ▶ Agents adapt their resource preference according to the perceived local environment



Create the Environment – Discretisation



Create the Environment – Features

Environment

Variable

Process ("?" = conditional process)

Global Parameter (or Additional Info)



Human Environment Interaction

Variable Dependency

Cell c of N_c

Geographic Properties

Area $A(c)$

Midpoint (c_x, c_y)

Elevation $el(c)$

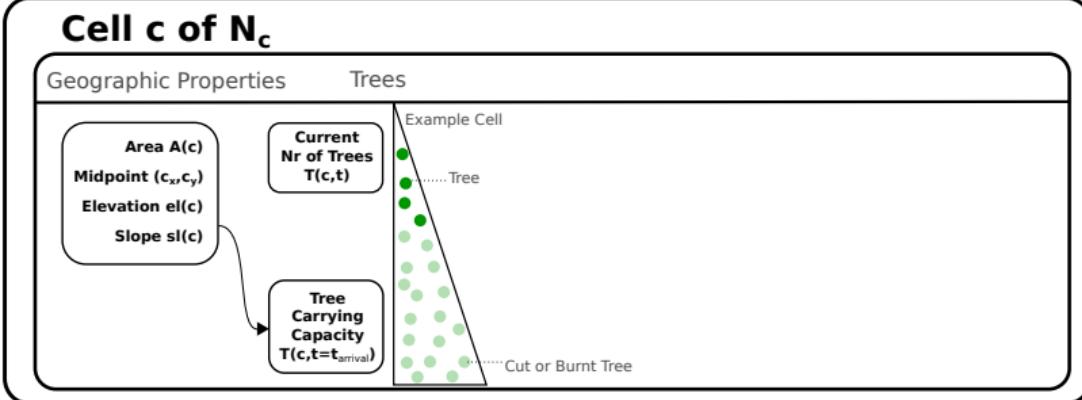
Slope $sl(c)$

Create the Environment – Features

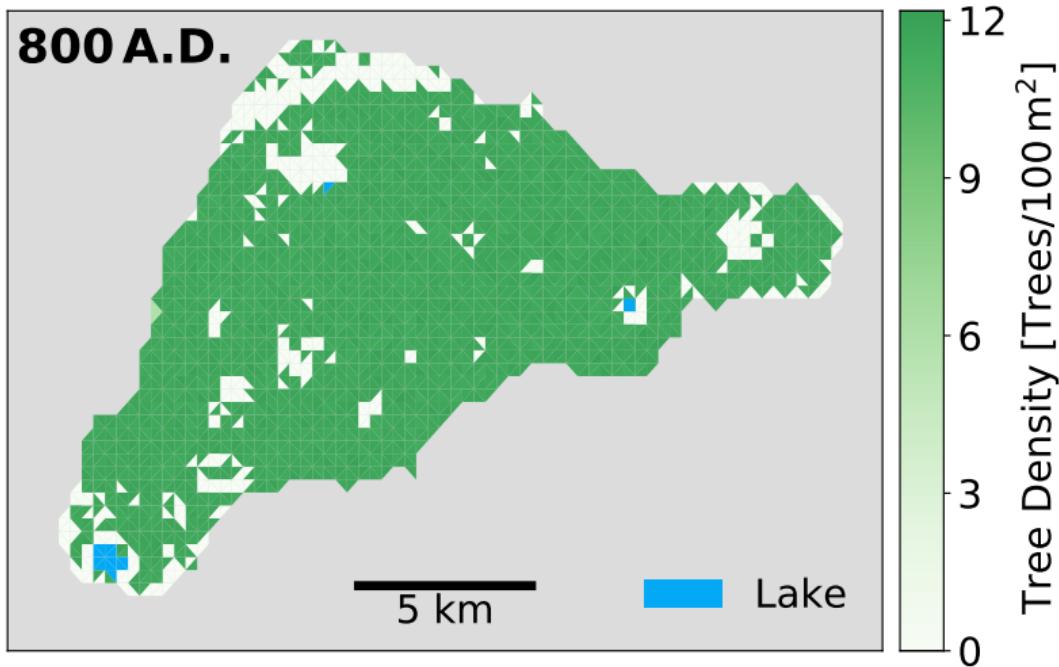
Environment

Variable
Process ("?" = conditional process)
Global Parameter (or Additional Info)

→ Human Environment Interaction
→ Variable Dependency



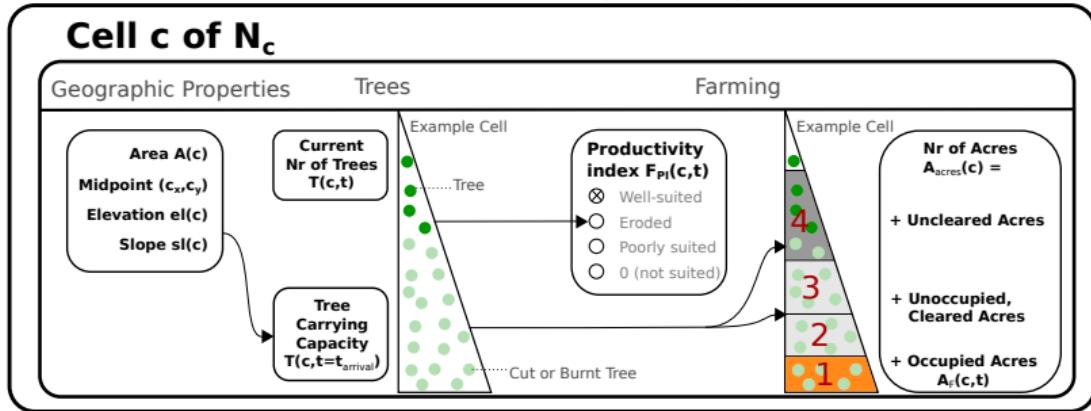
Create the Environment – Features



Based on Mieth and Bork (2015), Bahn and Flenley (2017), Rull (2020)

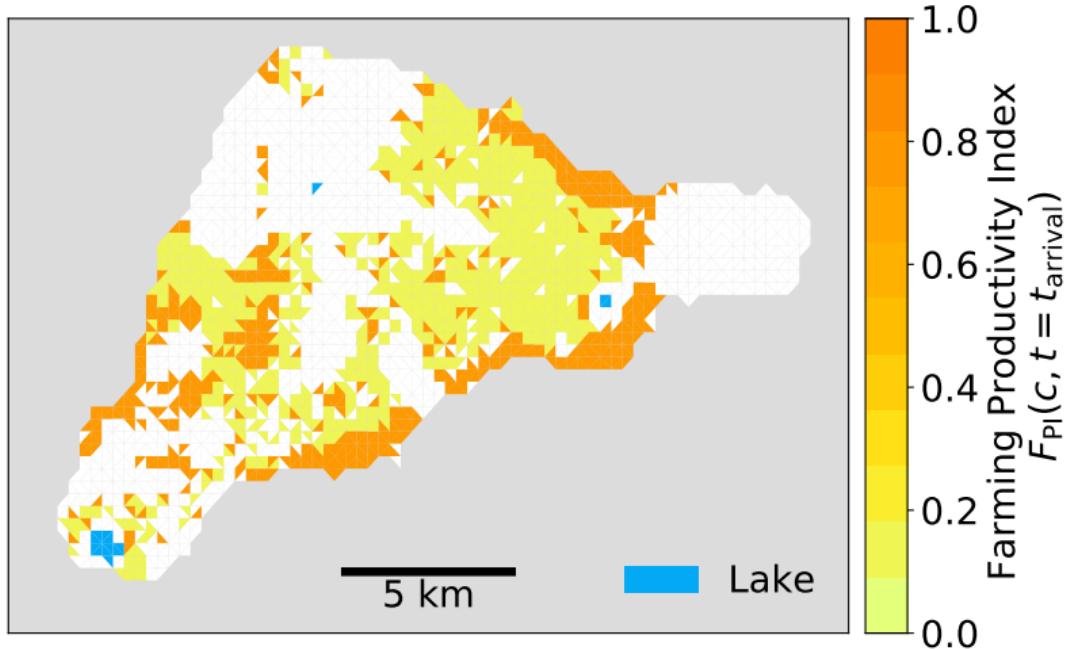
Create the Environment – Features

Environment



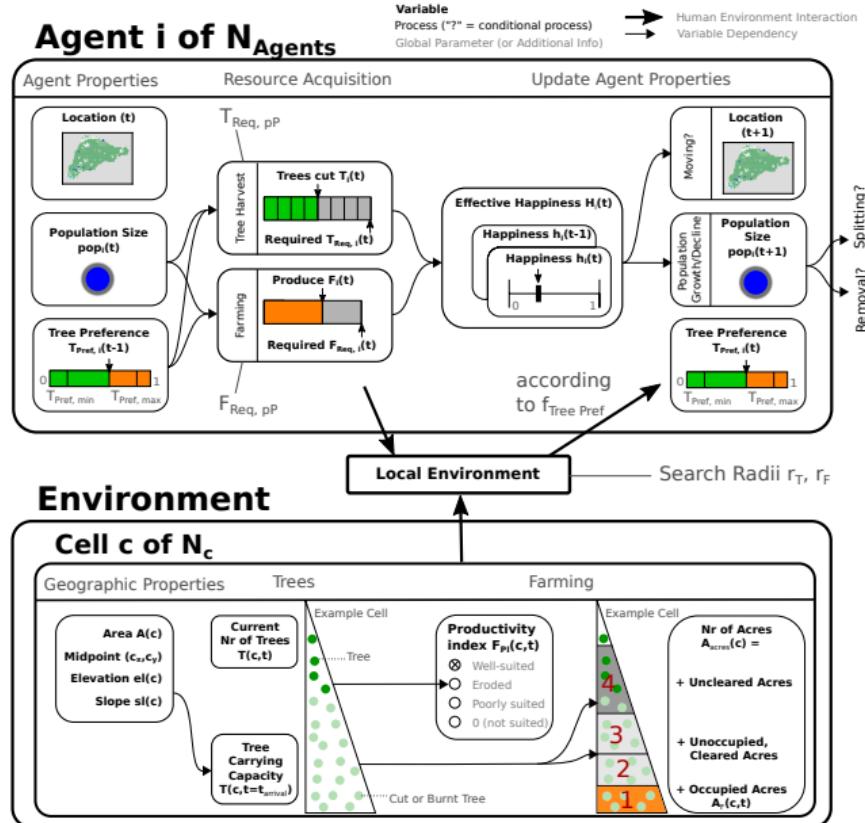
1 acre $\approx 100 \text{ m} \times 40 \text{ m.}$

Create the Environment – Features



Based on Louwagie, Stevenson, and Langohr (2006), Puleston et al. (2017)

Agents and Interaction with Environment



Agents and Interaction with Environment

Agent i of N_{Agents}

Variable

Process ("?" = conditional process)

Global Parameter (or Additional Info)



Human Environment Interaction
Variable Dependency

Agent Properties

Location (t)



Population Size $pop_i(t)$



Tree Preference $T_{Pref, i}(t-1)$



Agents and Interaction with Environment

Agent i of N_{Agents}

Variable

Process ("?" = conditional process)

Global Parameter (or Additional Info)



Human Environment Interaction
Variable Dependency

Agent Properties

Resource Acquisition

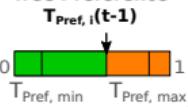
Location (t)



