Climate Risk in Provisioning Ecosystem Services:
An Explorative Hybrid Model of Adaptive Behaviour in Clam Harvesting

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Additional Contribution: Gavin Wilkinson (Head of Marketing at Decision Lab)

Università Ca'Foscari Venezia

Fondazione Eni Enrico Mattei

DECISION LAB


Complex Socio-Ecological System Analysis
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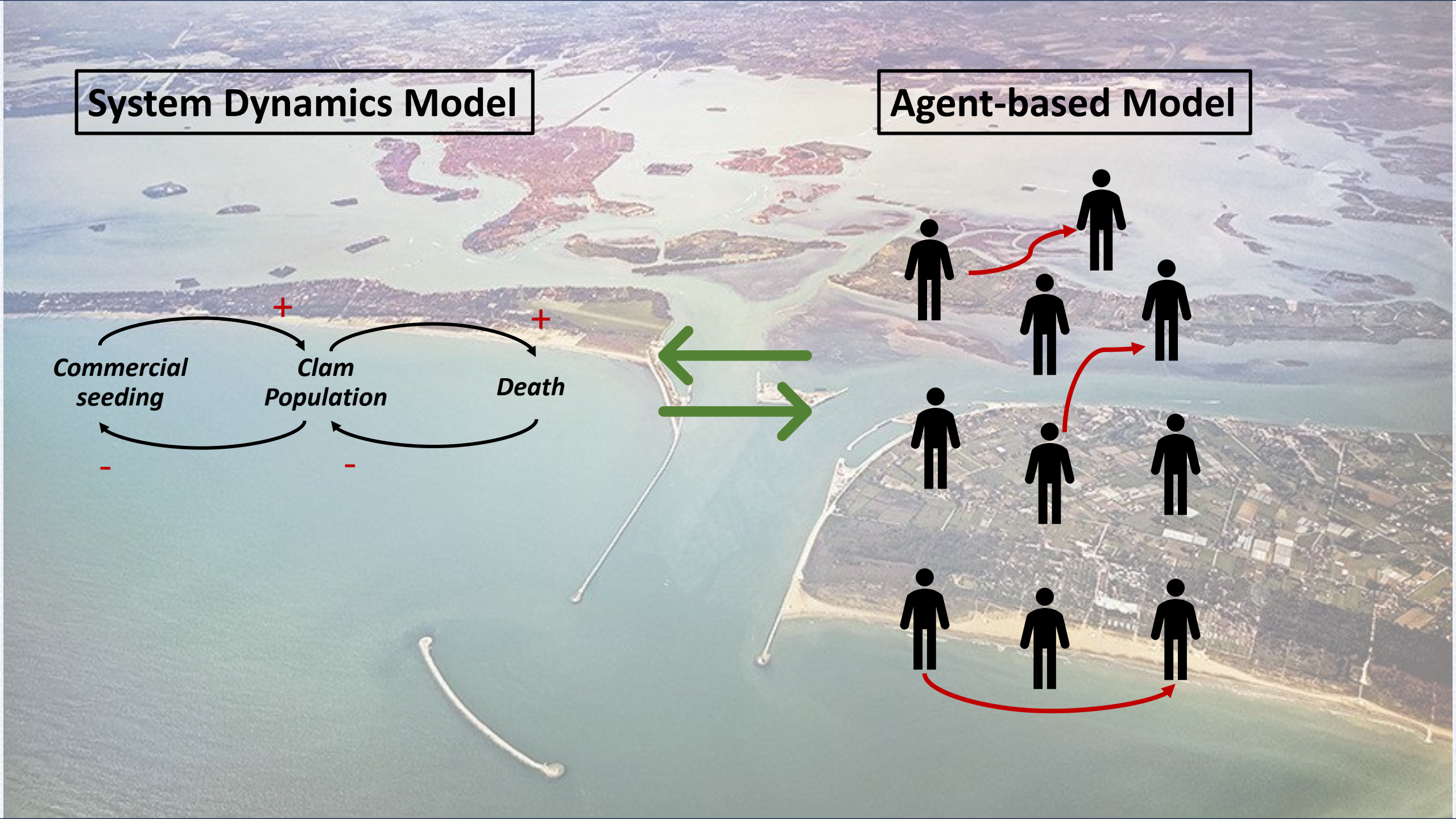
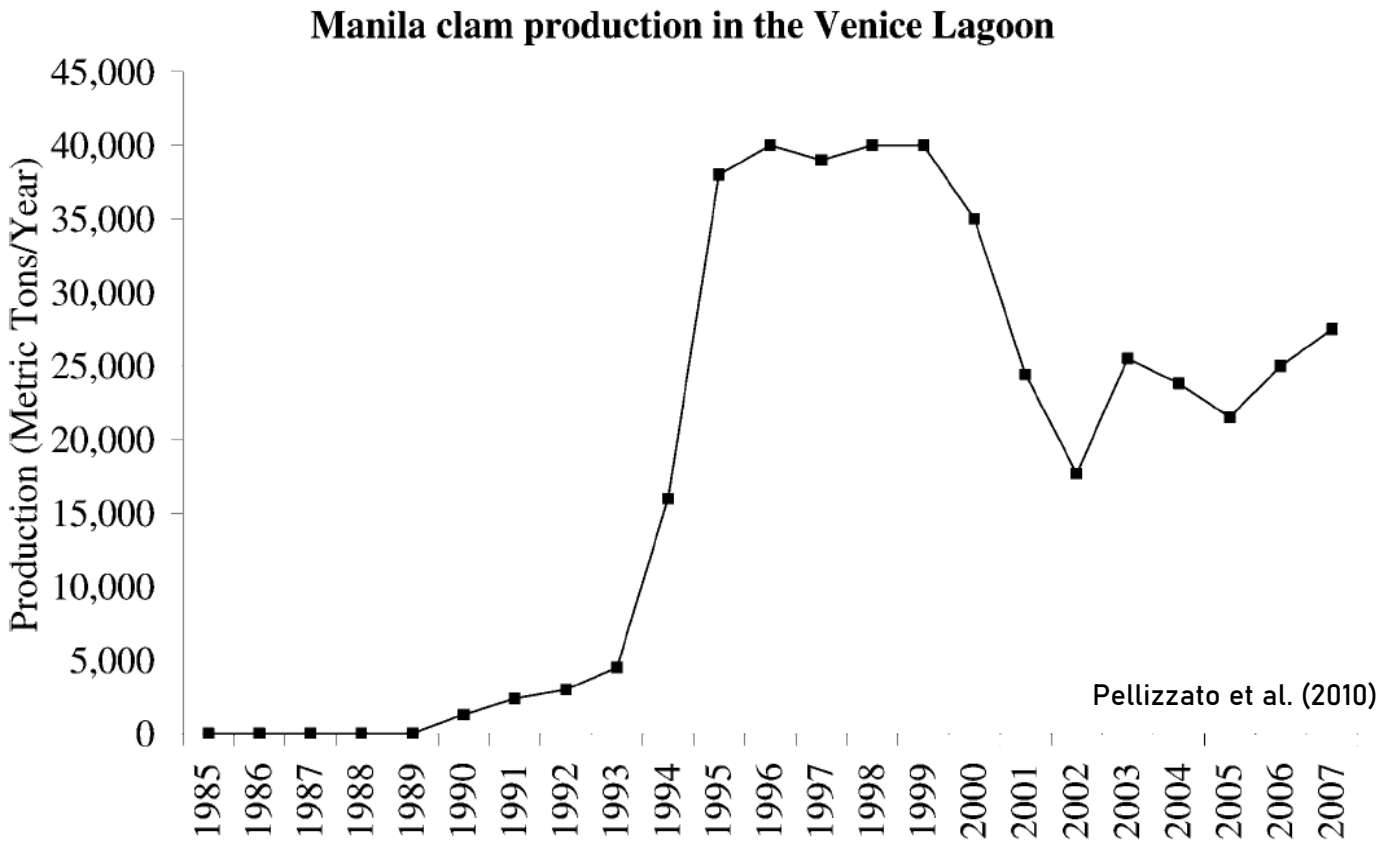
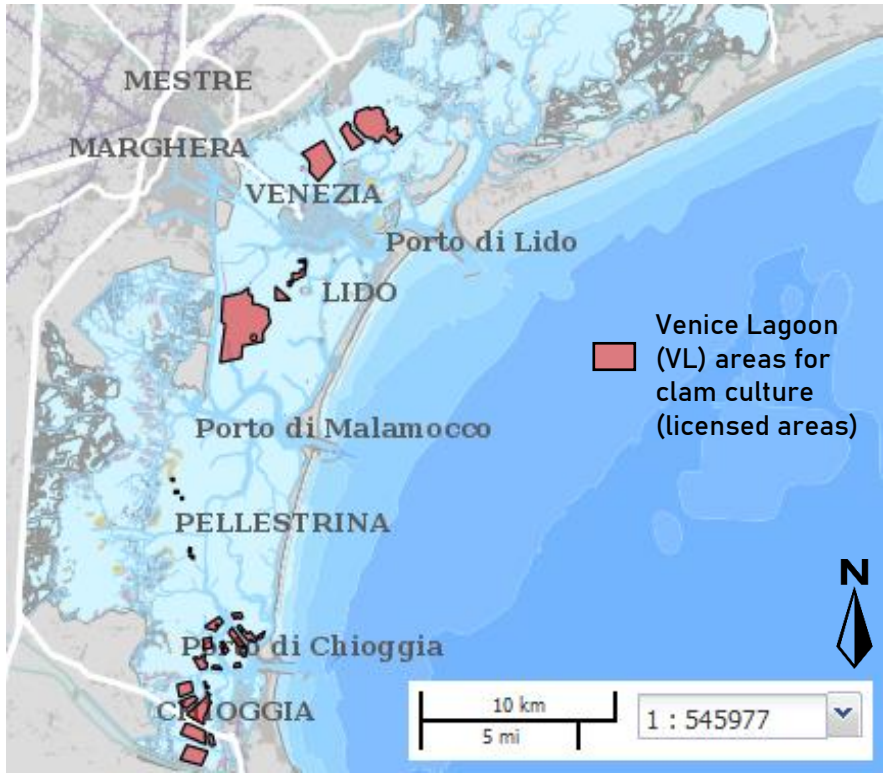

