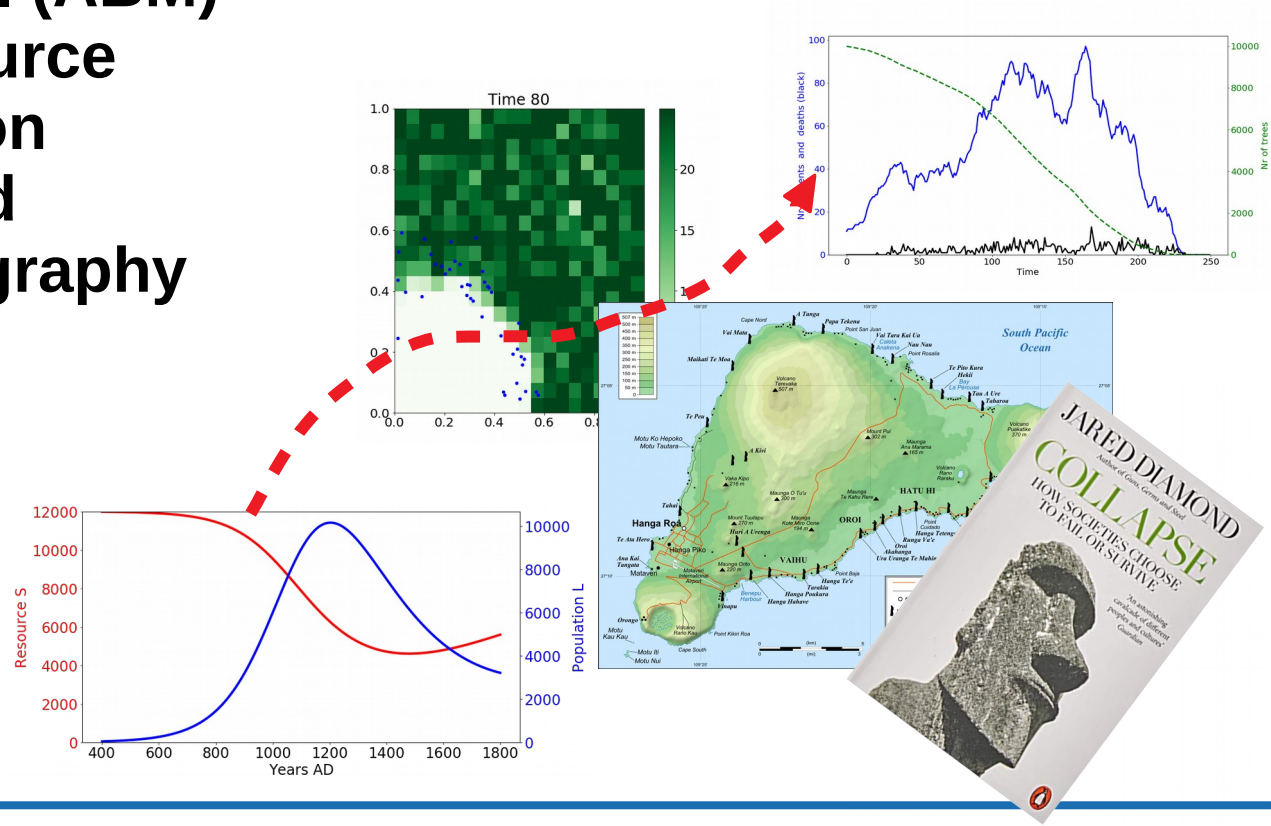
Development of an Agent-Based Model (ABM) of human-resource interactions on Easter Island based on real geography



“Why should I postpone my nap today?”

ZMT LEIBNIZ CENTRE for Tropical Marine Research

- 2 approaches to mathematically model an ecological system

- approaching an ancient history riddle

- find the hidden Trump quote → earn a high-five

Me

Bachelor in Physics (Erlangen, Germany)

Master in (Climate) Physics (Potsdam, Germany)

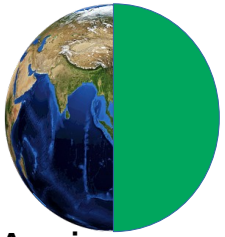
COSSE Year 2018 (Berlin, Stockholm)
now: Master's thesis in Bremen, Germany

Malthusian Catastrophe

https://en.wikipedia.org/wiki/File:Thomas_Robert_Malthus.jpg

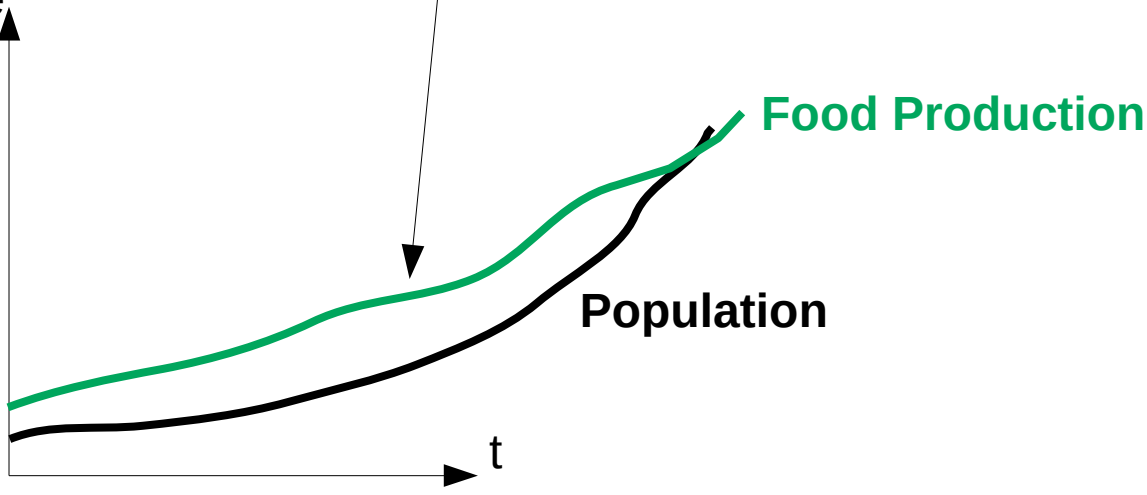
Thomas Malthus, 1798.
An Essay on the Principle of Population,
Chapter II.