Population Size
 $pop_i(t)$



Tree Preference



$T_{Req, pP}$

Trees cut $T_i(t)$

Required $T_{Req, i(t)}$

Farming

Produce $F_i(t)$

Required $F_{Req, i(t)}$

$F_{Req, pP}$

Local Environment

Search Radii r_T, r_F

Environment

Cell c of N_c

Geographic Properties

Trees

Farming

Agents and Interaction with Environment

Agent i of N_A Agents

Variable

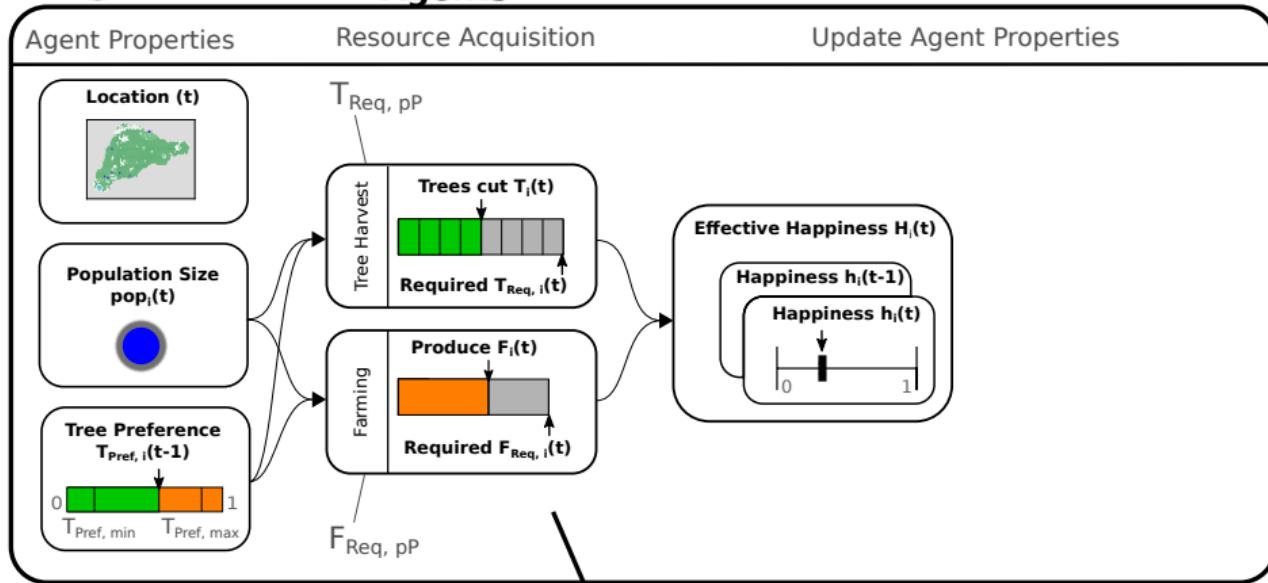
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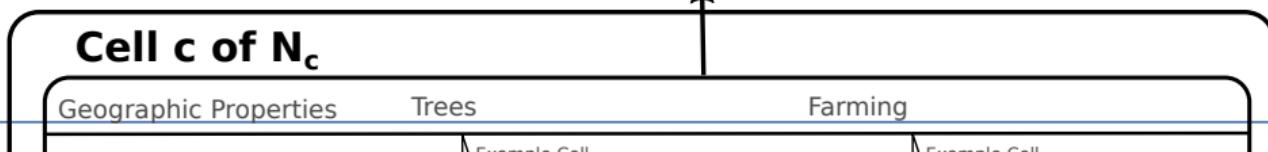


Human Environment Interaction

Variable Dependency



Environment



Agents and Interaction with Environment

Agent i of N_{Agents}

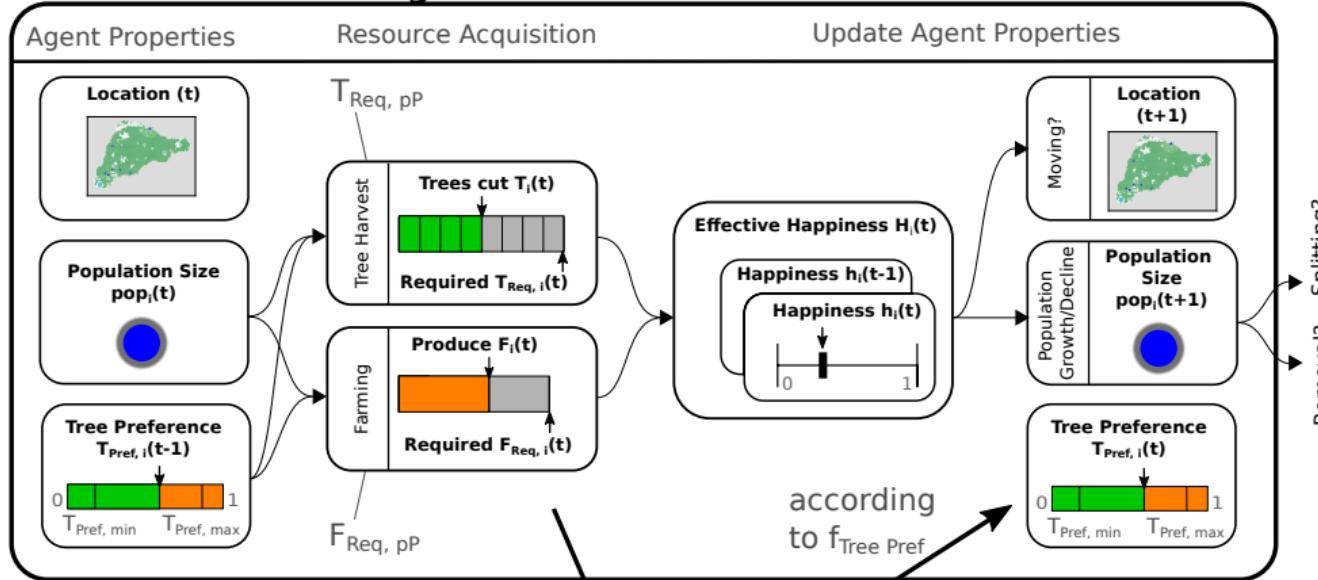
Variable

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Human Environment Interaction
Variable Dependency



Environment

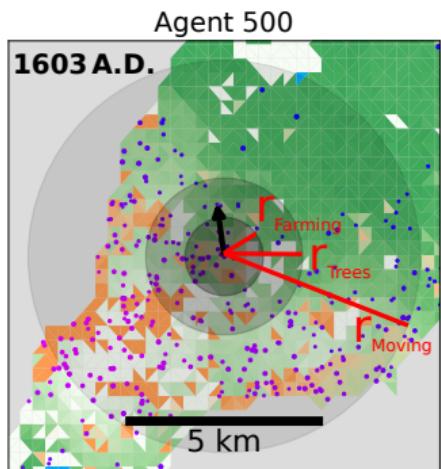
Cell c of N_c

Geographic Properties

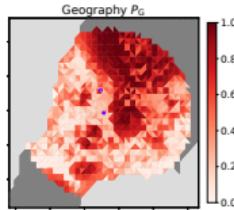
Trees

Farming

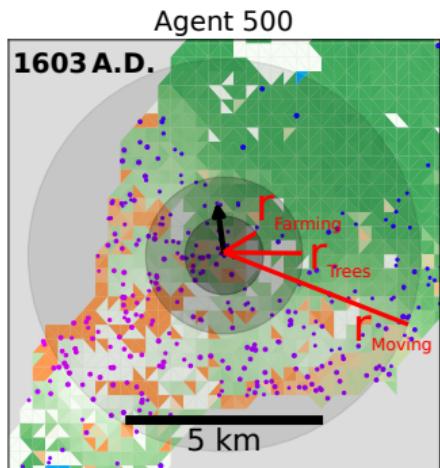
Moving: Decision Making based on Penalties



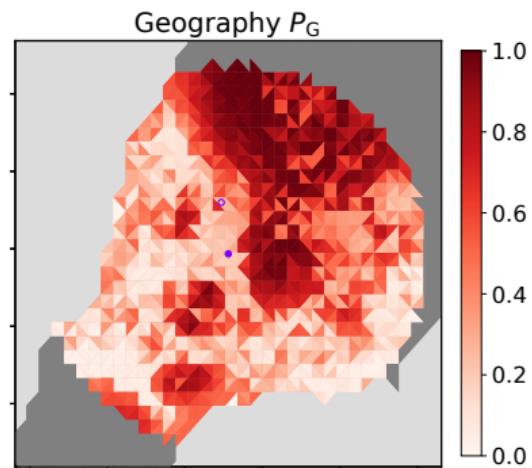
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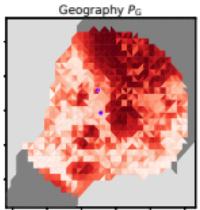
Geography



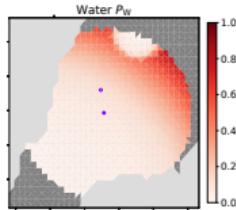
**Avoid cells...
... with large
elevation and large
slope**



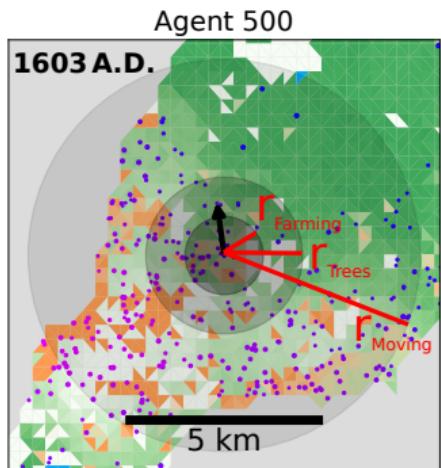
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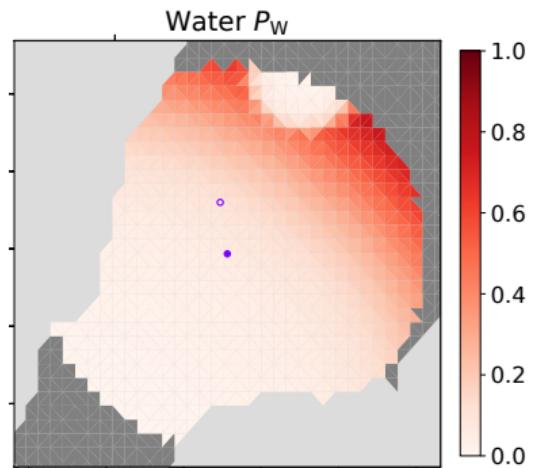
Geography



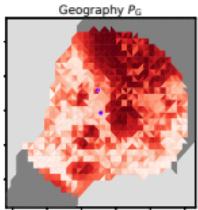
Water



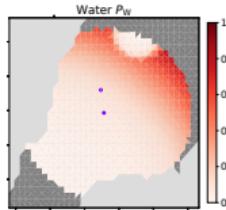
Avoid cells...
... far from a (big)
freshwater source