System Dynamics Model
Agent-based Model
+
+
Commercial seeding
Clam Population
Death
-
-

Clam Aquaculture: A Crucial Resource Under Climate Pressure

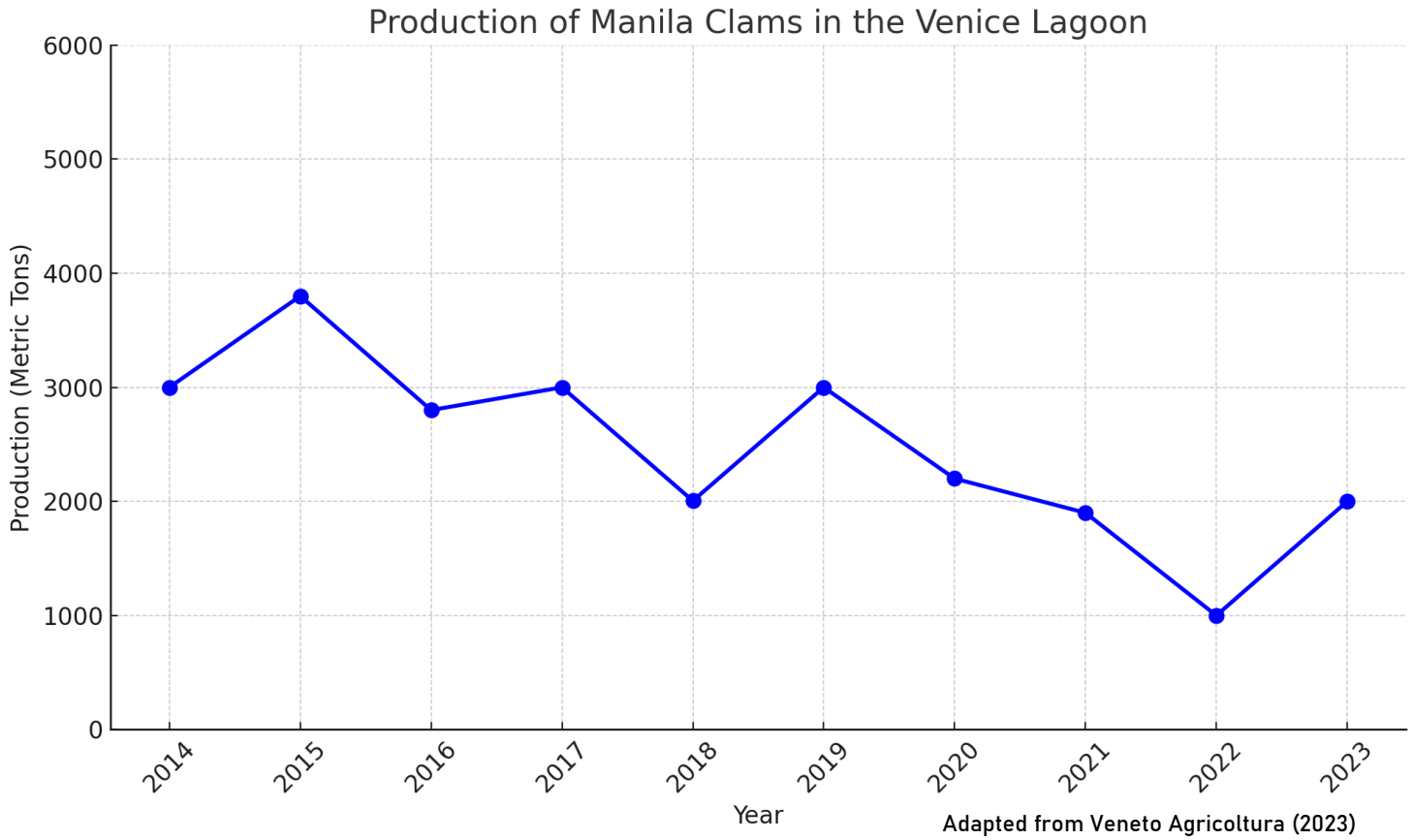


Pellizzato et al. (2010)

Clam Aquaculture: A Crucial Resource Under Climate Pressure



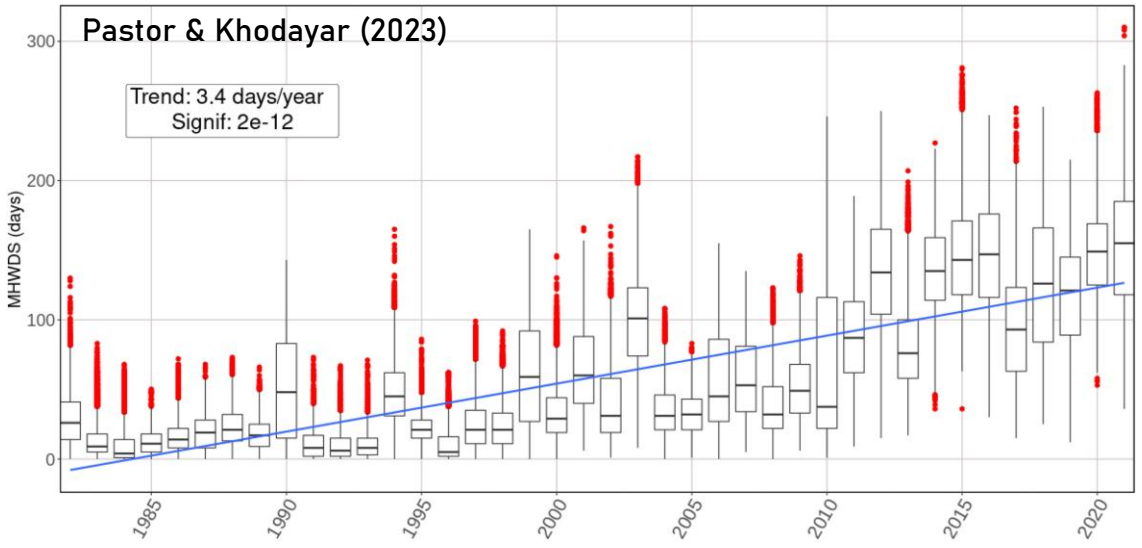
Source: atlantedellalaguna.it



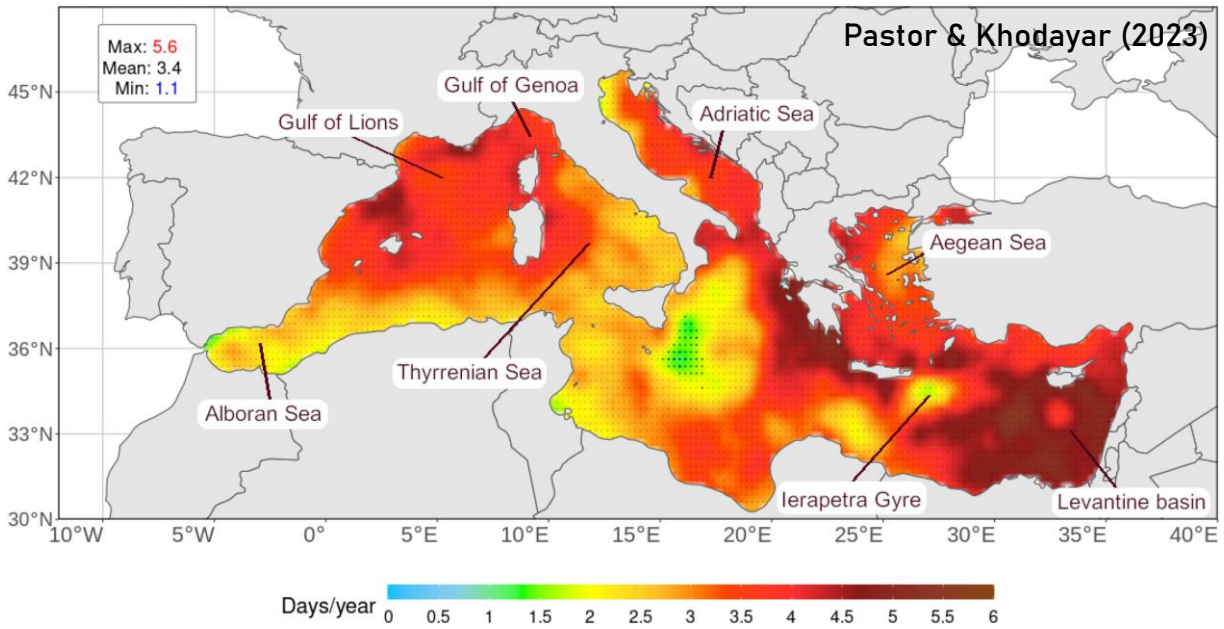
Adapted from Veneto Agricoltura (2023)