Malthusian Catastrophe

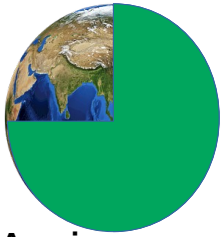


Agri-culture

Food Production rises as more land is cultivated
→ Population grows



Malthusian Catastrophe

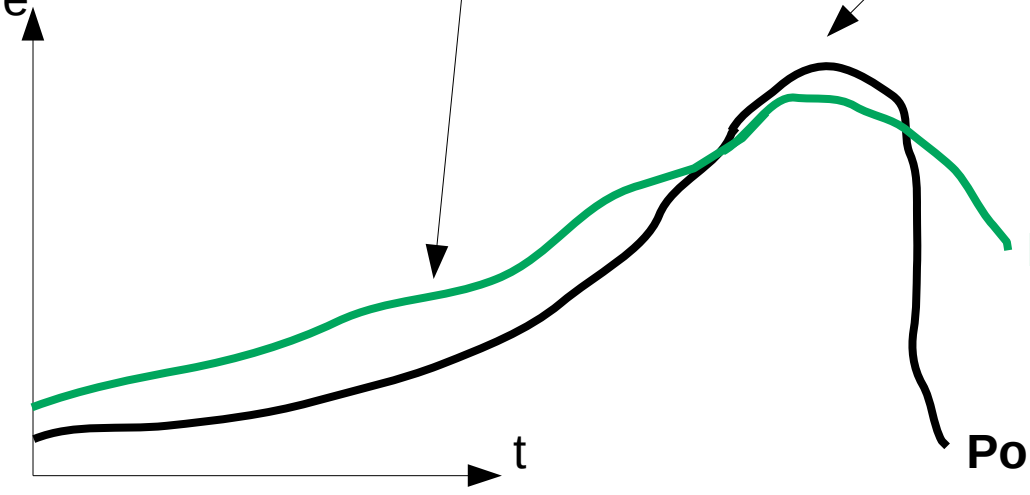


Agri-
culture

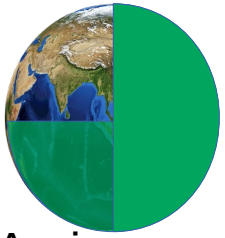
Food Production rises as
more land is cultivated
→ Population grows

Population > Food Production

→ prices rise
→ per capita consumption
decline
→ conflict
→ **collapse**

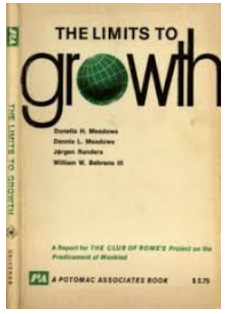


Malthusian Catastrophe

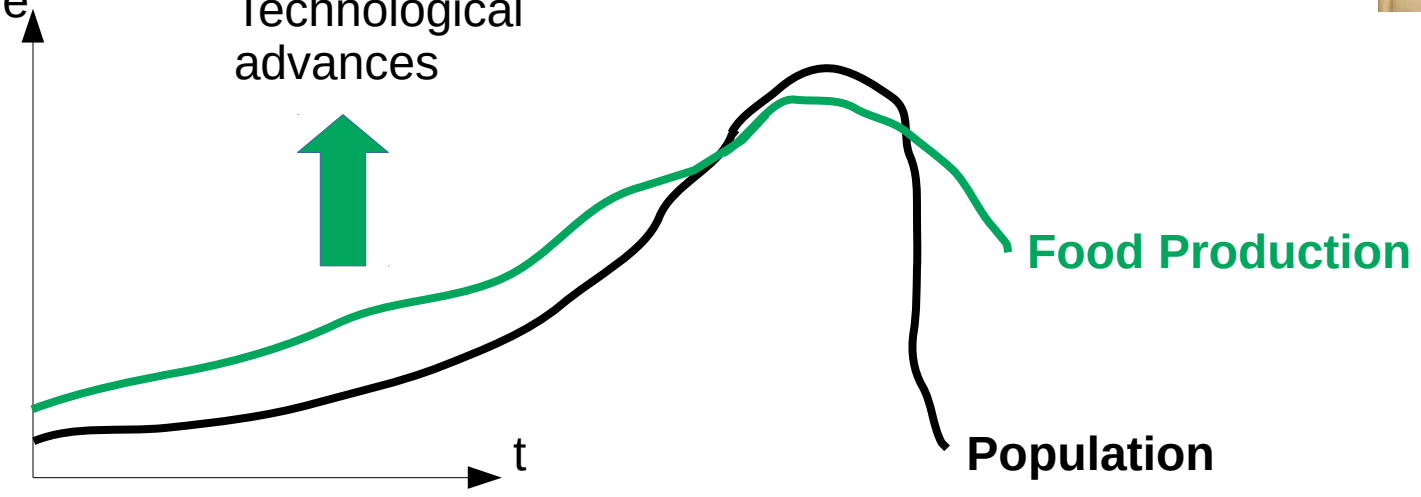


Agri-culture

de.wikipedia.org/wiki/Wissenschaftlicher_Sozialismus



Clubofrome.org



Collapse of Easter Island population?