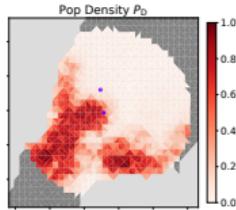
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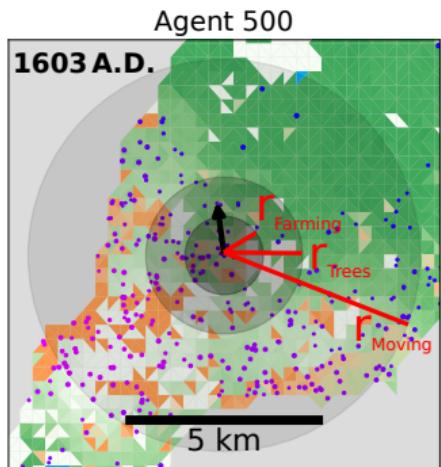
Geography



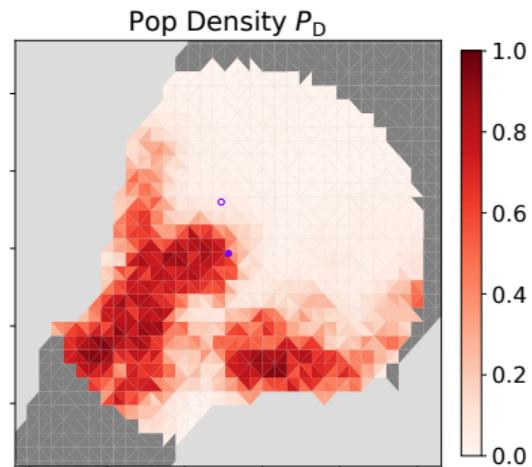
Water



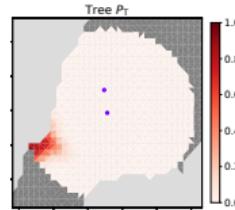
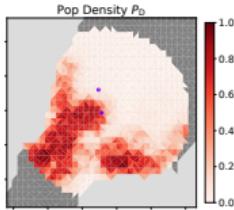
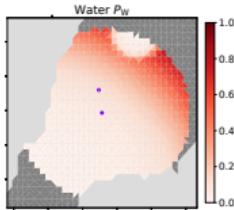
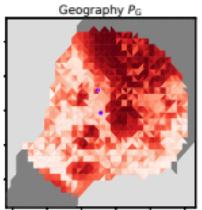
Pop. Density



**Avoid cells...
... in regions with
large population
density**



Moving: Decision Making based on Penalties



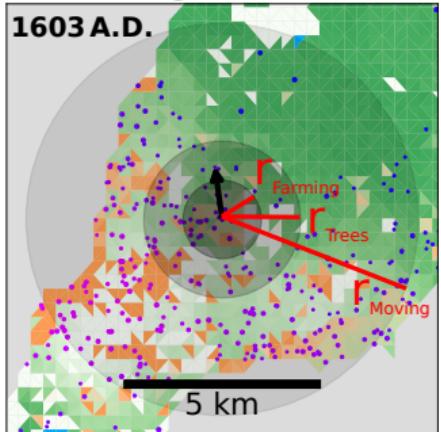
Geography

Water

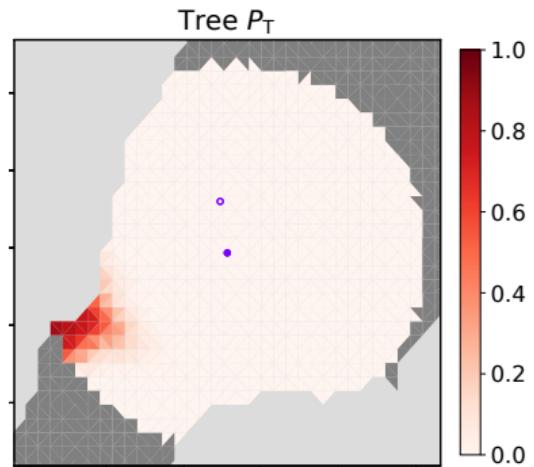
Pop. Density

Trees

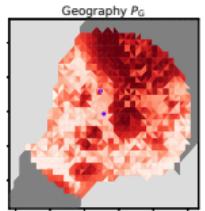
Agent 500



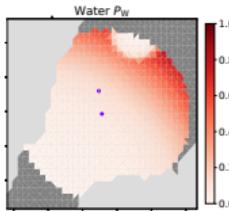
Avoid cells...
... with few trees
nearby



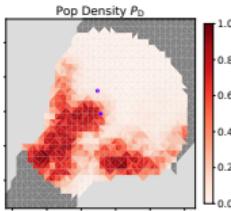
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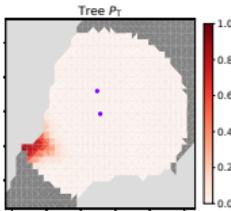
Geography



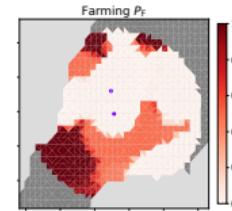
Water



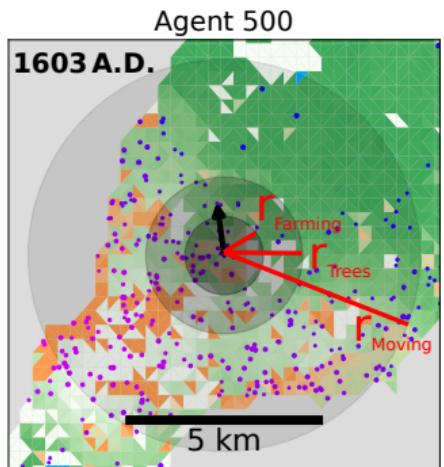
Pop. Density



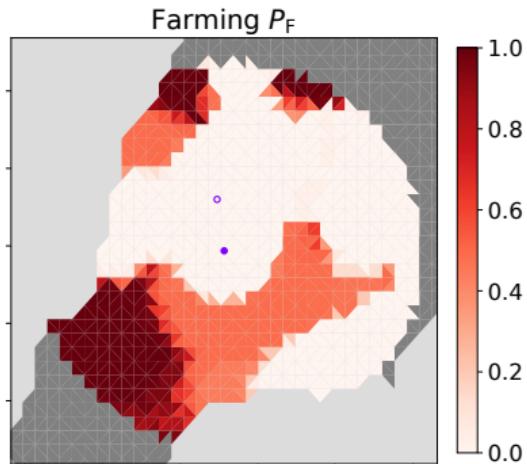
Trees



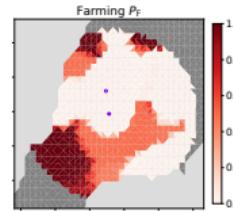
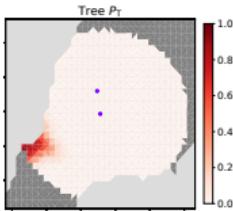
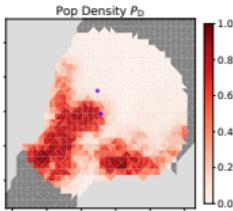
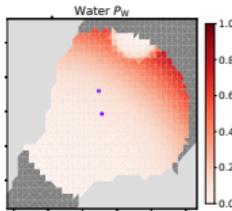
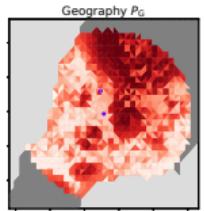
Farming Sites



Avoid cells...
... with few
(well-suited)
available farming
sites nearby



Moving: Decision Making based on Penalties



Geography

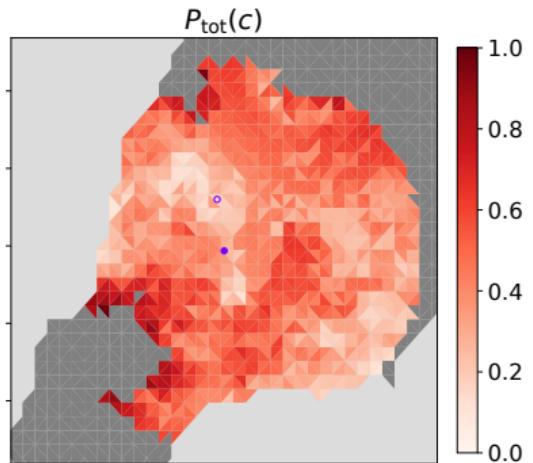
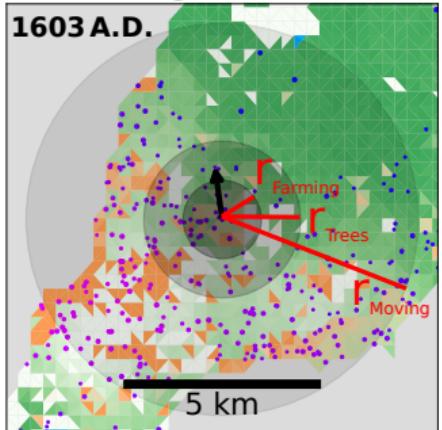
Water

Pop. Density

Trees

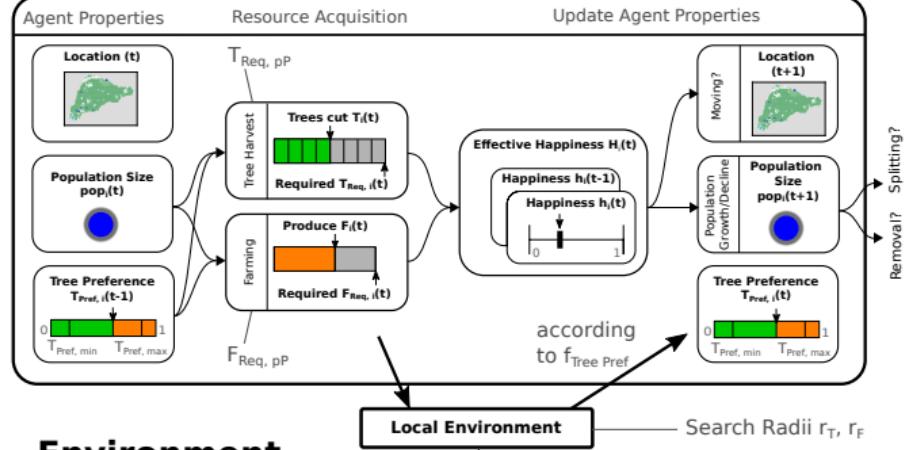
Farming Sites

Agent 500

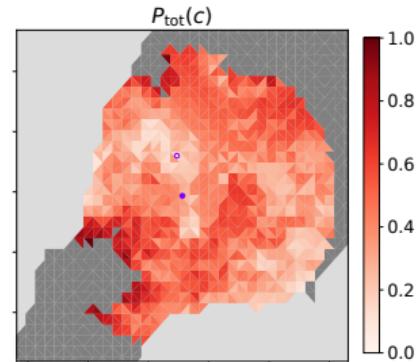
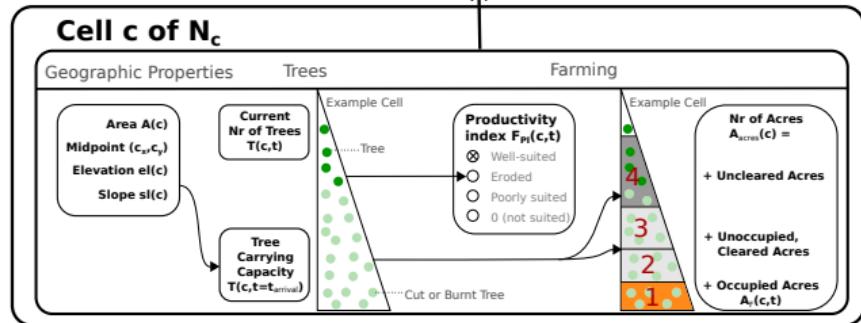