Clam Aquaculture: A Crucial Resource Under Climate Pressure

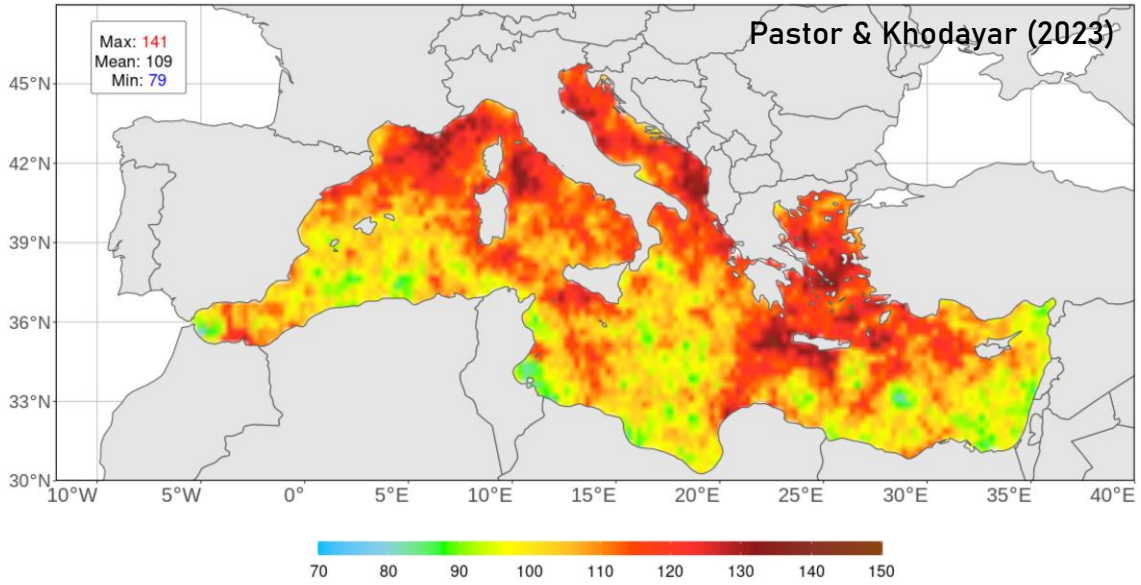
Annual evolution of the MHWDs (1982–2021)



MHWDs annual frequency trend (1982–2021)



MHWDs total count (1982–2021)



To what extent is clam production in the Venice Lagoon sustainable in the long term under climate-induced thermal risk?

Knowledge Gap

Previous studies embed site-specific relationships (**difficult to generalize**) and **lack dynamic integration of thermal risk and agents' adaptive behaviour**, leaving **long-term management under uncertainty unexplored**

Research Objective and Questions

Operationalizing the Tolerance Landscape Approach (temperature-dependent mortality framework)

Integrating thermal mortality and adaptive behaviour in a **hybrid model**: *Under what conditions does this system remain controllable through management, and when does it decouple?*

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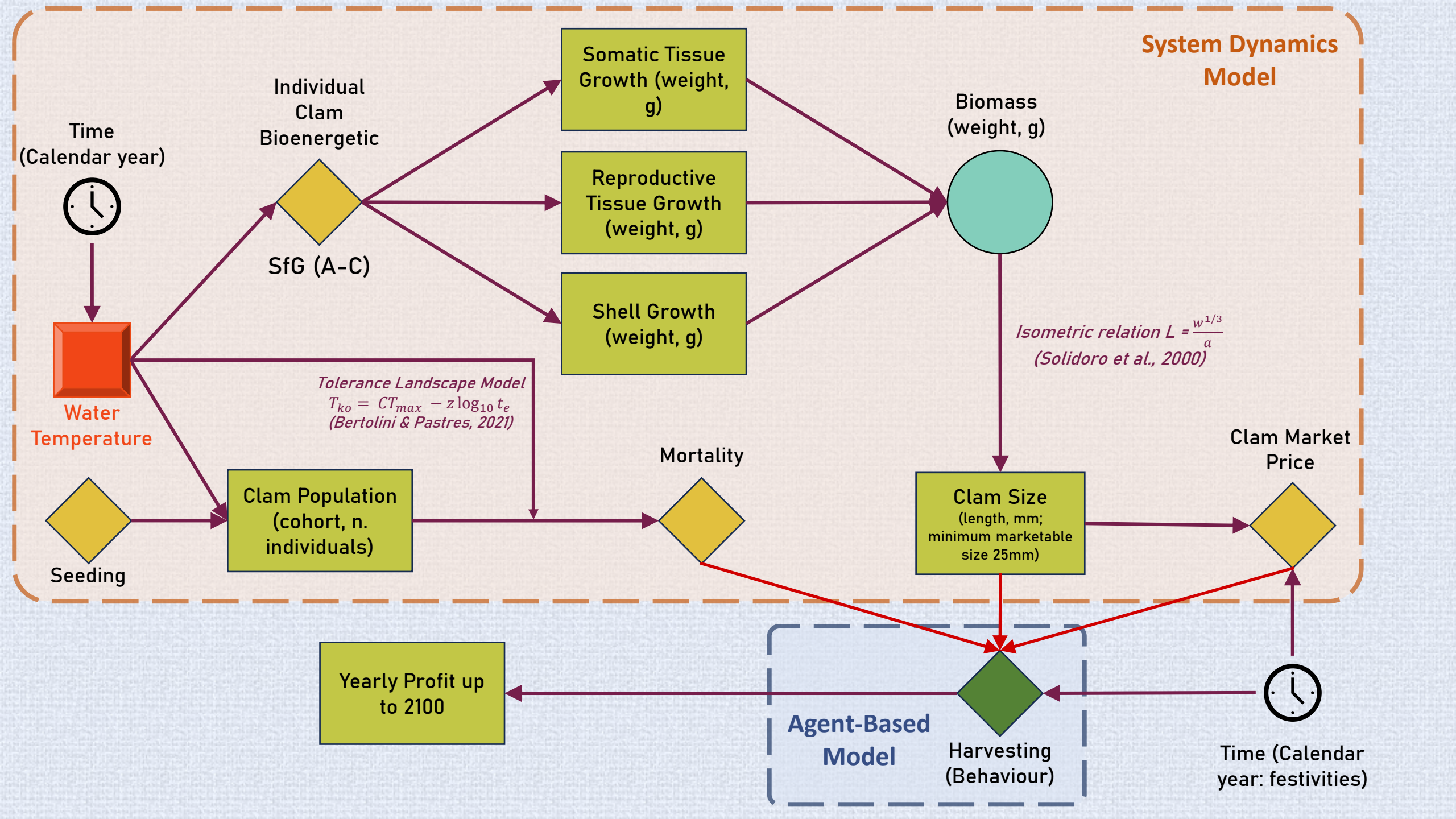
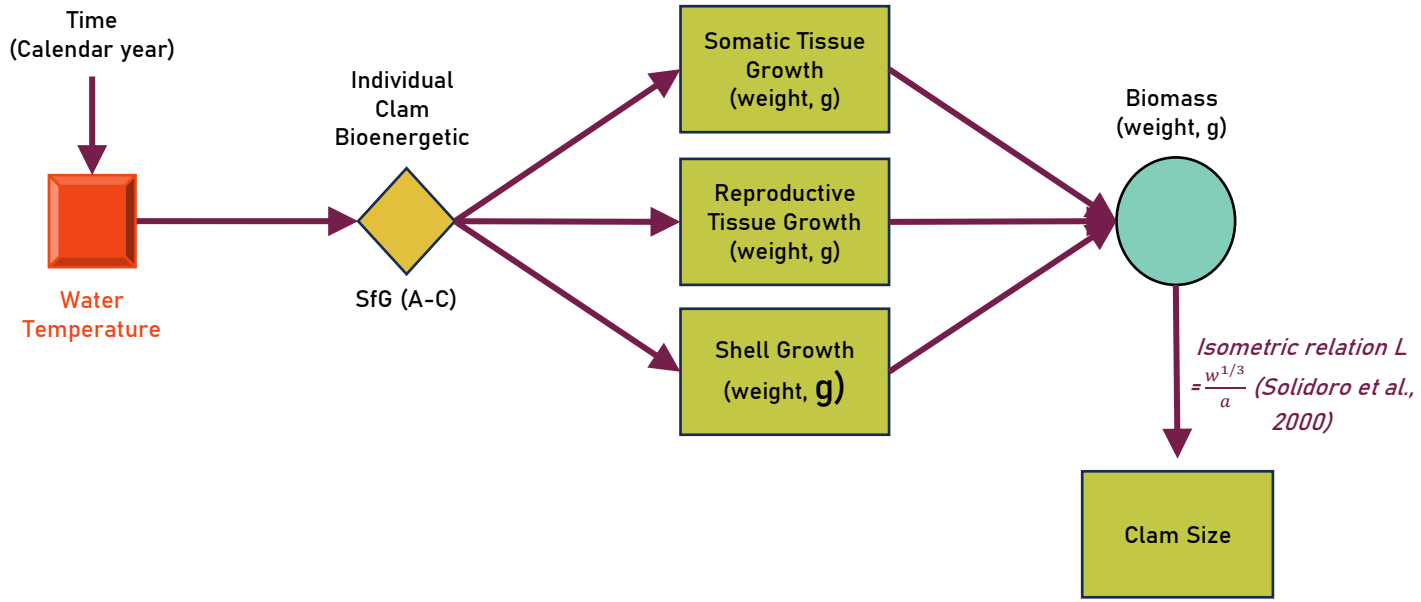
Specific Objectives