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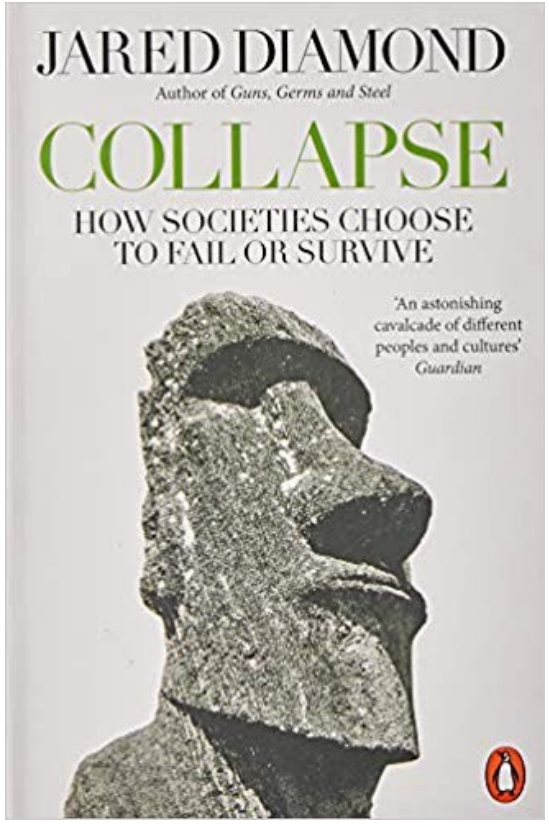
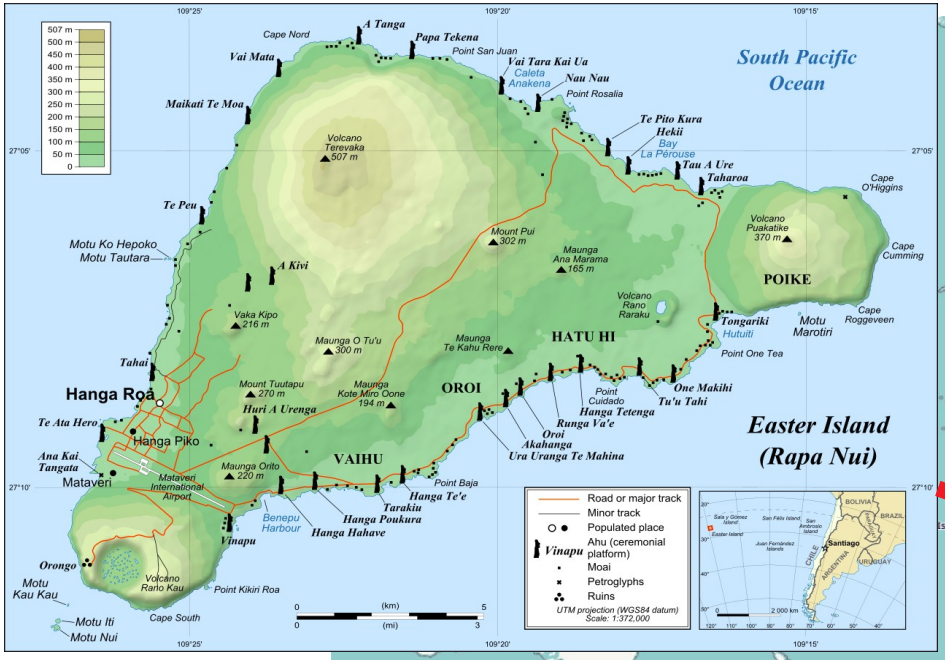
Diamond, 2005



https://www.amazon.de/Collapse-Societies-Choose-Fail-Survive/dp/0241958687

Diamond, J. (2005). Collapse: How States Choose to Fail or Succeed. In Penguin Group.

Easter Island – Overview



https://en.wikipedia.org/wiki/Moai#/media/File:Easter_Island_map-en.svg

Easter Island – The Facts

feeds on palm tree seeds

(1)

https://en.wikipedia.org/wiki/Easter_Island

(4)

https://en.wikipedia.org/wiki/Polynesian_rat

Polynesian/Pacific Rat

Deforestation by humans (ca. from 1200)

(2)

Advanced culture (1250-1500)

(3)

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

Europeans arrive in 1722+x

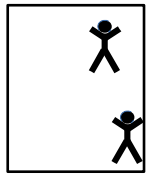
bring diseases and slave trade

Hunt, T. (2006). Rethinking the Fall of Easter Island. American Scientist.
Brandt, G., & Merico, A. (2015). The slow demise of Easter Island: Insights from a modeling investigation. Frontiers in Ecology and Evolution.

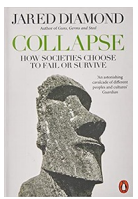
SUMMARY

ZMT LEIBNIZ CENTRE for Tropical Marine Research

The Problem:

How did  turn from  via   to   ?

Is it an example of a Malthusian Collapse?



(1) (simple) Macroscopic System Models

- coupled differential equations (highly non-linear)
  - for the Population Size
  - for the Resource Stock (here: Trees)
  - (- for other invasive species)

- modelled as simple predator (humans) vs. prey (resource) model
  (`Lotka-Volterra-Model')

- decision makers (humans) maximise their utility
  (here: through harvest and manufactured goods)

- control variable
  (here: consumption rate, i.e. resource extraction rate)

Reuveny, R. (2012). Taking Stock of Malthus: Modeling the Collapse of Historical Civilizations. Annual Review of Resource Economics.