The Full Model

Agent i of N_{Agents}



Environment



Outline

A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

Easter Island History

Traditional Approach: Dynamic System Modelling

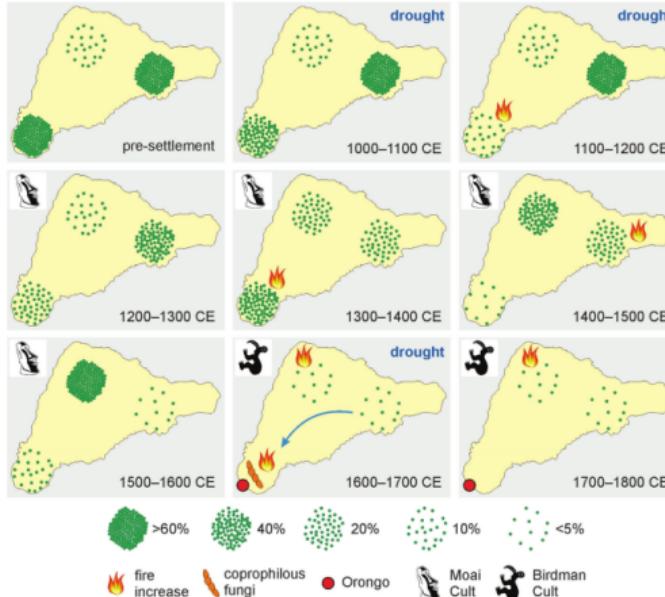
New Approach: Agent-Based Modelling (ABM)

The Easter Island ABM

Results and Discussion

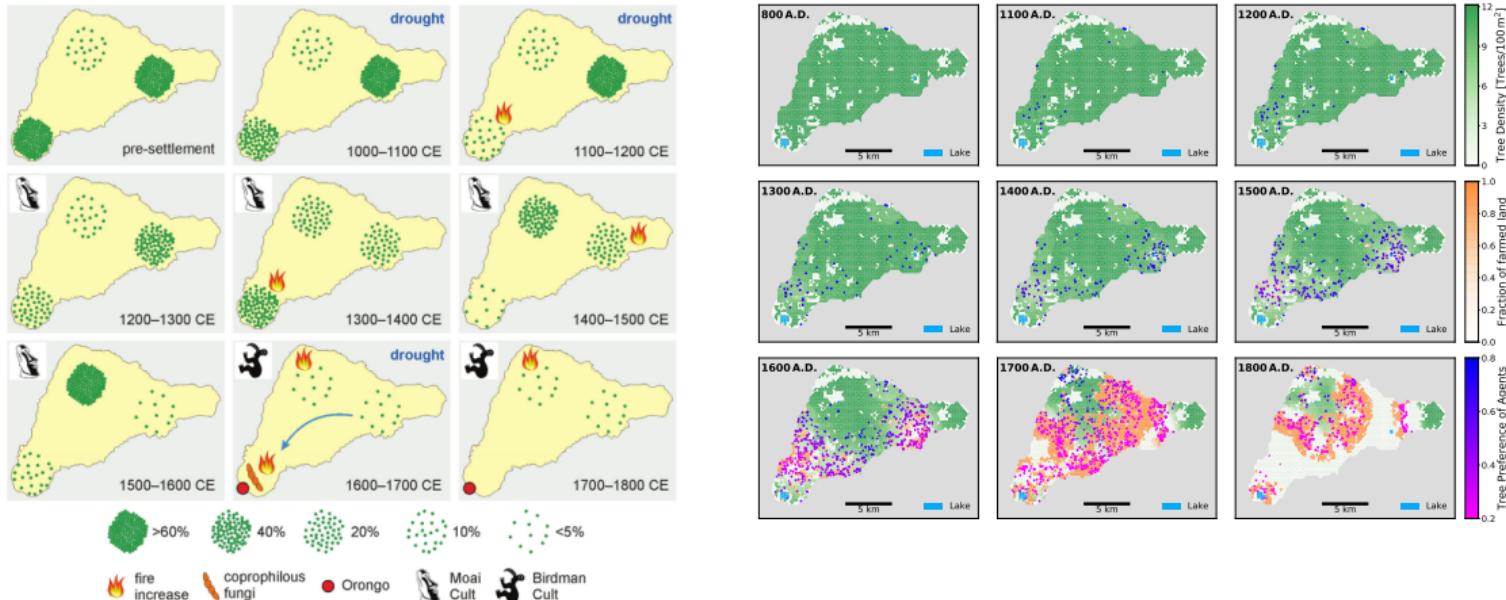
Spatial Patterns

Spatial Patterns



Rull (2020)

Spatial Patterns

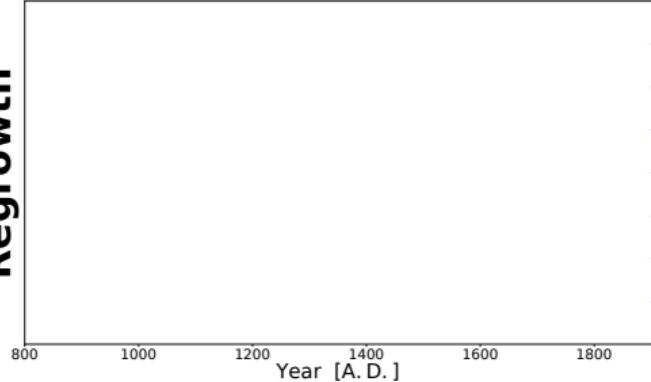


Rull (2020)

Different Environmental Conditions & Myopic Agents

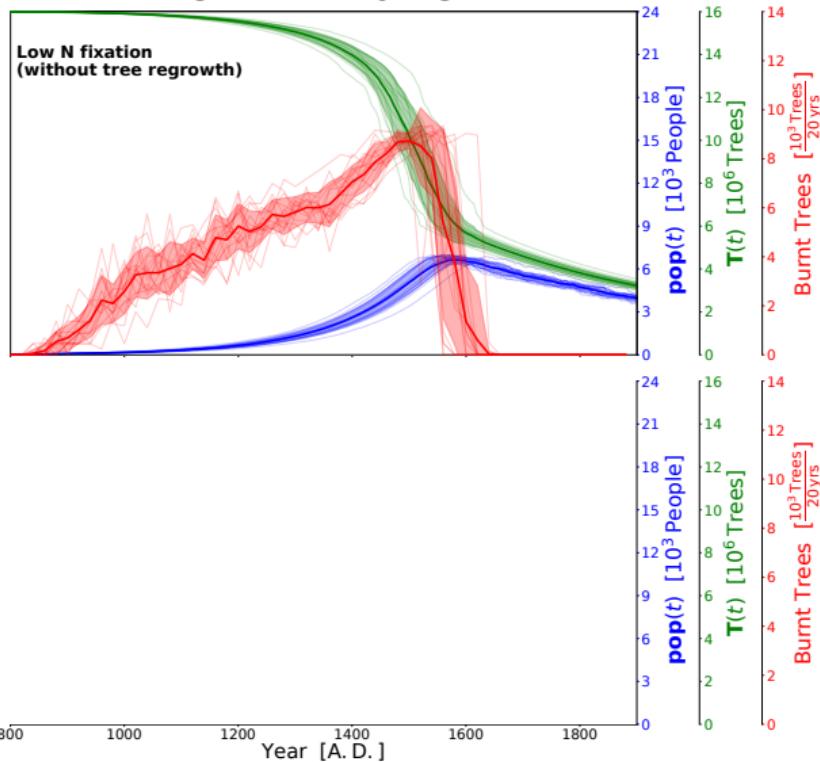
Without Tree Regrowth

High N Fixation



With Tree Regrowth

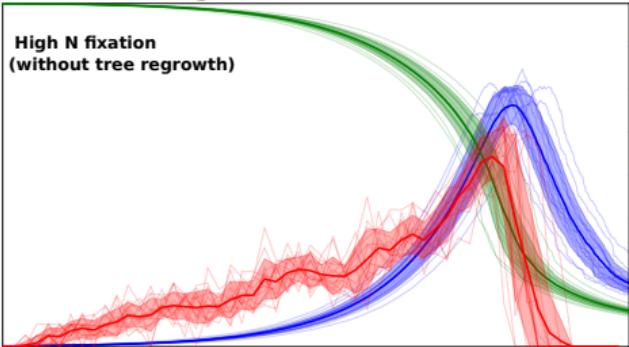
Low N Fixation



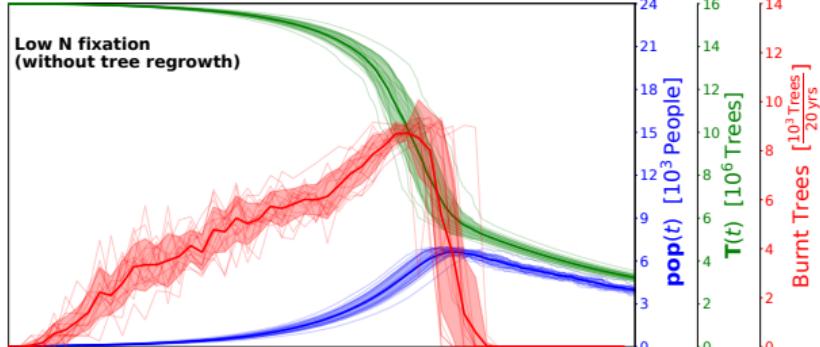
Different Environmental Conditions & Myopic Agents

Without Tree Regrowth

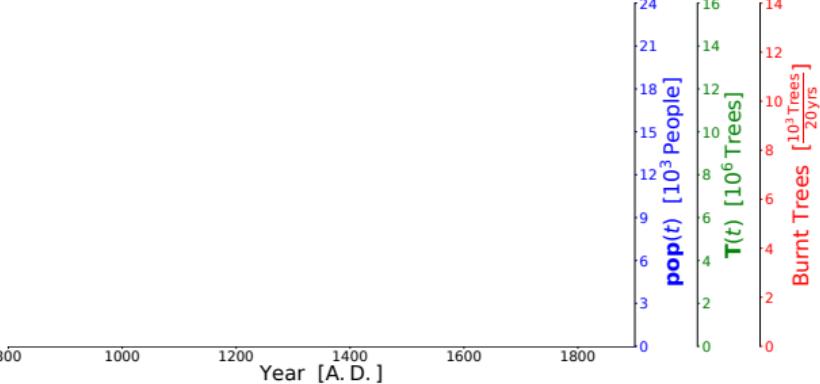
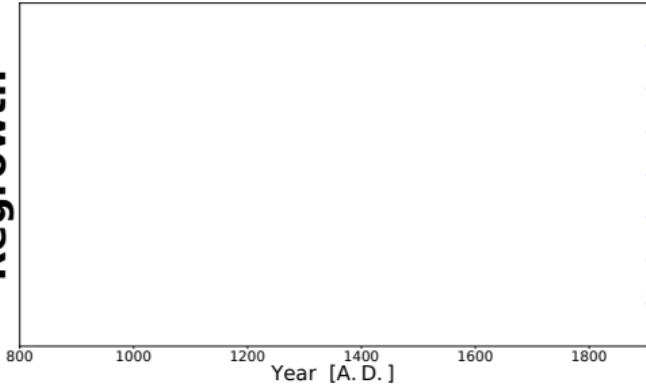
High N Fixation