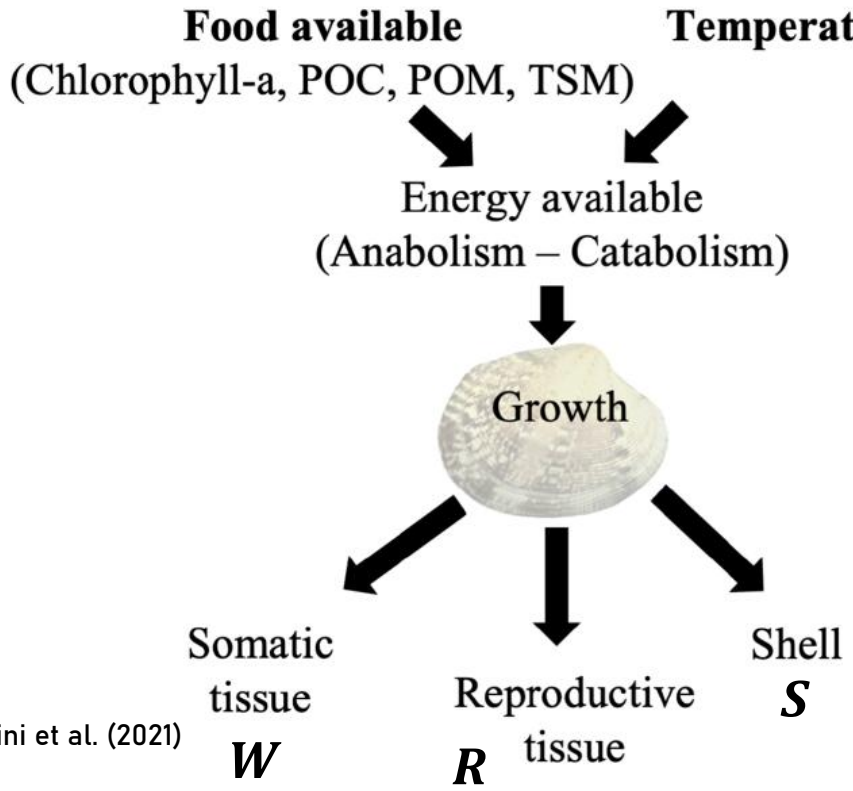
1. Simulate clam aquaculture under rising temperatures
2. Explore adaptive harvesting behaviour in a changing climate (e.g., risk perception)
3. Test future viability of the provisioning service (potential tipping points?)


THE MODEL


System Dynamics Model
Time (Calendar year)
Individual Clam Bioenergetic
SfG (A-C)
Somatic Tissue Growth (weight, g)
Reproductive Tissue Growth (weight, g)
Shell Growth (weight, g)
Biomass (weight, g)
Isometric relation $L = \frac{w^{1/3}}{a}$ (Solidoro et al., 2000)
Water Temperature
Tolerance Landscape Model $T_{ko} = CT_{max} - z \log_{10} t_e$ (Bertolini & Pastres, 2021)
Seeding
Clam Population (cohort, n. individuals)
Mortality
Clam Size (length, mm; minimum marketable size 25mm)
Clam Market Price
Yearly Profit up to 2100
Agent-Based Model
Harvesting (Behaviour)
Time (Calendar year: festivities)