The First Model: Brander and Taylor (1998)

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Variables

L = Population size
S = Resource Stock = Nr of trees

Exponential growth/decay

The more harvest the more population growth

$$\frac{dL}{dt} = L \cdot (b - d) + \phi \cdot H(L, S)$$

$$\frac{dS}{dt} = G(S) \cdot S - H(L, S)$$

Logistic growth

Harvest

Parameters

b = birth rate
d = death rate
ϕ = relation between fertility and consumption
H(L,S) = harvest rate of population
G(S) = logistic growth rate of resource

Brander, J. A., & Taylor, M. S. (1998). The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use. American Economic Review.

The First Model: Brander and Taylor (1998)

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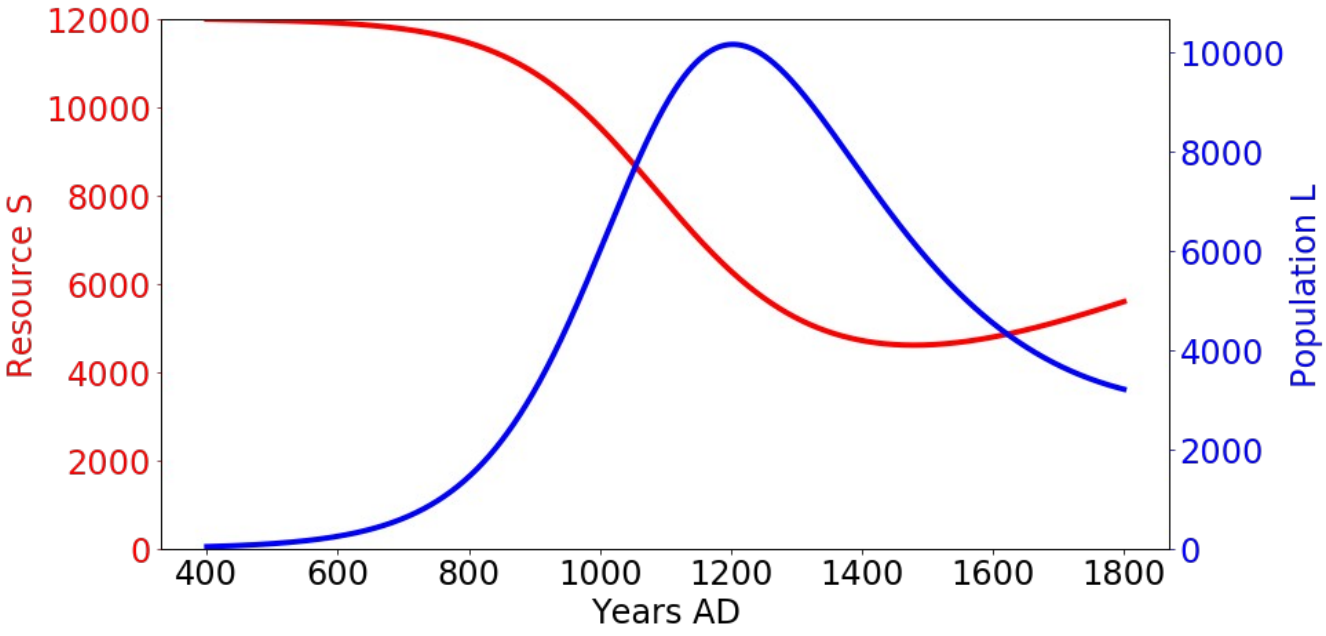
“ Boom and Bust”



Extensions to Brander and Taylor (1998)

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How could we improve this model?

Agriculture

Far-sightedness vs. short-sightedness of the population

Social/Organisational Responses:

- positive
  - + institutions i.e. social planning
  - + technological advances
- negative
  - + war, rivalry

e.g.
Reuveny, R. (2012). Taking Stock of Malthus: Modeling the Collapse of Historical Civilizations. Annual Review of Resource Economics.

Hunt (2006): Role of the Pacific Rat

New Archaeological Evidence:

- Pacific rat responsible for ecological catastrophe

New Narrative about population collapse:

- Not an example of an `ecocide'.

- "Consequence of European contacts, with Old World diseases and slave-trading"
  → genocide

Hunt, T. (2006). Rethinking the Fall of Easter Island. American Scientist.