Low N Fixation



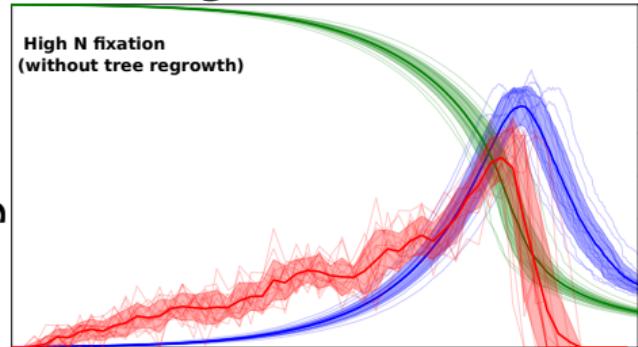
With Tree Regrowth



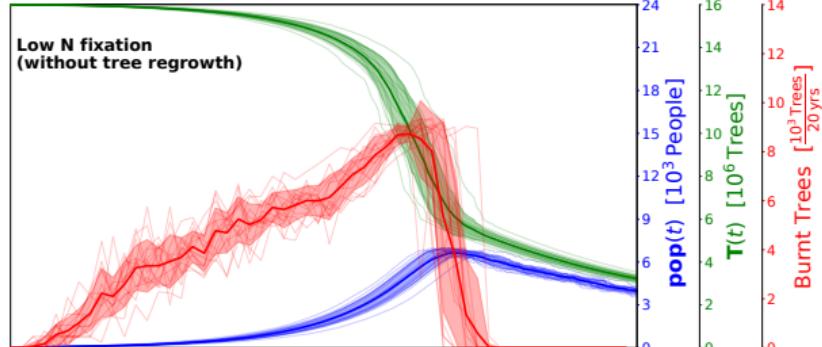
Different Environmental Conditions & Myopic Agents

Without Tree Regrowth

High N Fixation

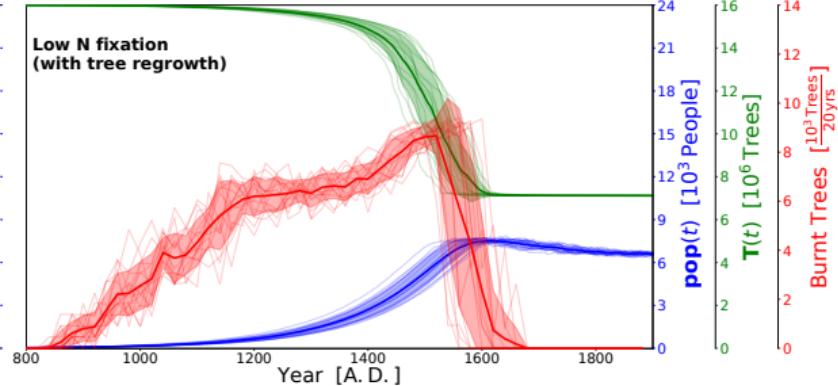


Low N Fixation

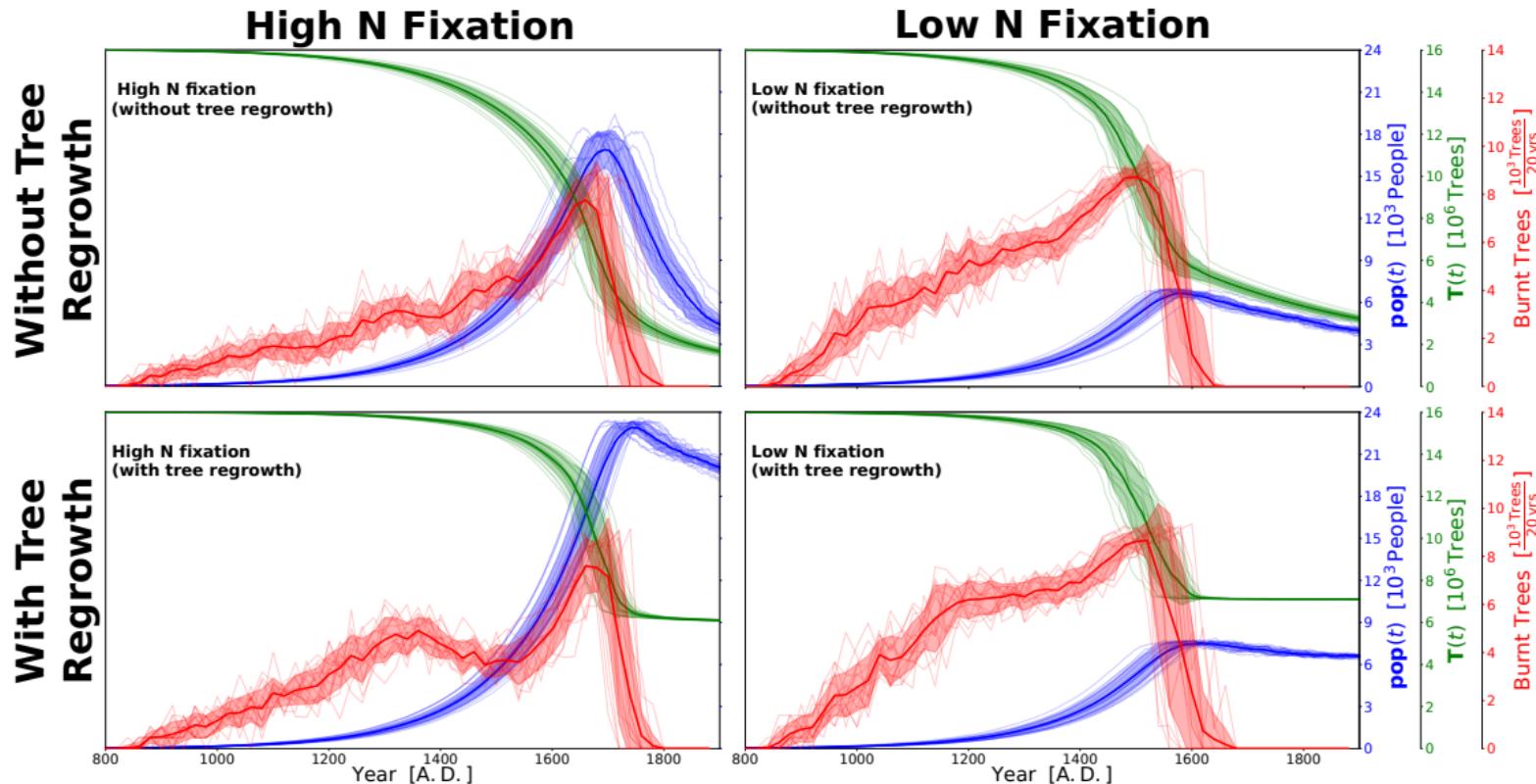


With Tree Regrowth

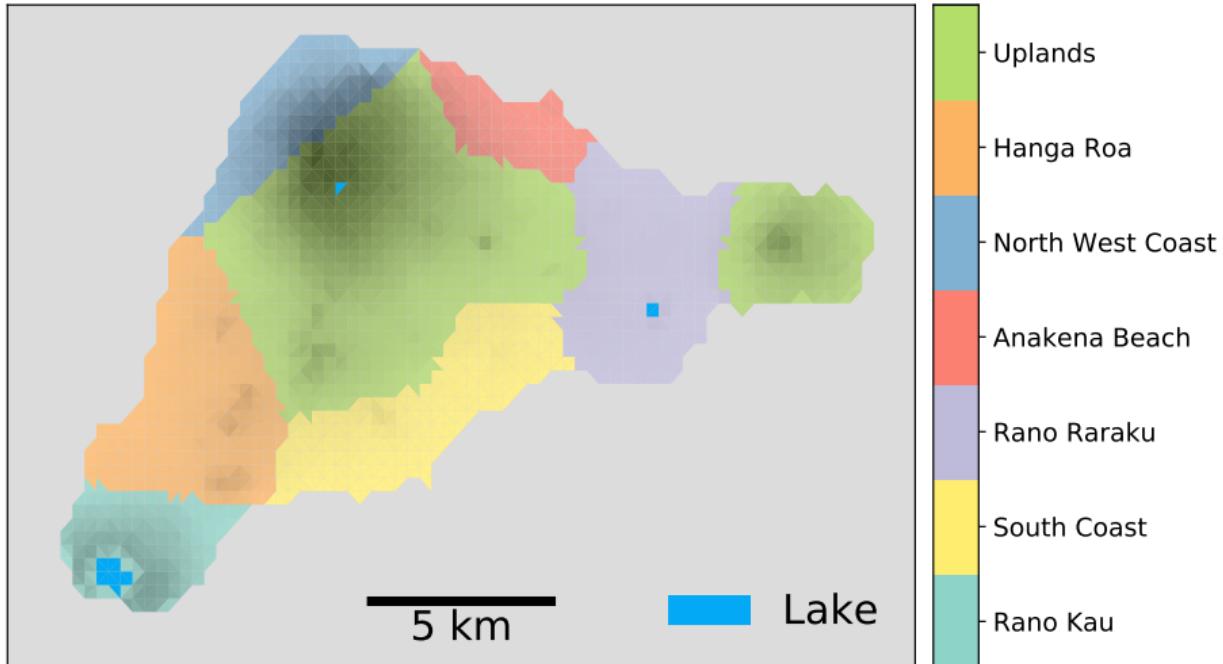
Low N fixation (with tree regrowth)



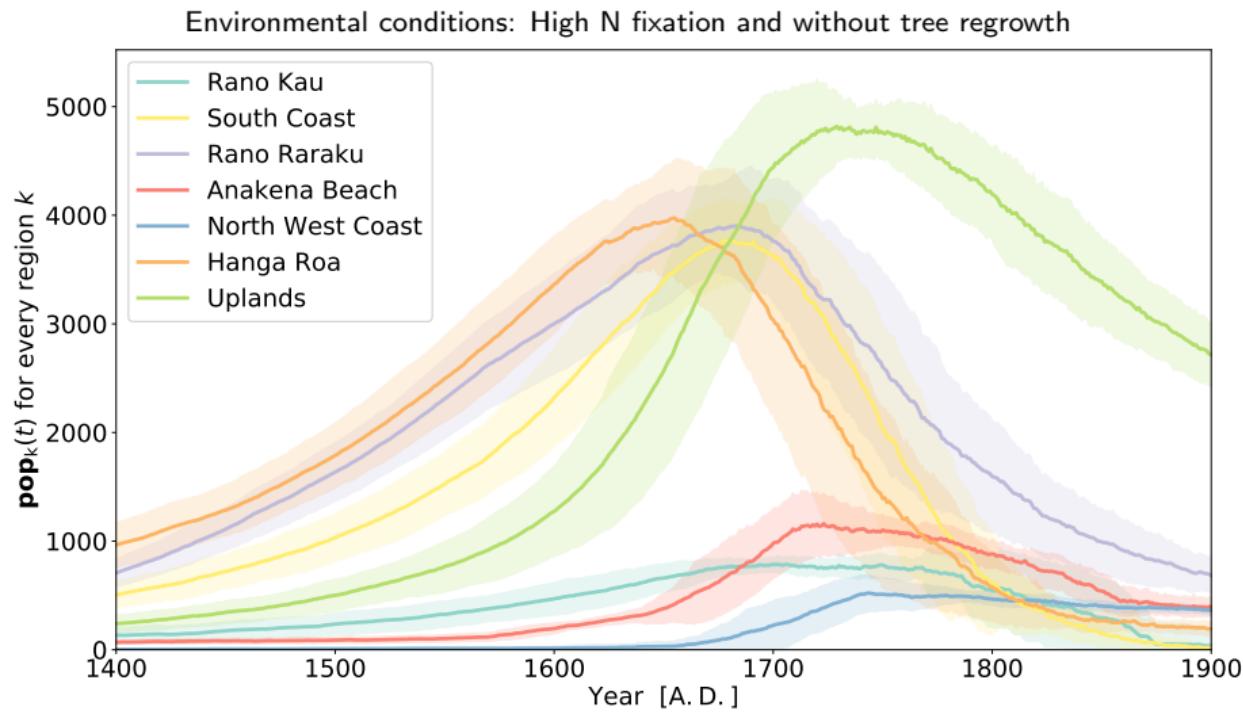
Different Environmental Conditions & Myopic Agents



Dynamics in Separate Regions



Dynamics in Separate Regions



→ Heterogeneous regional dynamics!