Clam Individual Growth

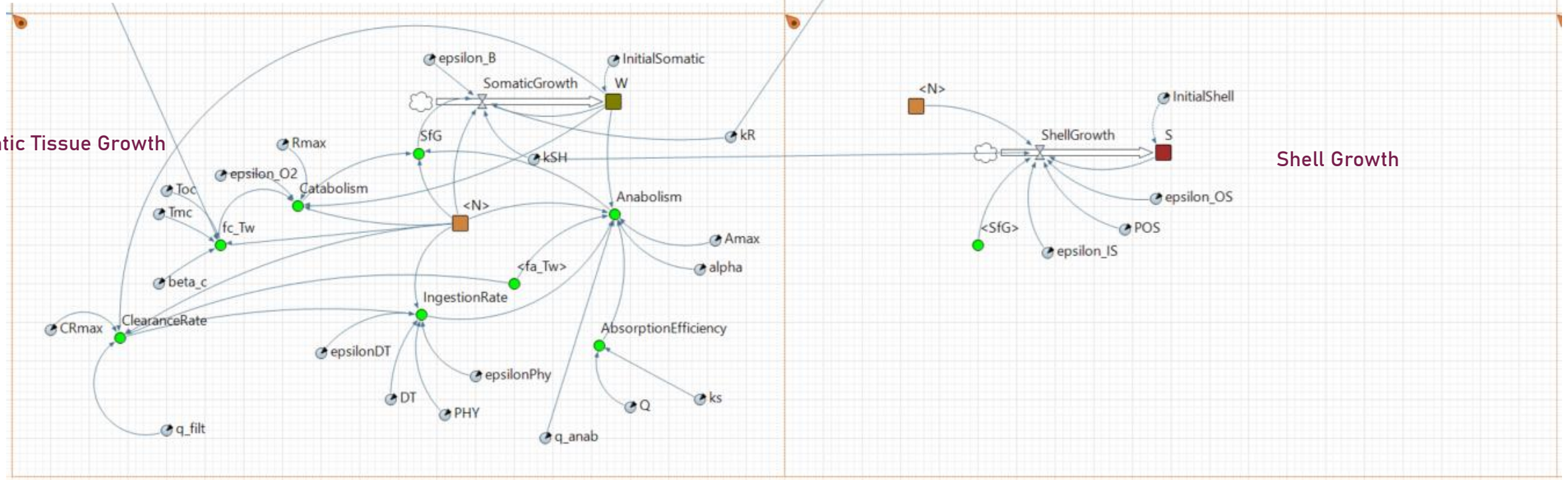


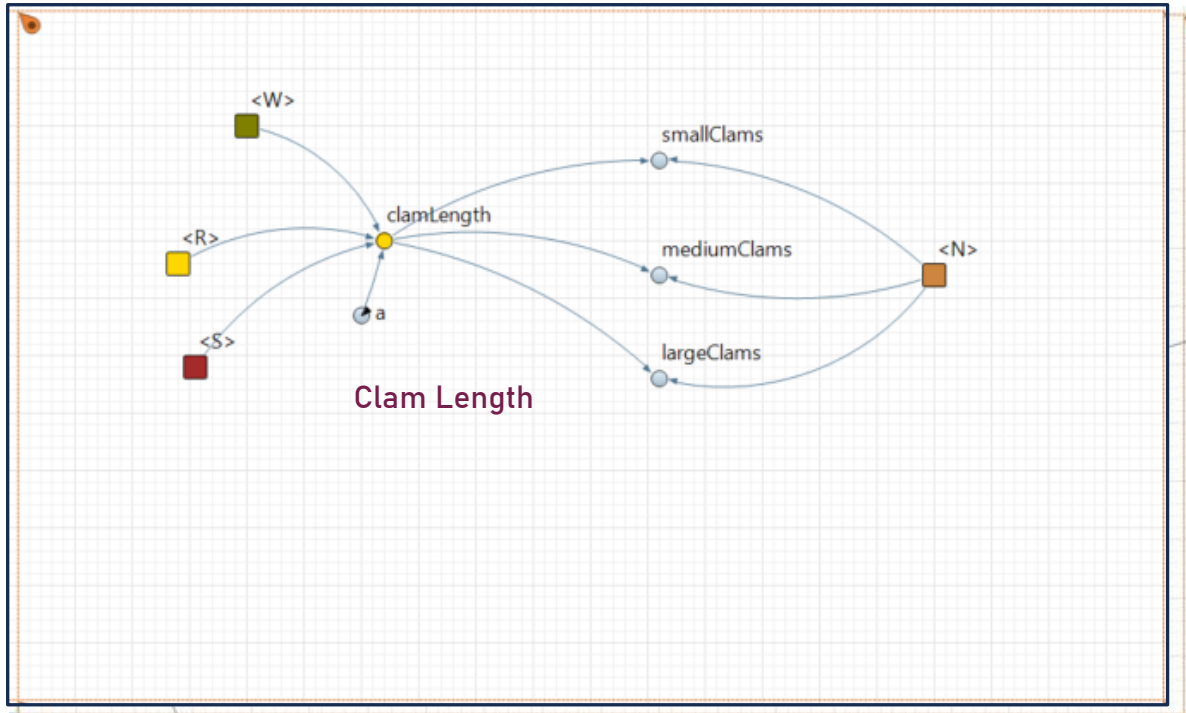


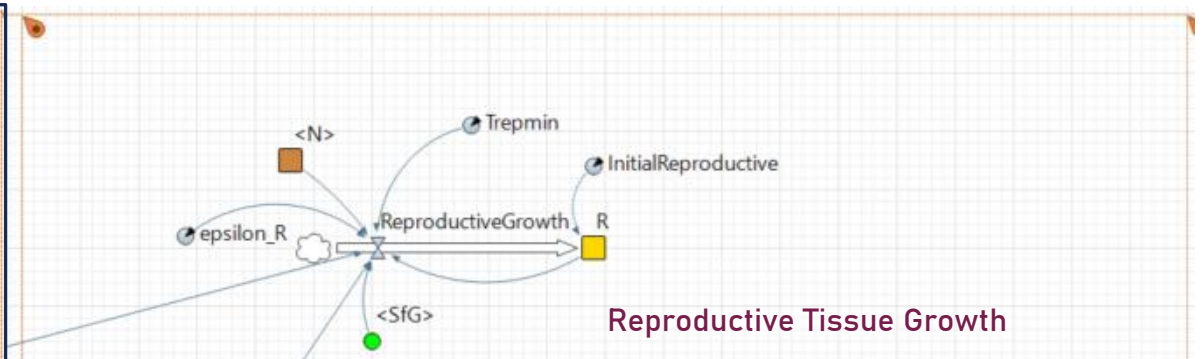
Bertolini et al. (2021)

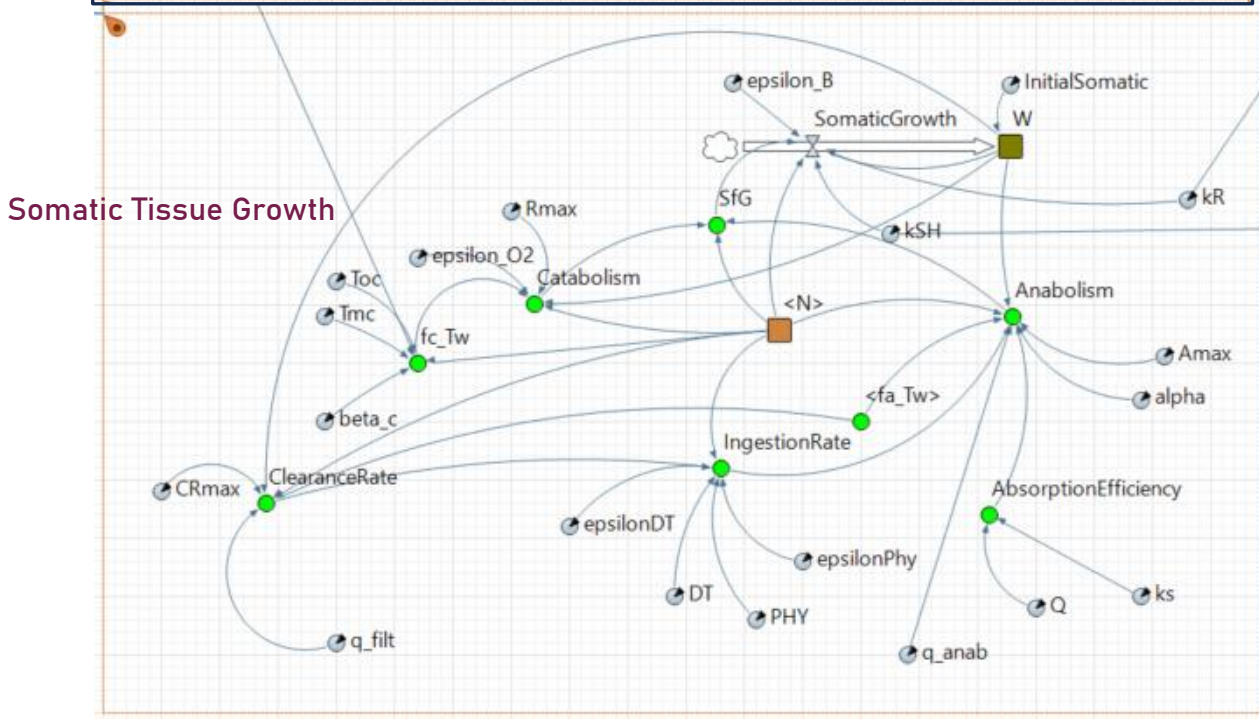
$$\mathrm{SfG} = A - C$$

Scope for Growth


Somatic Tissue Growth
epsilon_B
InitialSomatic
SomaticGrowth
W
kR
SfG
Rmax
kSH
epsilon_O2
Catabolism
Toc
Tmc
fc_Tw
<N>
Anabolism
Amax
alpha
<fa_Tw>
beta_c
IngestionRate
CRmax
ClearanceRate
AbsorptionEfficiency
epsilonDT
epsilonPhy
DT
PHY
Q
ks
q_filt
q_anab
<N>
InitialShell
ShellGrowth
S
epsilon_OS
POS
<SfG>
epsilon_IS
Shell Growth
<N>
Trepmin
InitialReproductive
epsilon_R
ReproductiveGrowth
R
<SfG>
Reproductive Tissue Growth