Adjusted Model

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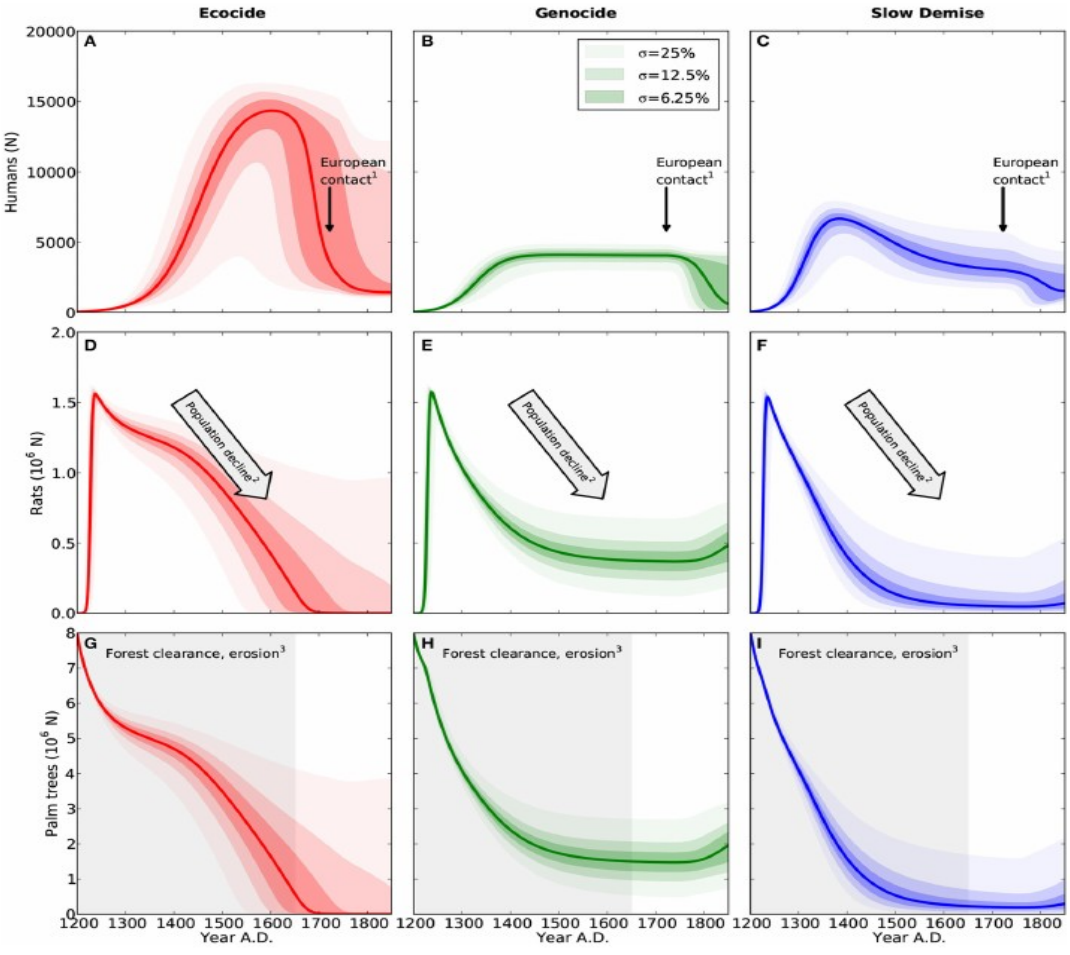
- 3 instead of 2 variables and differential equations (Basener, 2008):

  Human Population (L)
  Resource Stock (S)
  Rat Population (R)

- Include a Diseases Spread Model after European Contact (Brandt and Merico, 2015)

Brandt, G., & Merico, A. (2015). The slow demise of Easter Island: Insights from a modeling investigation. Frontiers in Ecology and Evolution.
Basener, W., Brooks, B., Radin, M., & Wiandt, T. (2008). Rat instigated human population collapse on Easter Island. Nonlinear Dynamics, Psychology, and Life Sciences.

So which theory is the right one now?



Brandt, G., & Merico, A. (2015). The slow demise of Easter Island: Insights from a modeling investigation. Frontiers in Ecology and Evolution.

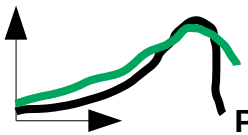
SUMMARY

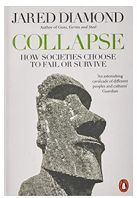
ZMT LEIBNIZ CENTRE for Tropical Marine Research

The Problem:

How did  turn from  via  to  ?

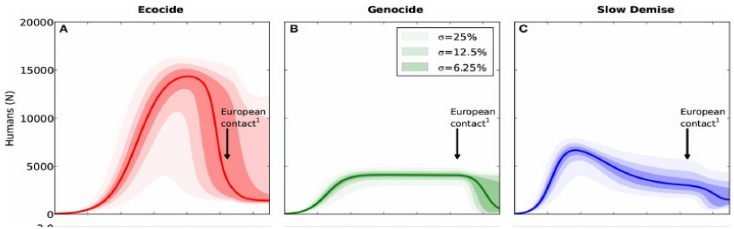
Is it an example of a Malthusian Collapse?





Modelling Approaches:

(1) Macroscopic System Models



(2) Microscopic Agent Based Modelling (ABM)

Now: ABM, but why?

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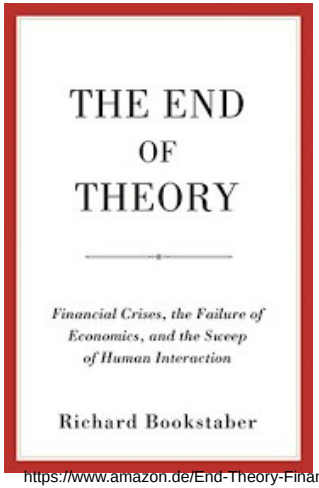
- Agents are unique and heterogeneous

- Agents act in response to **local** environment/context

- System Models assume a fixed relationship between Environment and Behaviour (except for global change of an equation; no bottom-up emergence)

Benefits of Agent Based Model (ABM):

- can capture emergent phenomena
- explicit space dependency of microscopic behaviour
- natural description of a social system
- very flexible

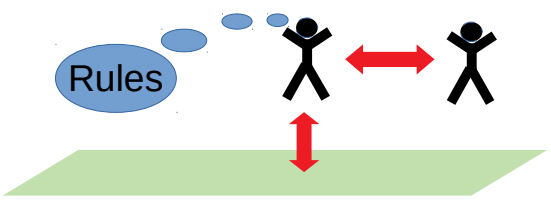


https://www.amazon.de/End-Theory-Financial-Economics-Interaction-ebook/dp/B01M2BVG7M

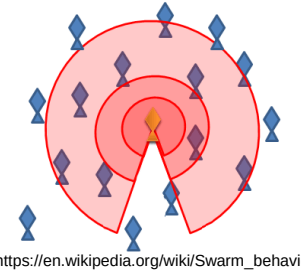
Bousquet, F., & Le Page, C. (2004). Multi-agent simulations and ecosystem management: A review. Ecological Modelling.
Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences of the USA.

