Resource Competition Agent-Based Model

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Under the same environmental condition, the physical ability of species can be a determinant factor of one species' survival over others competing for the same resources. This model aims to understand what measures could augment the survival of species with inferior physical attributes, such as low energy absorption abilities and reproduction rates.

1. Research Questions

1.1. To what extent can controlling the population of three different species enhance the survival prospects of species with inferior physical attributes?

1.2. Does species' exploratory food searching behaviour enhance the survival of inferior species?

2. ODD

2.1. Purpose and Patterns

This model illustrates the dynamics of the population of three interacting species sharing the same food resources in an ecosystem, based on resource competition theory (Tilman, 1981). The model aims to investigate whether controlling species' populations and implementing an agent's exploratory foraging behaviour in unoccupied and unknown areas can increase the survival probability of species with inferior physical attributes.

The model can be evaluated by its capacity to reproduce the following patterns:

- The species with lower energy absorption ability would likely lose from the ecological competition
- Population control would prevent species with superior physical attributes from dominating the competition
- Exploratory foraging behaviour could compensate for the species' low levels of energy absorption ability

2.2. Entities, state variables, and scales

The model incorporates the following entities: There are three types of agents, with types representing different species (i.e. *specie1s*, *specie2s* and *specie3s*). The patches denote the food resources that the species compete for. The observer is a single entity which manages both global variables and submodels.

Table 1 describes the state variables of the agents and patches, whilst Table 2 lists the state variables of observer.

Table 1. Agent/Patch state variables

Variable name	Variable type & units	Meaning
energy	Dynamic; Integer	The current energy levels of species
memory	Dynamic; Coordinates	Memory of locations where species previously visited
energy-increment	Static; Integer	Species' energy absorption levels they consume food
growth-time	Static; Integer	Growth time of food

Note. The row coloured in light grey is a patch state variable, and the rest are agent state variables. Dynamic state variables change over simulated time, whilst static observer variables remain constant during simulated time.

Table 2. Observer state variables

Variable name	Variable type & units	Meaning
initial-number-specie1s	Static; Integer	Initial number of species 1 ranging between 10 and 15, default = 15
initial-number-specie2s	Static; Integer	Initial number of species 2 ranging between 10 and 15, default = 15
initial-number-specie3s	Static; Integer	Initial number of species 3, ranging between 10 and 15, default = 10
gained-energy-1	Static; Integer	Energy absorption levels of species 1 ranging between 5 and 10, default = 10
gained-energy-2	Static; Integer	Energy absorption levels of species 2 ranging between 5 and 10, default = 10
gained-energy-3	Static; Integer	Energy absorption levels of species 3 ranging between 5 and 10, default = 5
specie1s-reproduce	Static; Integer	Reproduction rates for species 1 ranging between 10 and 50, default = 50
specie2s-reproduce	Static; Integer	Reproduction rates for species 2 ranging between 10 and 50, default = 50
specie3s-reproduce	Static; Integer	Reproduction rates for species 3 ranging between 10 and 50, default = 10
patch-regrowth-time	Static; Integer	Food regrowth time ranging between 1 and 5, default = 5
pop-controller	Static; Integer	Population threshold ranging between 100 and 1,000, default = 500
memory-activation	Static; Boolean	Activation switch for exploratory food searching, on/off (default = off)
intervention-on?	Static; Boolean	Activation switch for an intervention on population, on/off (default = off)
target-search?	Static; Boolean	Activation switch for smart exploratory food searching, on/off (default = off)

Note. The values of observer state variables should be predefined by users.

The model covers an approximate 10 ha area in a 33*33 square grid, where each grid measures 9*9 meters as this size is large enough to sustain three species. The model's space is not bounded indicating species located at one edge can move to cells on the opposite edge. The model operates with a time step of 1 day, and simulations run either until the population of one species becomes zero or 500 time steps, which seems sufficient time for the model to reach a stable state (Railsback and Grimm, 2019).

2.3. Process overview and scheduling

Process: There are 8 processes in the model, where two concerning environment setup, five regarding species (move, food consumption, death, reproduction, and population control), and one performed by patch (food growth).

Scheduling:

1 The environment executes "setup" procedure - "setup-patch" and "create-agents" submodels.
  1.1 "setup-patch" creates lands with/without food resources.
  1.2 "create-agents" initialises each species with its own pre-defined attributes.