<W>
smallClams
clamLength
<R>
mediumClams
<N>
a
<S>
largeClams
Clam Length


<N>
Trepmin
InitialReproductive
epsilon_R
ReproductiveGrowth
R
<SfG>
Reproductive Tissue Growth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epsilon_B
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W
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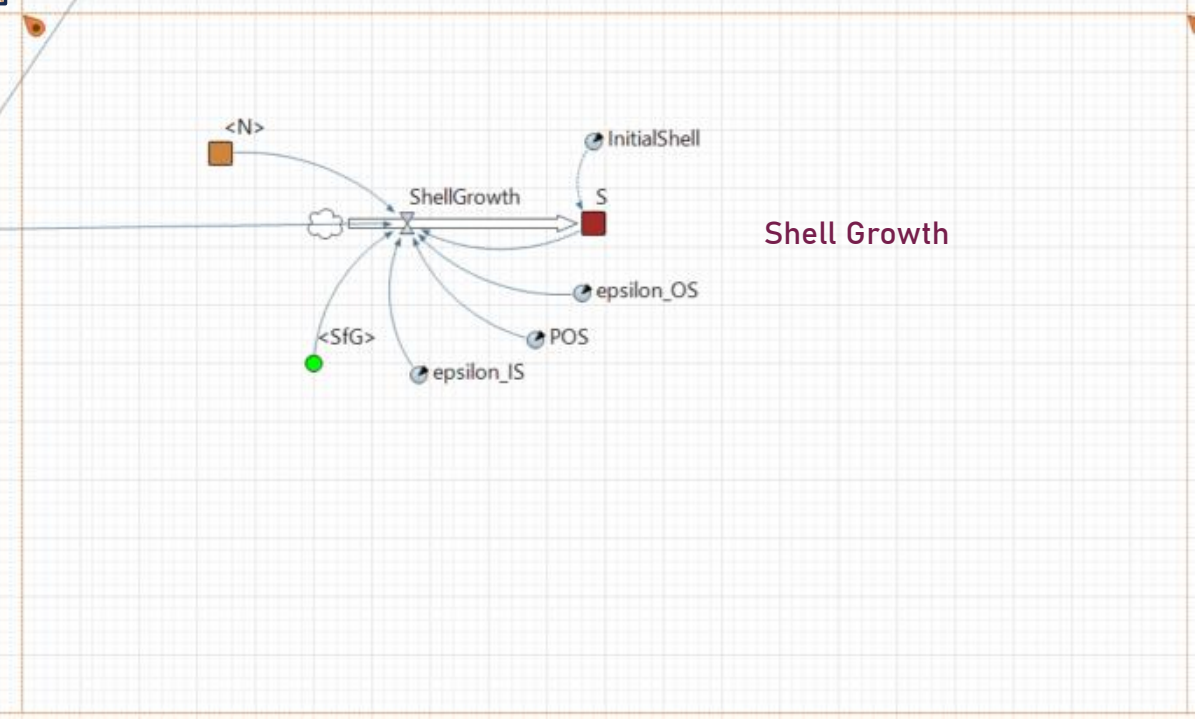
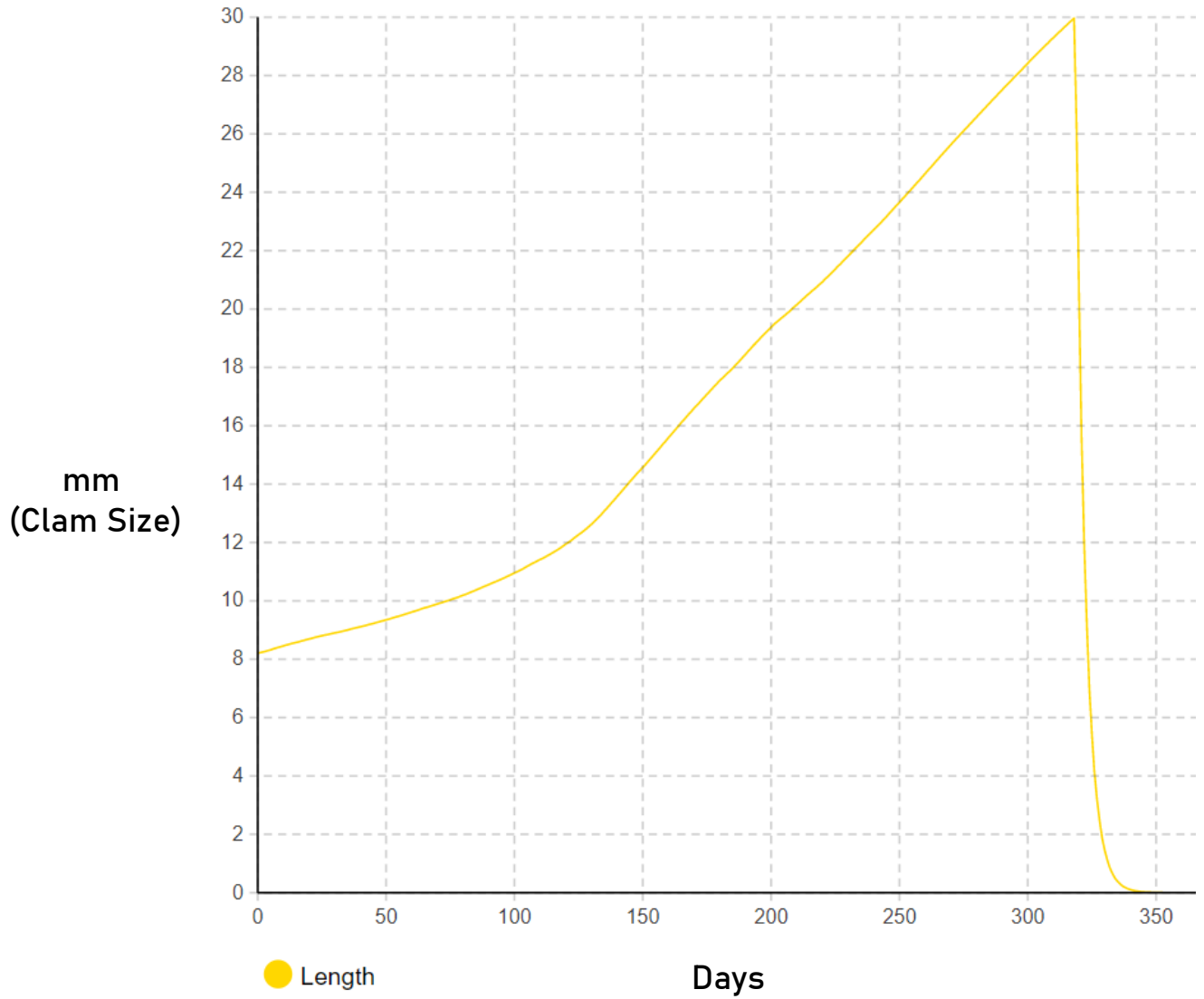
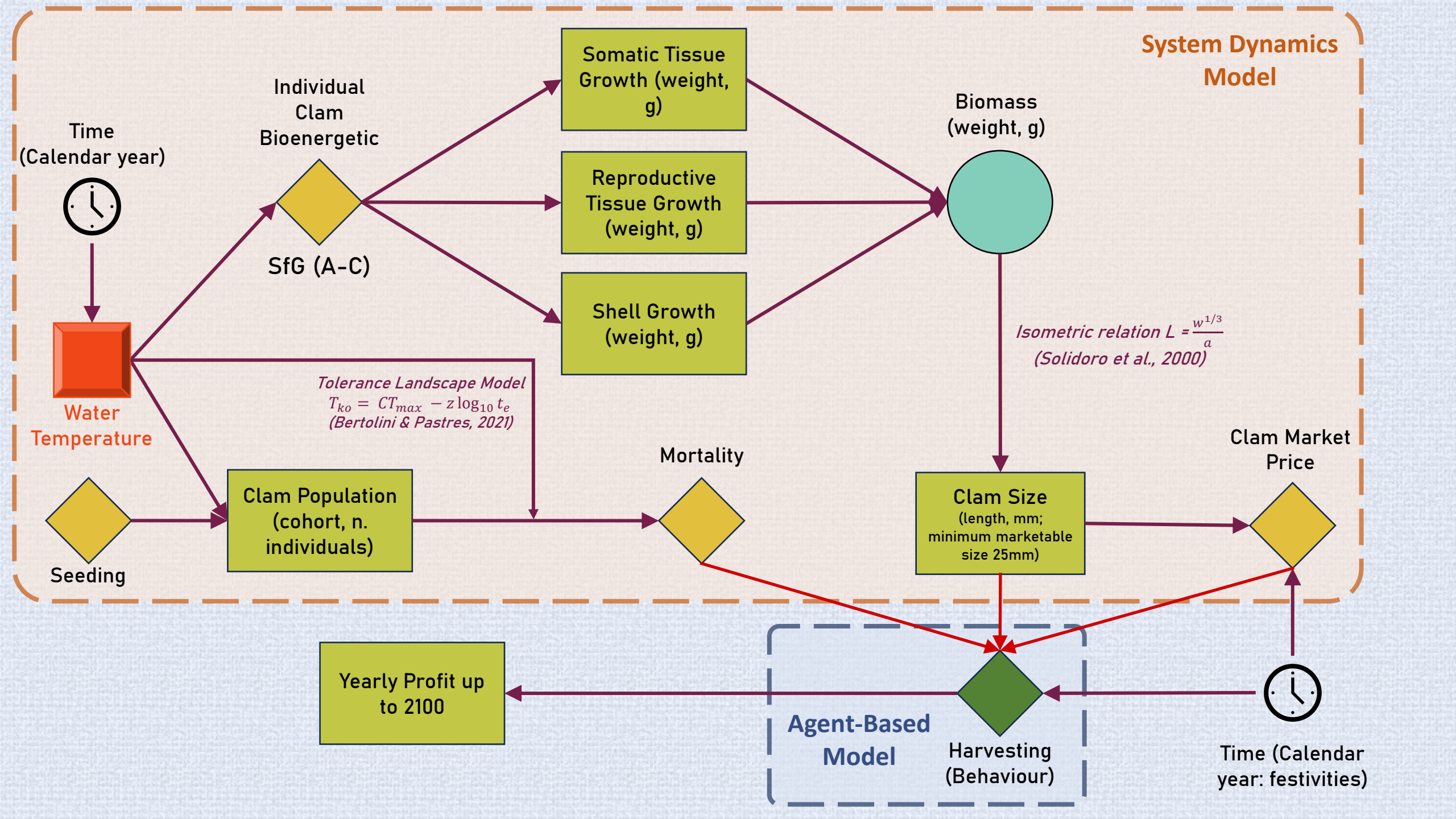
<N>
fc_Tw
Amax
alpha
<fa_Tw>
beta_c
IngestionRate
CRmax
ClearanceRate
AbsorptionEfficiency
epsilonDT
epsilonPhy
DT
Q
ks
PHY
q_filt
q_anab