What exactly is an ABM?

Agents	discrete, independent, heterogeneous entities placed in a dynamic, spatial environment rule-based interactions with the environment and each other given the local context
Environment /Resource	(dynamic) map that influences the agents' behaviour responds to agents' actions
Update	select agents randomly and update them autonomously



e.g. modelling Swarm behaviour



https://en.wikipedia.org/wiki/Swarm_behaviour

Comparison to simple System Model

Agents	discrete, ind… rule … given the local …
Environment /Resource	(dy… resp…
Update	

A “representative” agent with 1 set of global parameters

Interested in aggregate Variables

Dynamic aggregate Variables

Following Trajectory given by Differential Equation

A first Easter Island ABM

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.ipynb

A first Easter Island ABM (here or .ipynb)

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- Map is a homogeneous square filled with trees

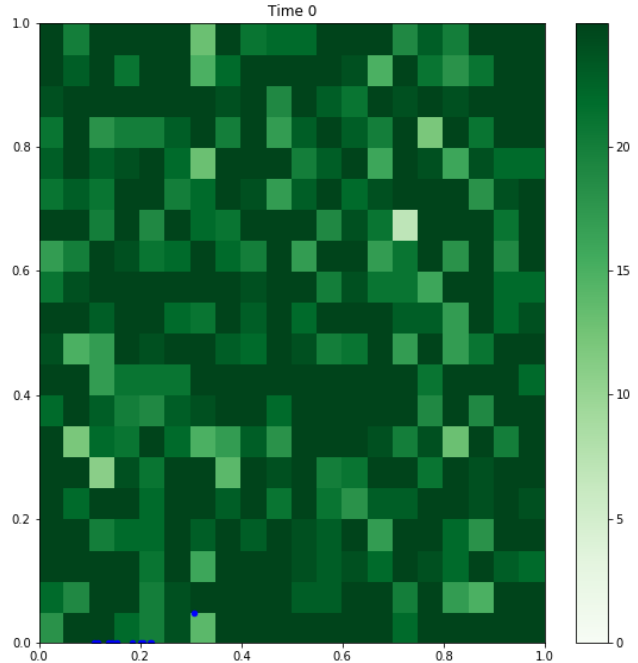
- Agents are initialised (1) at an edge or (2) equally distributed

- Environment (Trees) are harvested (can't
  (passive agents)

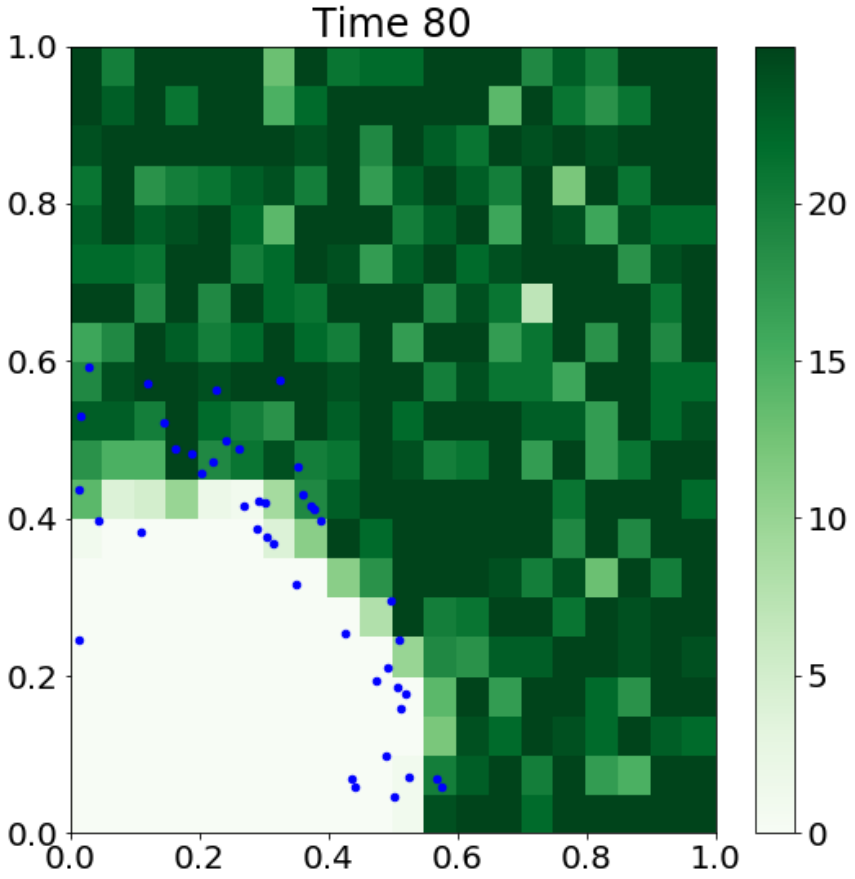
- Agents eat one tree per time step in circle

  IF they found a tree and cut it, they rep
  with fixed probability (parameter 2

  ELSE they
  (1) move to a random spot within
  get hungry or
  (2) die if they have been hungry a