2 "go" procedure is performed by observer, agents and patches.
  2.1 Observer inspects if any species does not exist, and stops or continues the simulation accordingly.
  2.2 Agents execute
    2.2.1 "move" submodel, where species move to a land and species' energy is subtracted by 1 at each move.
    2.2.2 "food-consumption" submodel to consume food from the land.
    2.2.3 "death" submodel kills species with no energy.
    2.2.4 "reproduction" submodel, where each species reproduces.
    2.2.5 "invisible-hand" submodel to control population, which is determined by the state of the "*intervention-on*?" observer state variable.
  2.3 Patches execute "grow-food" sub-model, which regrows food in consumed lands.

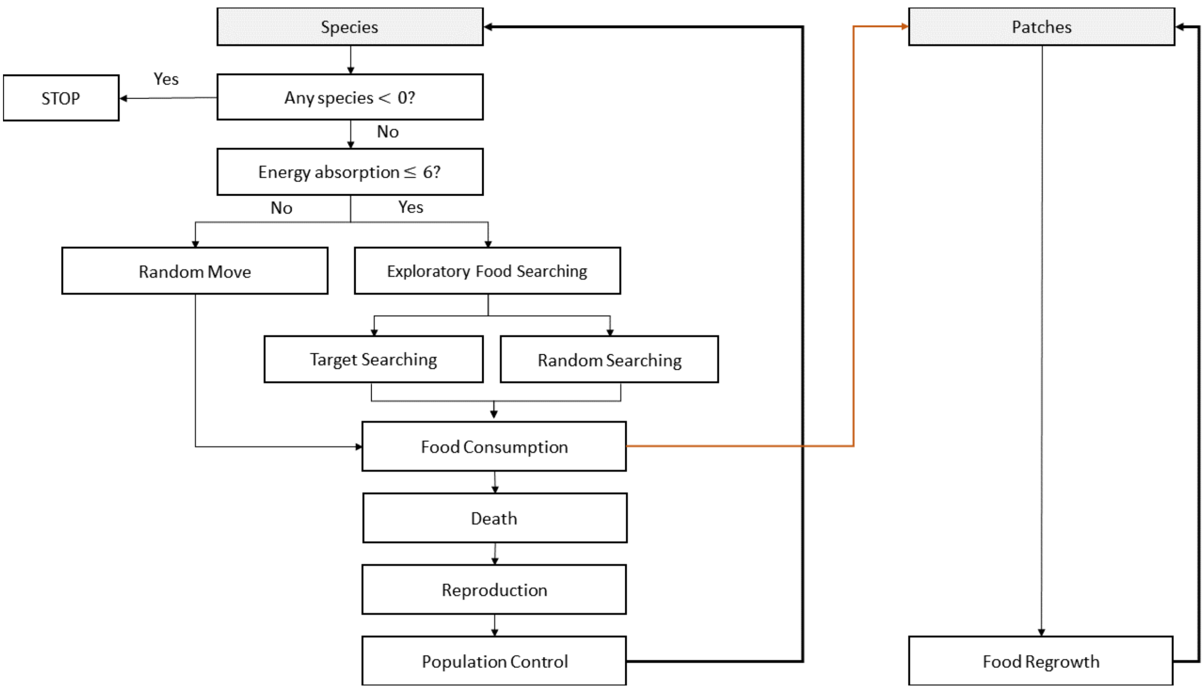

Figure 1. Flow chart of model processes

2.4. Design concepts

Basic principles: This model addresses the resource management problem for species' coexistence in an ecosystem where each species compete for limited resources. It includes the concept of "spatial avoidance" as a mechanism for species coexistence where species partition resources in space and time (Grover, 1997). The "exploratory-food-searching" sub-submodel integrates this concept with the ability of species to remember recently visited-locations, which enables them to avoid lands where resources have been recently depleted. The “invisible-hand” sub-model incorporates the density dependent mechanism to promote species coexistence by regulating the abundance of dominant species (Tilman, 1982) .

Interaction: The interactions among species in the model are primarily mediated by the limited resources they compete for. When two or more agents overlap in their foraging areas and one of them consumes resources, those resources become unavailable to others that rely on the same resources. Furthermore, the “target-searching” and “random-searching” sub-submodels demonstrate how agent’s behaviours of sensing potentially available lands are influenced by the presence of other agents, without direct interaction or communication. This indirect influence can be thought of as a form of mediated interaction among species in the model.