<N>
InitialShell
ShellGrowth
S
epsilon_OS
<SfG>
POS
epsilon_IS
Shell Growth


mm
(Clam Size)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
Length
Days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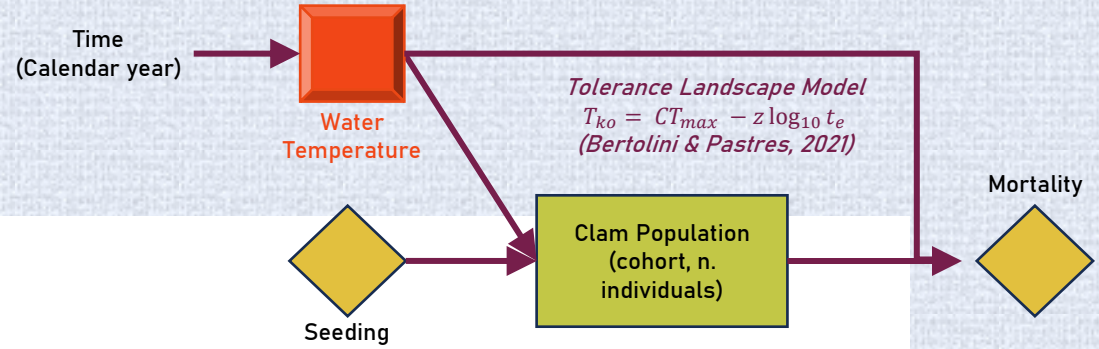
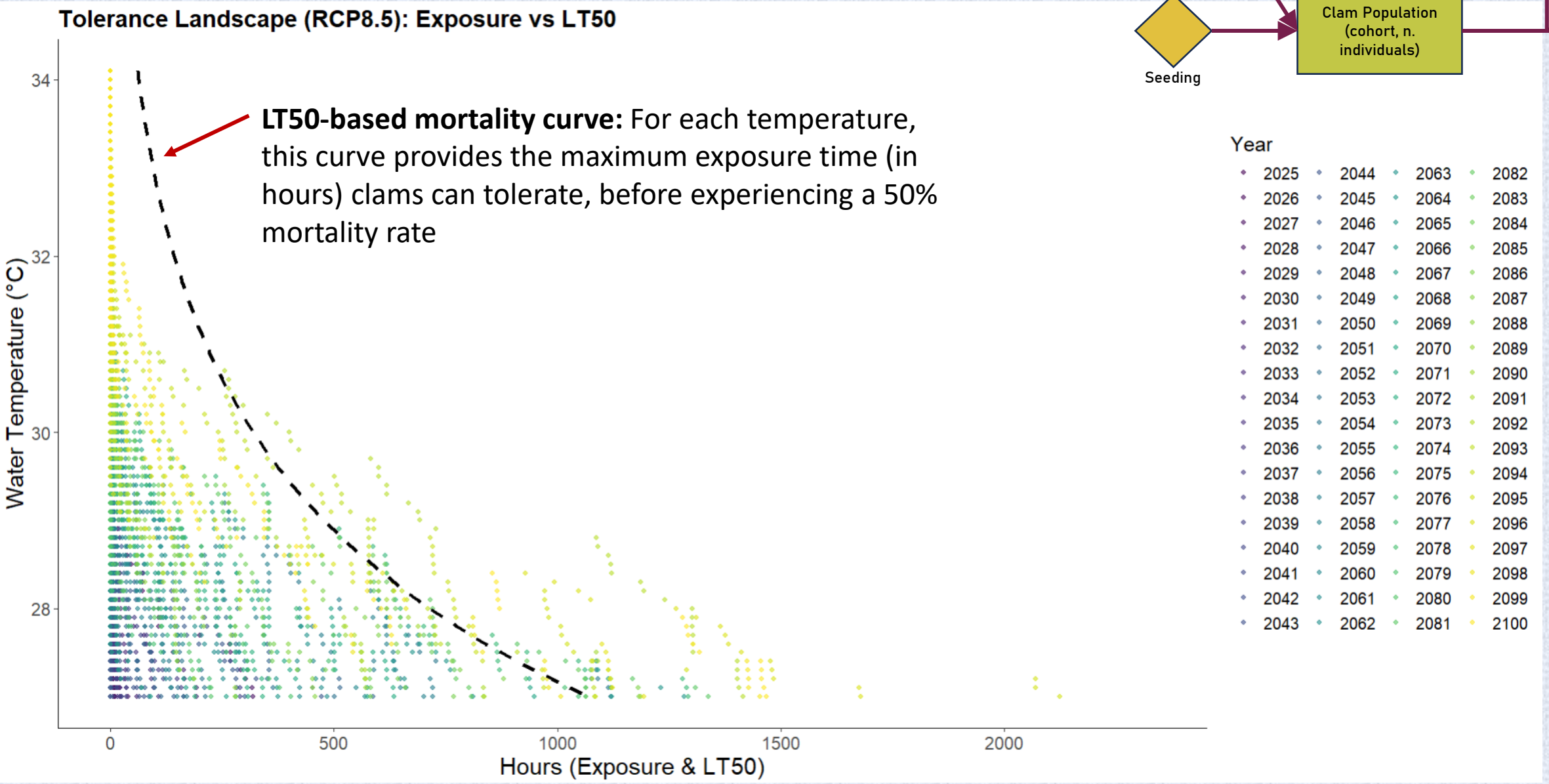
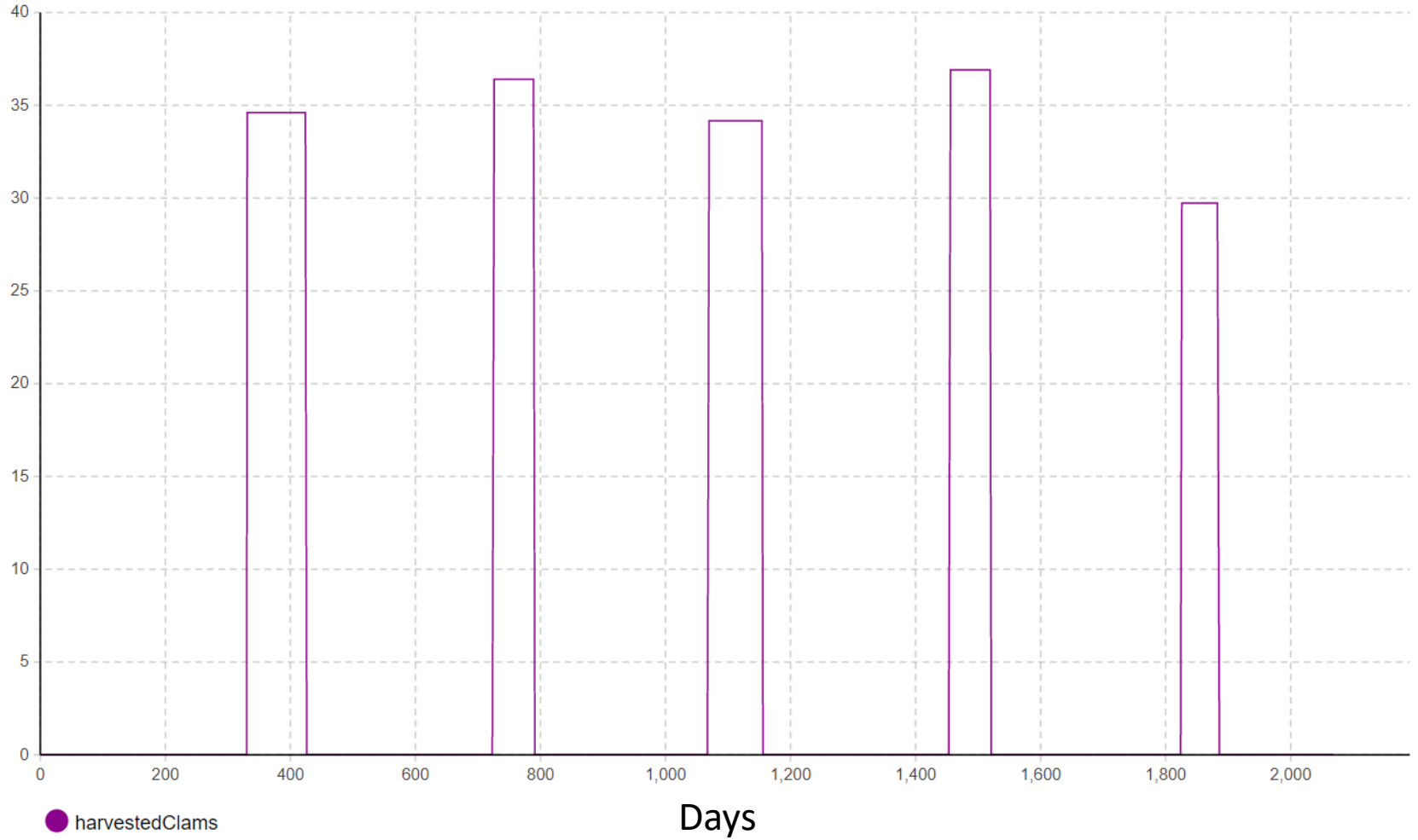
Clam Population Thermal Mortality