Further Results

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- ▶ Microscopic spatial confinement is crucial for aggregate dynamics
- ▶ Strategy to adapt to environmental degradation: Early, slow adaptation better than late, fast adaptation!
- ▶ Moving strategy impacts both spatial AND aggregate temporal patterns

Conclusions

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- ▶ Limits of the study:
 - ▶ Rules and processes often based on plausibility arguments
 - ▶ Uncertainty in the available data
 - ▶ More complex than macroscopic ODE models.
 - ▶ Possible improvements of the model
 - ▶ Social structure
 - ▶ From myopic to far-sighted, sustainable harvest behaviour of agents
 - ▶ Stochasticity and uncertainty in the harvest behaviour of agents

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 - ▶ Stochasticity and uncertainty in the harvest behaviour of agents
- ▶ Benefits of the Model:
 - ▶ Change of perspective on Easter Island:
From macroscopic, top-down to microscopic, bottom-up
 - ▶ Spatial considerations
 - ▶ Identifying regions of interest for archaeological work &
Interpret data from single locations

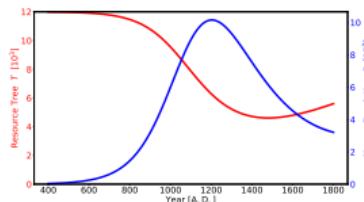
Summary

A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

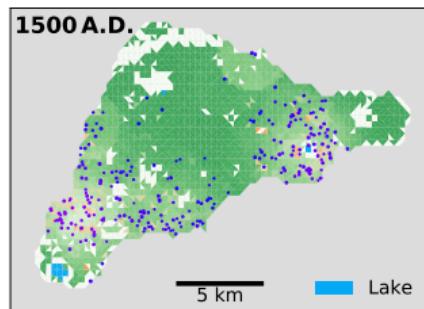
Easter Island History



Traditional Approach: Dynamic System Modelling



New Approach: Agent-Based Modelling (ABM)

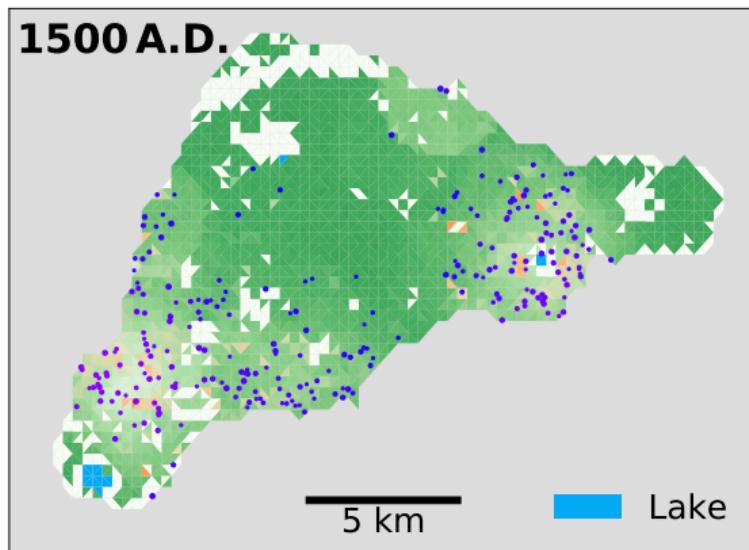


The Easter Island ABM

Results and Discussion

Thank you!

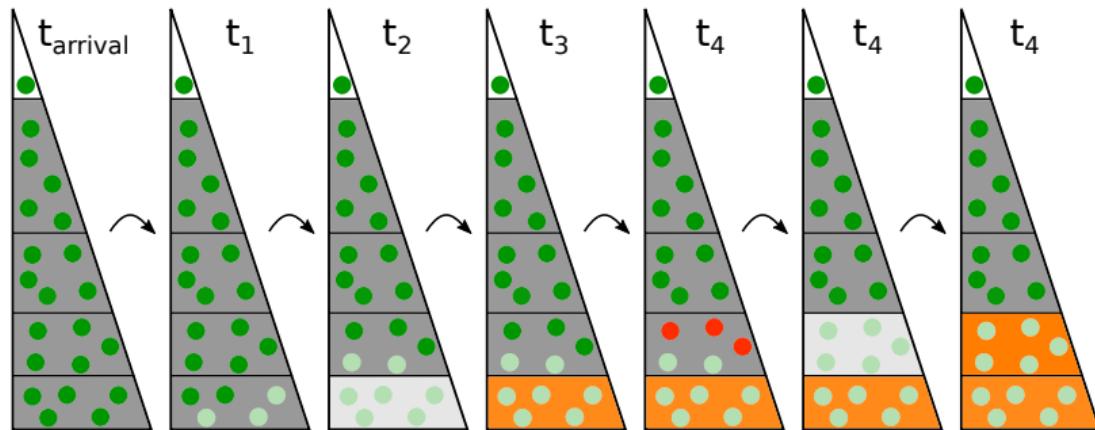
A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island



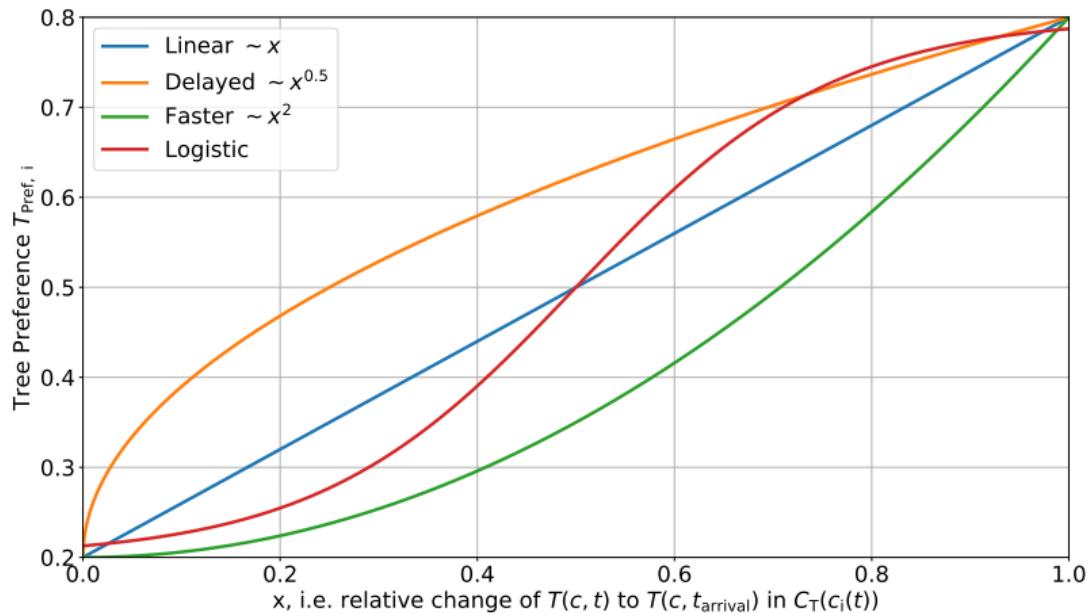
Special thanks to Agostino Merico, Esteban Acevedo Trejos, and Michael Hanke.

A Spatially Explicit Agent-Based Model for Human-Resource Interaction on Easter Island