A first Easter Island ABM

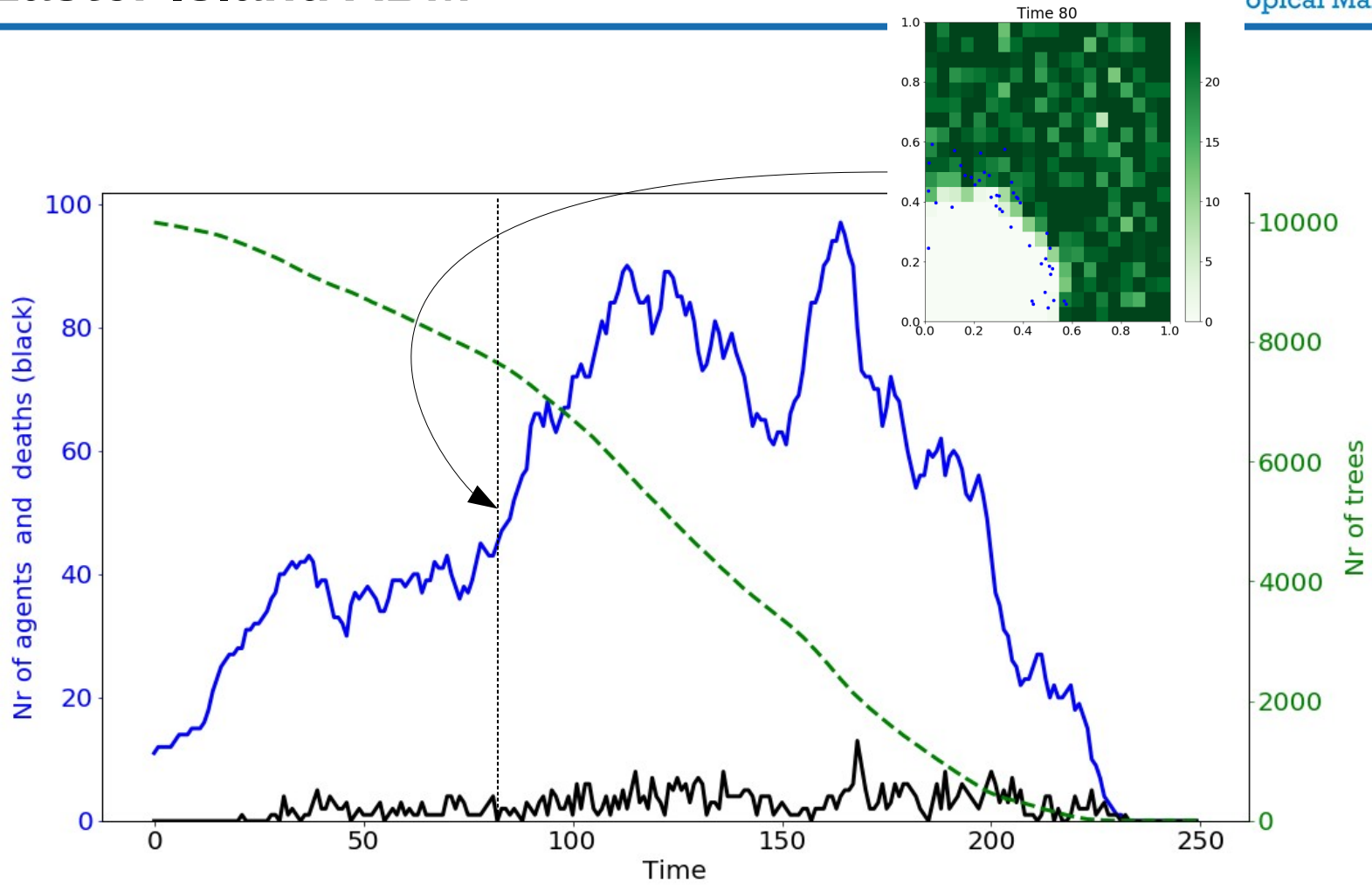


A first Easter Island ABM

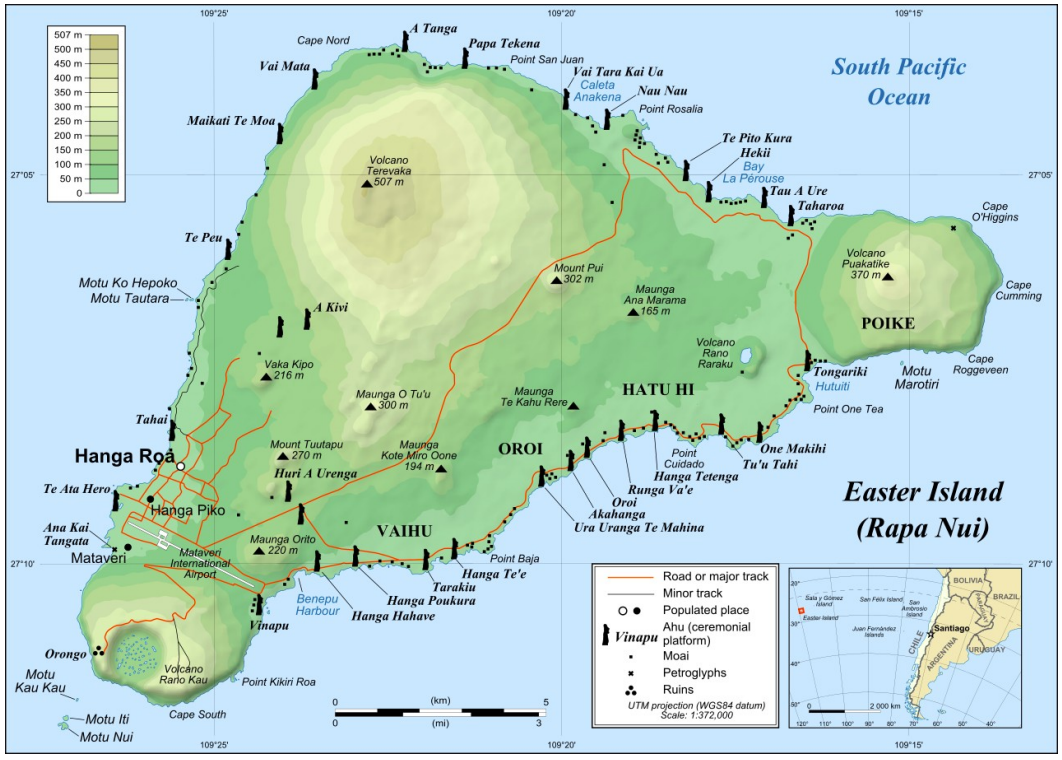
ZMT LEIBNIZ CENTRE for Tropical Marine Research

.gif

A first Easter Island ABM



My Master's Thesis



Experiments:

- Are there limits to the scenarios introduced by the spatial constraints?