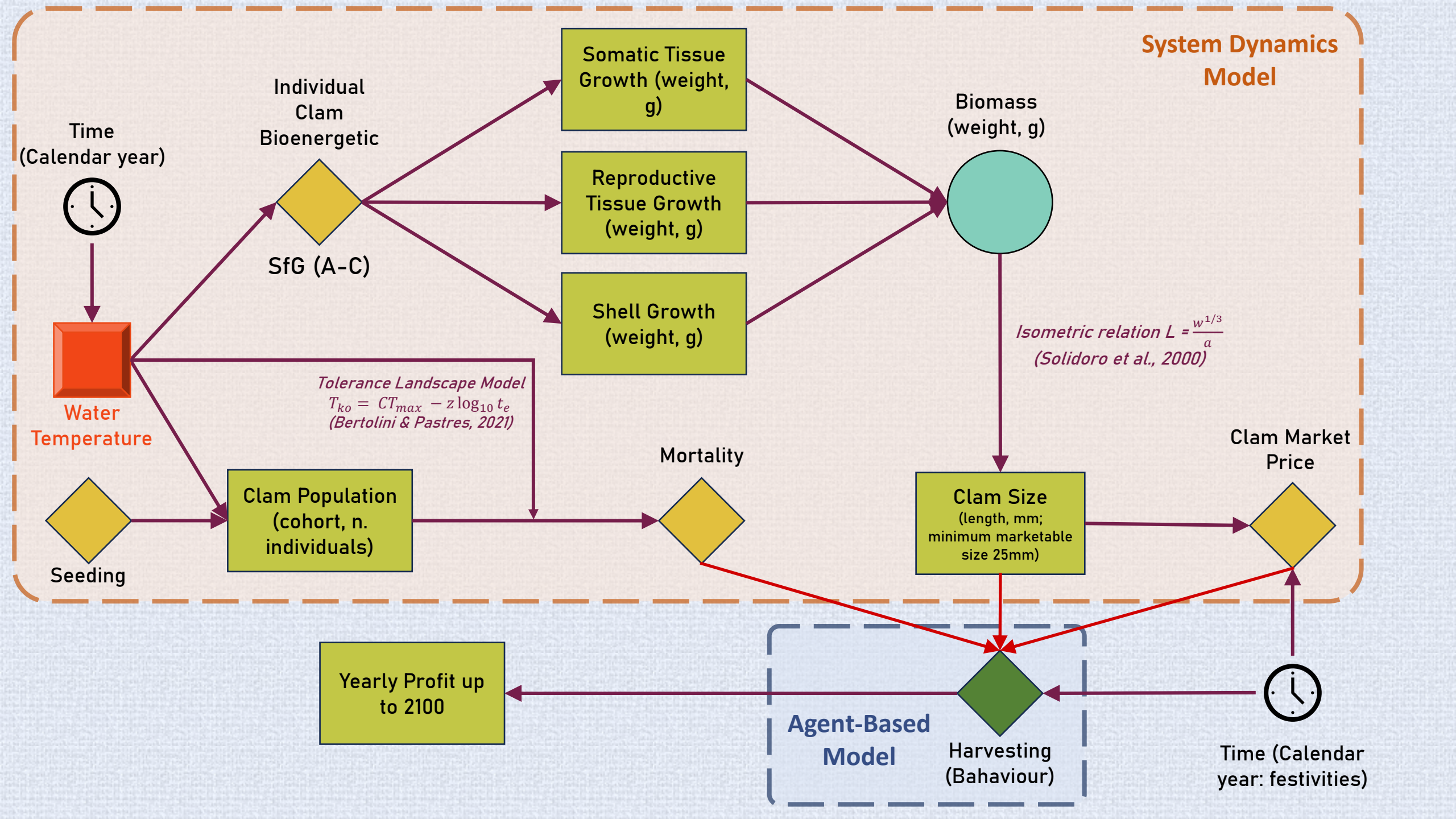




LT50-based mortality curve: For each temperature, this curve provides the maximum exposure time (in hours) clams can tolerate, before experiencing a 50% mortality rate

Harvestable Clams per square meter

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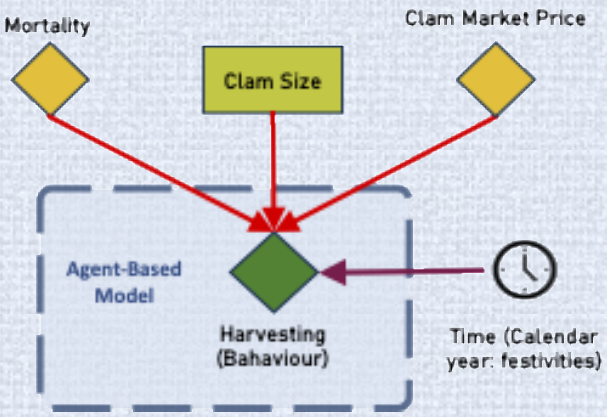
Yearly Profit up to 2100
Agent-Based Model
Harvesting (Bahaviour)
Time (Calendar year: festivities)

Decision Tree



A0

WAIT p_0

HARVEST $1 - p_0$

A1 *Wait*

Utility maximizer

PRICE UP p_1

PRICE DOWN $1 - p_1$

A2 *Price up*

A2 *Price down*

Mortality Event p_2

Survive $1 - p_2$

A3 Mort

A3 Surv

$U_{A3} = 0.5 * Biomass_t * Price_t - Costs_t$

$U_{A3} = Biomass_t * Price_t - Costs_t$

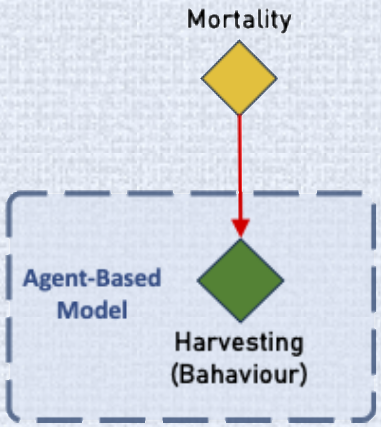
A1 *Now*

Myopic harvester

$U_{A3} = Biomass_{25mm} * Price - Costs$

$$\mathbf{E}[U_{\mathrm{A0}}] = \sum_{\substack{p_0=0 \text{ or } 1 \\ i\in\{\mathrm{Up},\,\mathrm{Down}\} \\ m\in\{\mathrm{Survive},\,\mathrm{Mortality}\}}} p_0\, p_i\, p_m\, U(i,m)$$

Agent's Individual Thermal Mortality Risk Perception



Current Farmers:

Marine Heatwave

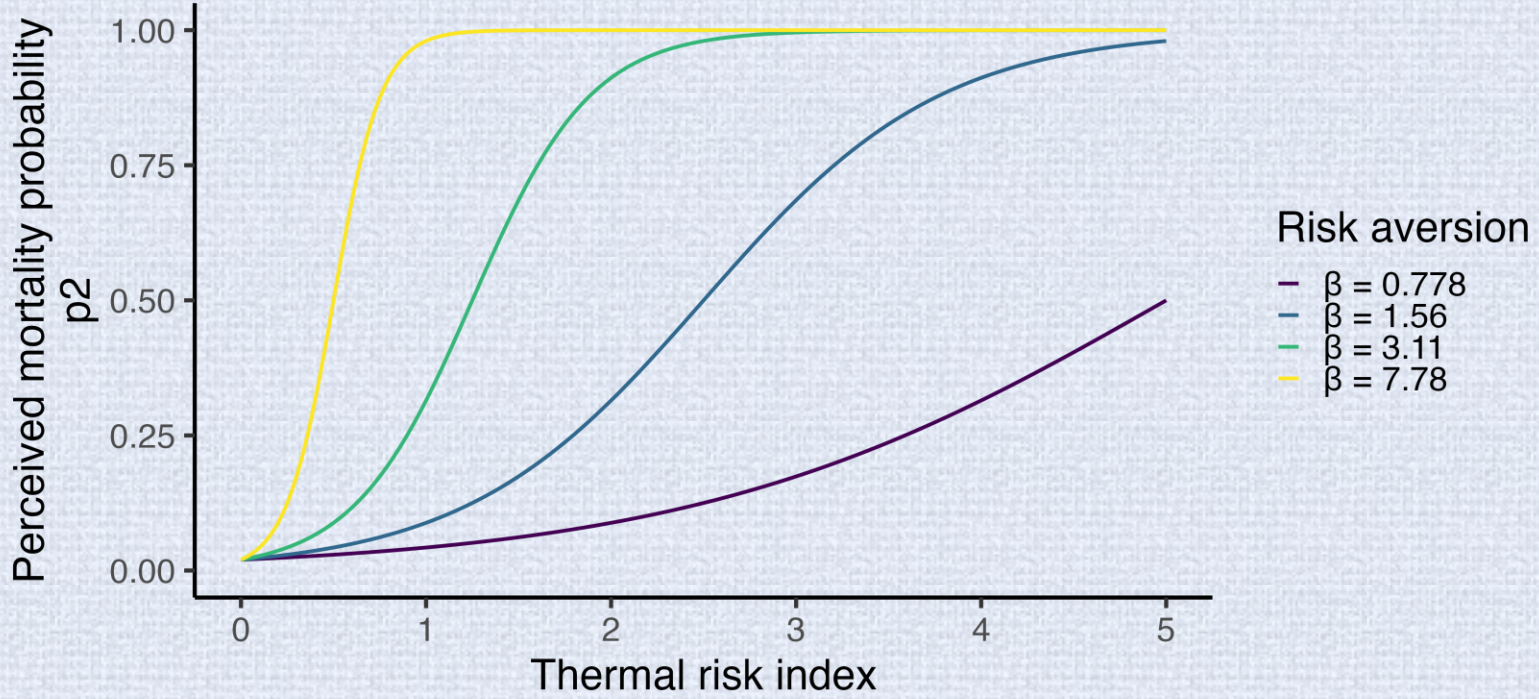
(exceeding the 90th percentile for five consecutive days)

Informed Farmers:

Tolerance Time Threshold

(dynamically based on exposure time)

Bertolini & Pastres (2021)





BENEFITS


Integrate ecological dynamics and agent behaviour in a single environment - an approach rarely adopted in ecosystem service assessment

Framework to explore adaptive management strategies and tipping points affecting the productive system

Replicable framework for other provisioning ecosystem services

Tangible Benefits:

- Estimated biomass trajectories
- Economic viability of aquaculture sector (e.g., modelling agent's annual revenues)

Intangible Benefits:

- Showcasing the potential of scenario analysis for medium-term decision support for resource managers and planners

Next steps

- Improve the model logic
- Complete the ABM (agent heterogeneity etc.)
- Monte Carlo experiment for sensitivity analysis
- Collaboration and/or training & service support from Decision Lab

Thank you
Q&A

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