2.5. Initialisation

Agents: Three types of species are created, each requiring parameter-setting. The “*initial-number-species*”, “*gained-energy*”, and “*species-reproduce*” parameters should be predefined by users to initialise species. Once values are given for the parameters, each species with different initial populations, energy absorption abilities, energy levels, and reproduction rates is initialised. To answer the research question, it is recommended to create one species with inferior physical attributes. The species’ locations are randomly assigned in the cells to avoid any bias in the model.

Patches: The “*patch-regrowth-time*” should be predefined by users to initialise patches. Once value is set, two types of lands, with different food growth time, are created and randomly distributed.

Depending on the activation/deactivation of “*intervention-on?*”, “*target-search?*”, and “*memory-activation*” parameters, scenarios will differ.

2.6. Input data

The model does not include any input data.

2.7. Submodels

Table 3 provides a detailed description of some submodels which were not fully described in previous ODD procedures.

Table 3. Description of submodels

Submodel	Description
move	This submodel moves species to one of locations in the grid cells. The followings are accompanied in this submodel. 1 It inspects the energy absorption ability of each species. 1.1 If the energy absorption level of a certain species falls below 6 and "*memory-activation*" is true, "exploratory-food-searching" sub-submodel is implemented for the species. 1.2 If not, agents move forward in a random direction to avoid any bias in the model and mimic natural process.
exploratory-food-searching	This sub-submodel incorporates the concept of "spatial-avoidance" or "habitat partitioning", which refers to the behaviour of species to avoid areas where resources have been depleted or competitors are present. This promotes coexistence among species by ensuring that each species has access to locations with potentially available resources, thereby enhancing its survival possibility. 1 Agents search for resources in a new and unoccupied location to alleviate competition pressure. 1.1 If any of these locations exists, the agent moves to the one with the shortest distance.
food-consumption	This submodel aggregates the sub-submodels of each species' food consumption procedures: 1 Species' energy levels increase by the amount predefined in the "*energy-gained*" parameter. 2 Once agents consume the resources, the land cannot provide food resources immediately as it requires some time to grow food again.
death	Agents whose current energy level is 0 dies.
reproduction	This submodel combines the individual sub-submodels of each species' reproduction procedure: 1 The reproduction rates are determined by the predefined "*species-reproduction*" parameter. 2 The offspring's initial energy is set to one-third of its parent.
nature-intervention	This submodel adopts the concept of "density dependent" mechanism, which limits the population growth of dominant species and allowing subordinate species to persist in the ecosystem. This helps prevent the exclusion of weaker competitors, thereby promoting coexistence. 1 The population threshold is predefined by the "*pop-controller*" parameter. 2 The exceeded number of species' population is eliminated to keep the population below the threshold.
grow-food	This submodel enriches the lands whose resources have been depleted. The "growth-time" is given to every patch in order to account for the amount of time that lands require to regrow foods. 1 If a patch variable "*growth-time*" reaches 0, the land becomes fertile again and the grow-time sets to the value predefined by the "*patch-regrowth-time*" parameter. 2 If "*growth-time*" is not 0, subtract 1 from the current value of "*growth-time*".

3. Brief methodology

In order to investigate whether population control and exploratory foraging behaviour can enhance the survival prospects of species with inferior physical attributes, a controlled experiment will be conducted. Firstly, the user-predefined physical attributes – initial population, energy absorption abilities, and reproduction rates – will be assigned to each species, with one species having relatively lower attributes. Various scenarios can be tested which include a control group without any intervention, population control only, exploratory foraging behaviour only, and both population control and exploratory foraging behaviour.

The population control can be implemented by turning on the ‘intervention-on’ switch. Then, the users can vary the values of ‘pop-controller’ parameter to explore to which extent the population intervention measure could enhance the survival rates of weaker species. The exploratory foraging behaviour amongst inferior species can be initiated by enabling the ‘memory-activation’ parameter, whilst smart food searching can be activated through the ‘target-search?’ parameter. A comparison can be then made to determine whether there is a noticeable difference in the population of weaker species between exploratory foraging and smart food searching, and whether this change has any impacts on the populations of other species.

Population size of each species will be measured in each scenario, which will offer insight into whether interventions provide weaker species with greater access to food resources. Furthermore, comparing population size across different scenarios would allow for an assessment of which intervention measure or combination of measures is most effective in enhancing survival probability of incompetent species.

References

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