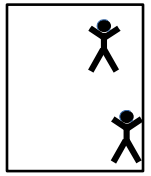
- Impact of fresh water availability on movement of settlements?

- Drying of a lake in 1450?

SUMMARY

ZMT LEIBNIZ CENTRE for Tropical Marine Research

The Problem:

How did  turn from  via   to   ?

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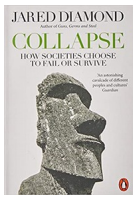

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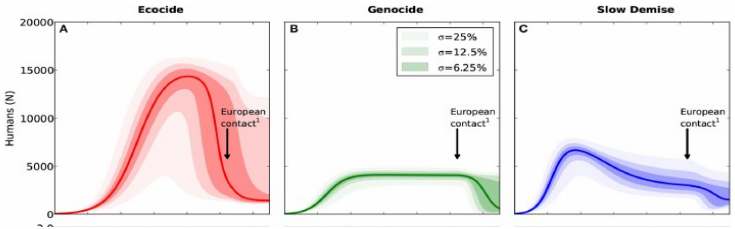
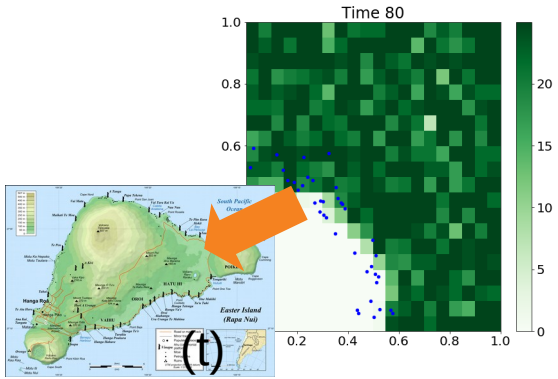
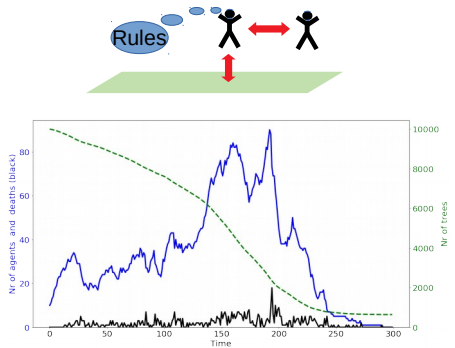


(2) Microscopic Agent Based Modelling (ABM)





Thanks for your interest!

Backup and Old Versions

$$\frac{dL}{dt} = L \cdot (b - d) + \phi \cdot \alpha \cdot \beta \cdot L \cdot S$$

$$\frac{dS}{dt} = r \cdot S \cdot \left(1 - \frac{S}{K}\right) - \alpha \cdot \beta \cdot L \cdot S$$

Variables

L = Population size
S = Resource Stock

Parameters

b = birth rate
d = death rate
ϕ = relation between fertility and consumption

α = resource exploitation rate
β = how much we value harvest over manufactured goods (e.g. leisure)

K = resource carrying capacity
r = resource growth rate

Good and Reuveny (2012):
A far-sighted social planner tries to maximise utility not instantaneously but over a certain, discounted timespan, then he/she tells everyone how much they should harvest

$$max_{f(t)} \int_0^T [\alpha \cdot f(t) \cdot S(t)]^{\beta} \cdot [1 - f(t)]^{(1-\beta)} \cdot e^{-\rho t} \text{ subject to}$$

$$\frac{dS}{dt} = G(S) \cdot S - H(L, S, f)$$

$$\frac{dL}{dt} = L(t) \cdot (b - d) + \phi \cdot H(L, S, f)$$

Result:

Even with optimal planning, collapse can't be averted

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$$\frac{dS}{dt} = rS(t)[1 - s(t)/K] - L(t) \cdot [\alpha \cdot f(t) \cdot S(t)]$$

$$\frac{dL}{dt} = L(t) \cdot (b - d) + \phi \cdot L(t) \cdot \alpha \cdot f(t) \cdot S(t)$$

Result:

Even with optimal planning, collapse can’t be averted

What exactly is an ABM?

ZMT LEIBNIZ CENTRE for Tropical Marine Research

		Python
Agents	Independent, heterogeneous entities that are placed in a dynamic, spatial environment Rule-based interactions with the Env and each other given the local context	objects of class `agent' with different params/attributes Class functions
Environment/ Resource	(dynamic) map that influences the agents' behaviour Environment responds to agents' actions	Here: list of objects of class `tree' located on map
Update	Each agent updates autonomously	Select random agent, Update given the local, current environment

Comparison to simple System Model

ZMT LEIBNIZ CENTRE for Tropical Marine Research

What	Description	Python
Agents	Independ… …tities that ar…	obj… …with
Environment/ Resource	(dynam… …agents' b…	H…
Update	Each…	S…

1 “representative” agent

Interested in 1 aggregate **variable**

Fixed parameters,
1 Variable

1 Variable and DiffEqu

1 Variable and DiffEqu

Following Trajectory from DiffEqus

Solve DiffEqu