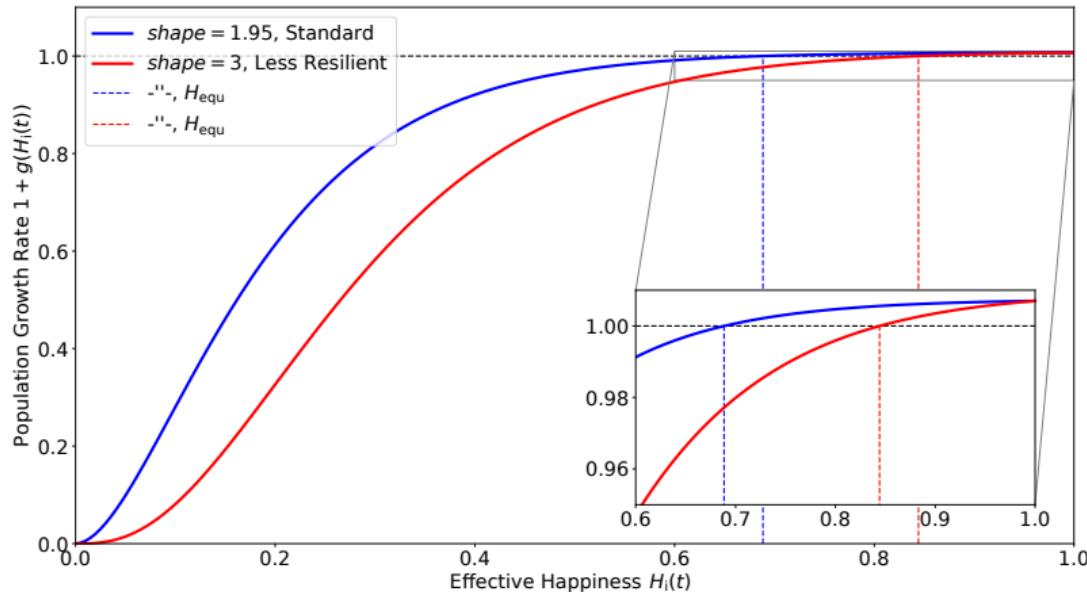
Burning and Occupying Land



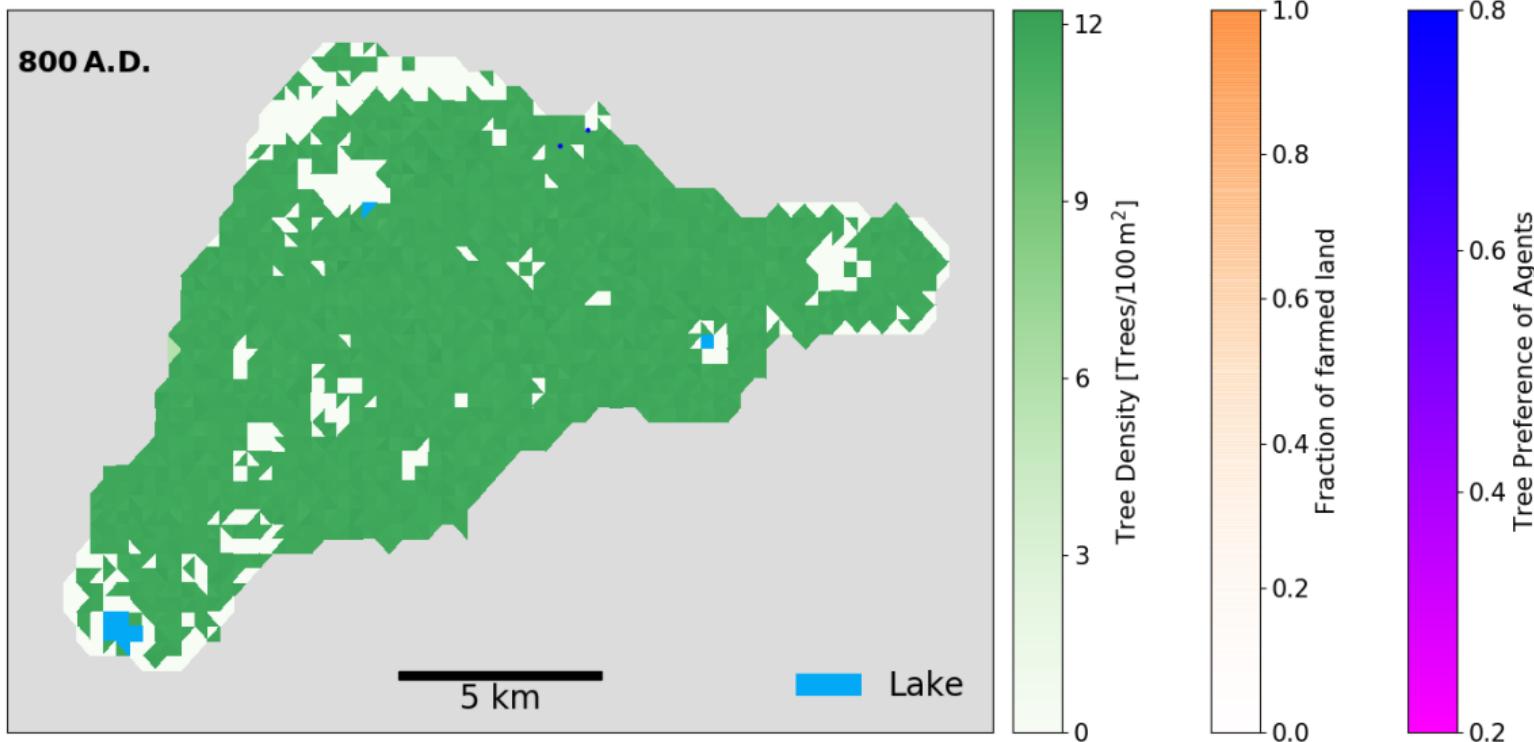
Different Tree Preference Strategies



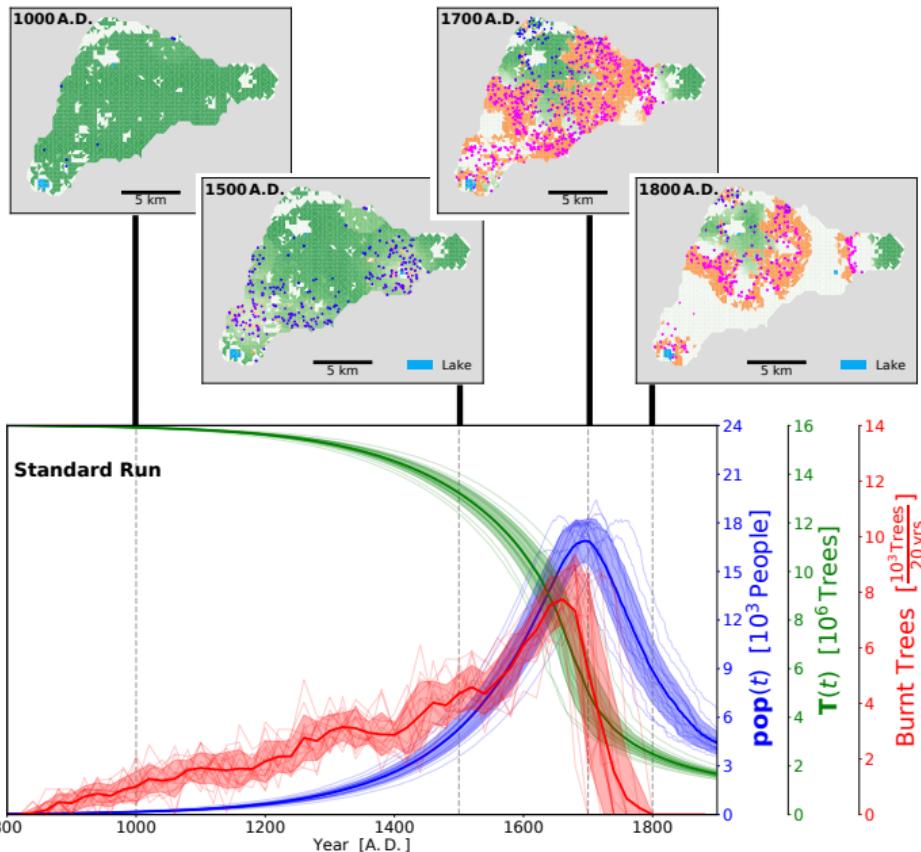
Population Growth Function



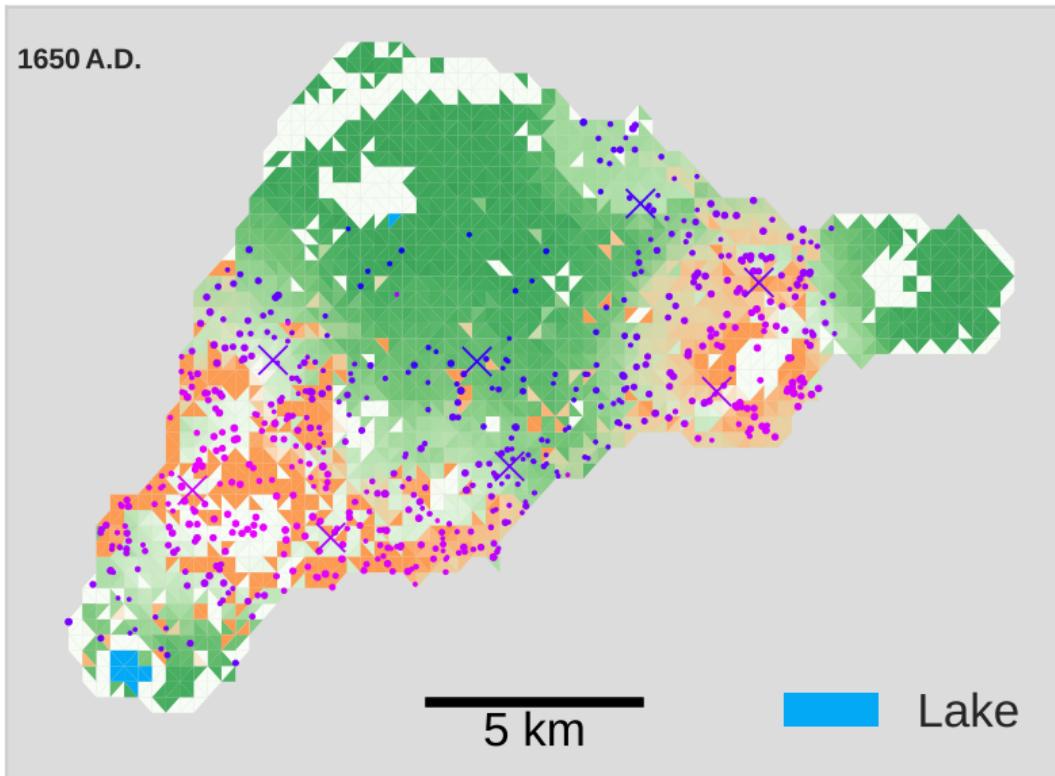
Movie



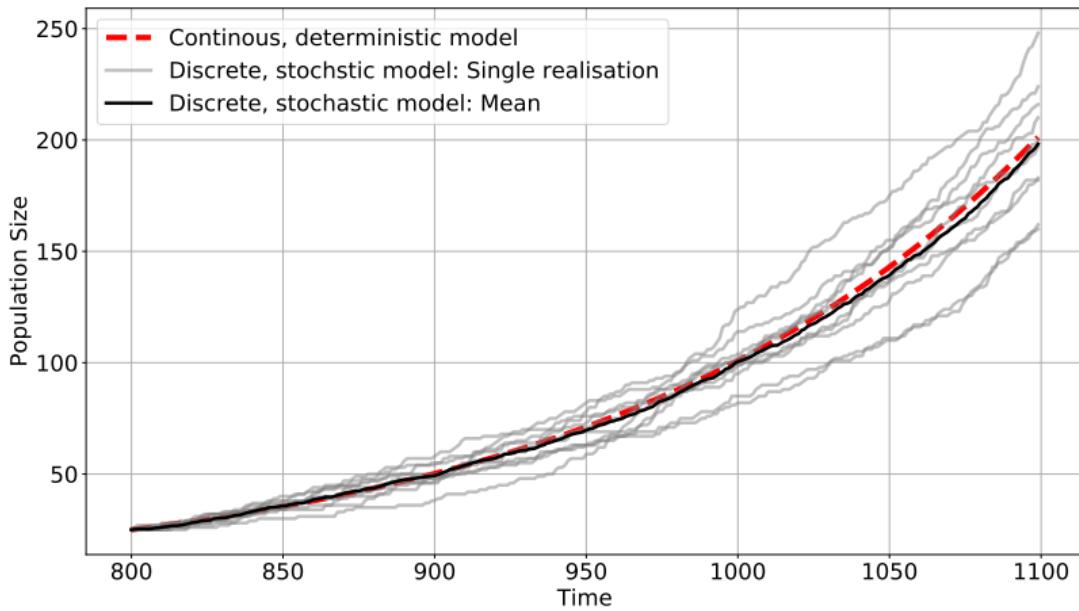
Result 1: Spatio Temporal



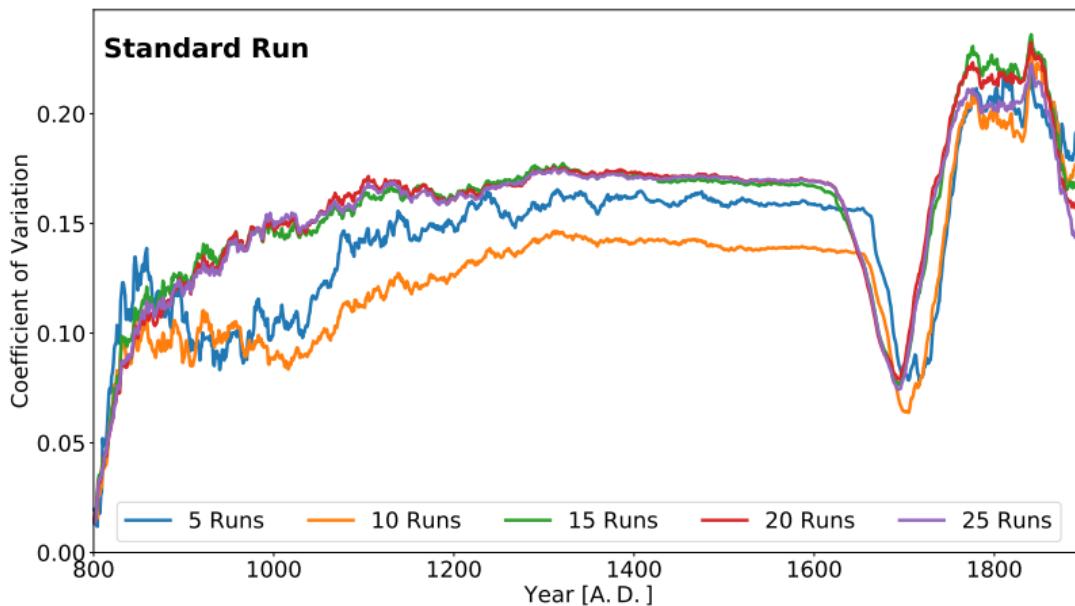
Clustering



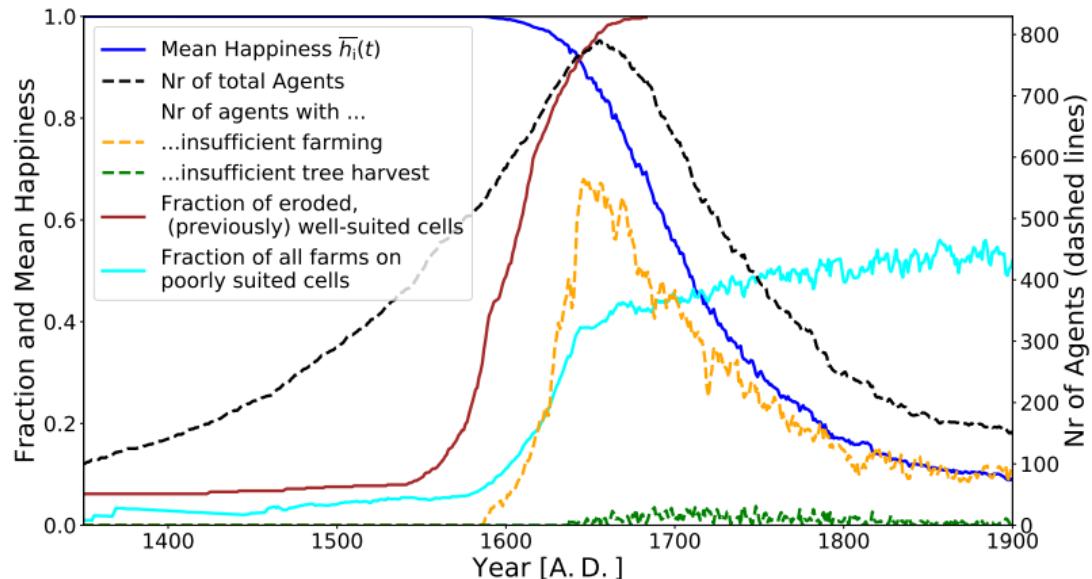
Ensemble: Realisations



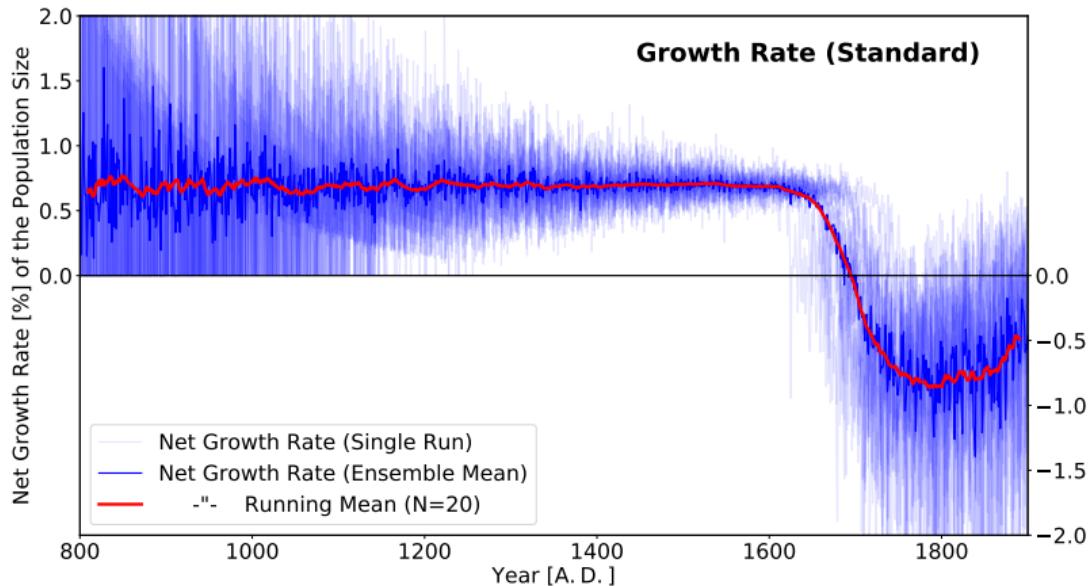
Ensemble: Coefficient of Variation



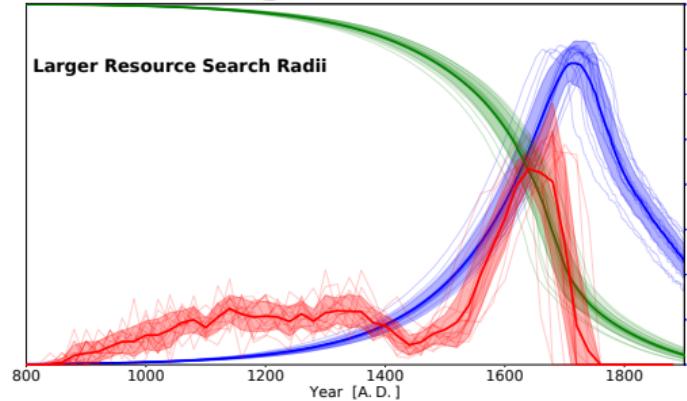
Indicators: Acceleration and Collapse Phase



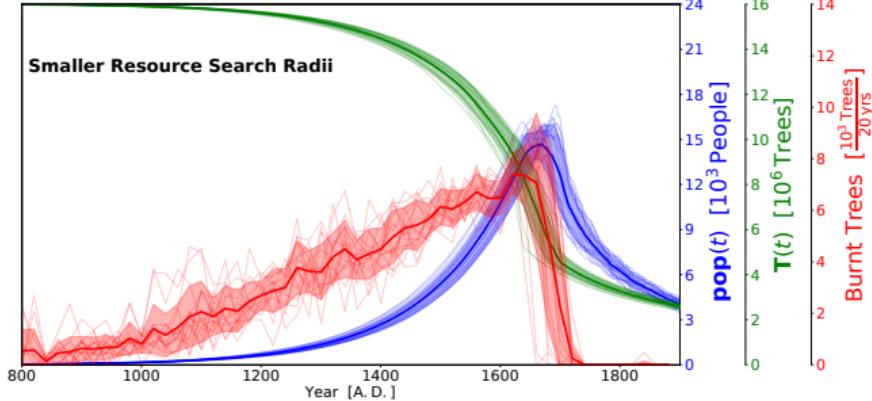
Net Growth Rate



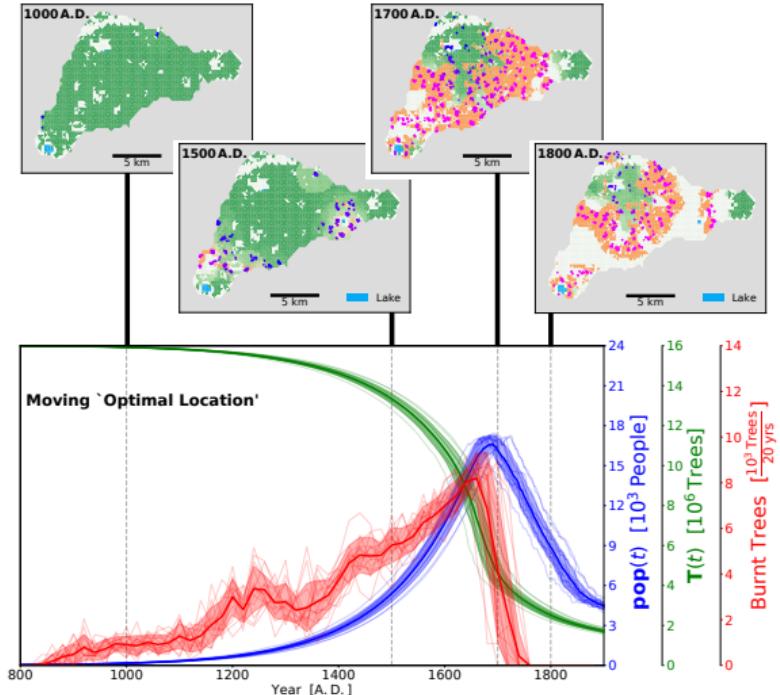
Larger Radii



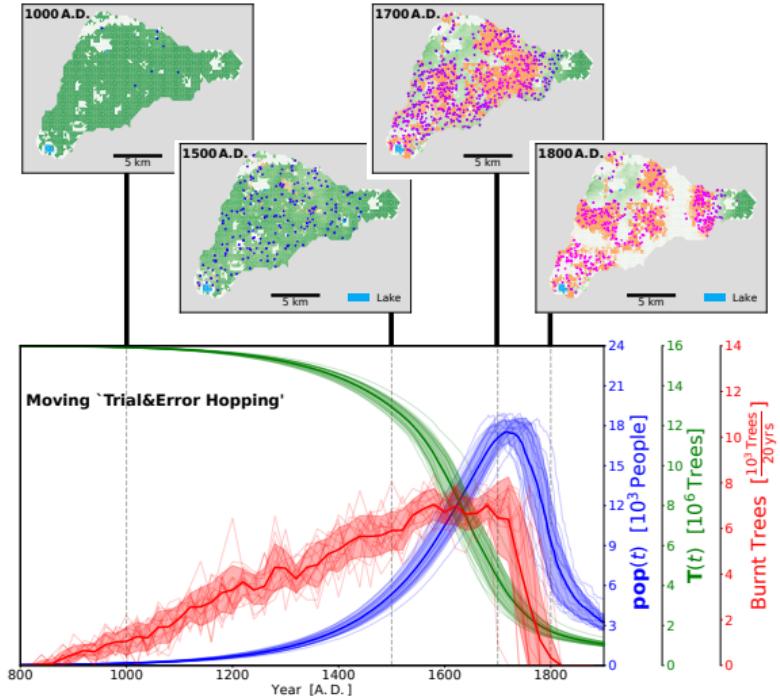
Smaller Radii



Optimal Location



Trial and Error Hopping



Resources Only

