ODD protocol

Overview

This ODD (Overview, Design concepts, and Details) protocol provides detailed information of our proof-of-concept migration ABM.

Purpose

This model is built upon a proof-of-concept condition to verify the effects of factor configuration in the environmentally induced migration. The model particularly focuses on incorporating cultural affinity as a social factor and water availability per resident as a natural factor. The model aims to (i) reveal how different factor configurations influence the emergent migration patterns and (ii) explore how factor configurations are related to changing regimes of migration outcomes in response to unexpected shock.

Entities, State variables, and scales

The environment of the model is five patches in a row (in the x-axis direction), representing five independent regions (Fig. 1). Neighboring regions are one patch away from each other. Available water in Region j (w^j) is linearly decreasing from Region 1 to 5: $w^j = s(j-3)+m$ (Table 1 for the explanation of parameters). Then, w^j is equally distributed to each resident in Region j (shown in the left bottom in Fig. 1).

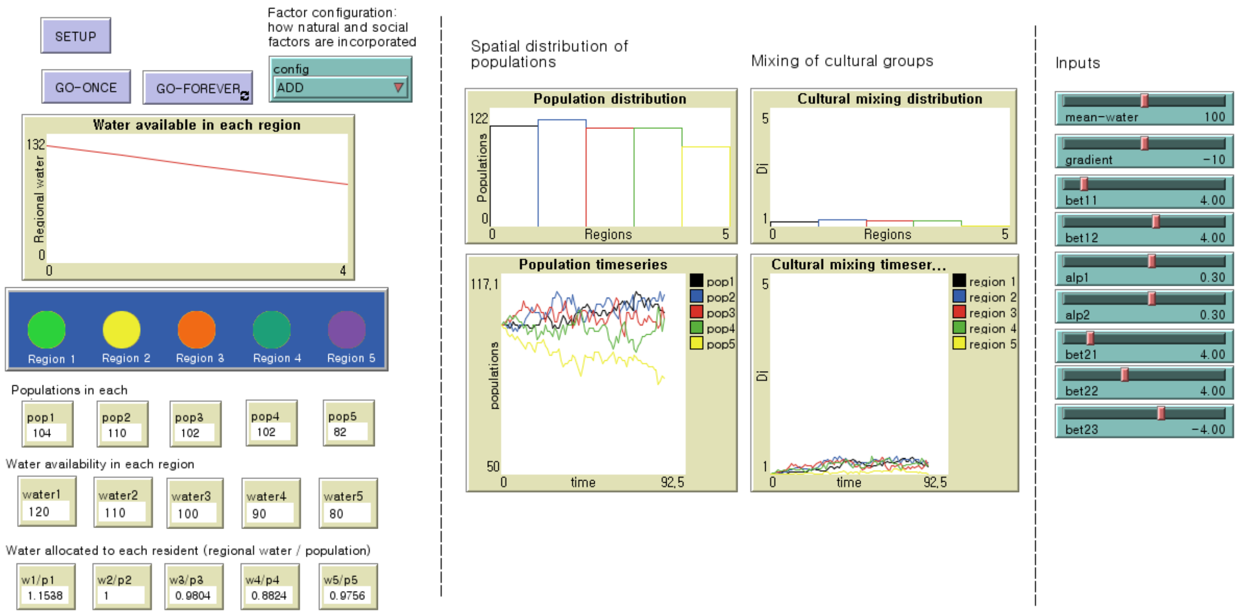

Figure 1. A NetLogo interface of our ABM. In the left top, you can select how natural and social factors are combined (factor configuration) in the chooser per simulation. Water available in each region is shown in the plot below the chooser. Left bottom part monitors attributes of Region j including population (p^j), water availability (w^j), and water allocated to each resident (w^j/p^j). In the center, we display model outcomes—spatial distributions of population and the mixing of cultural groups—in the forms of both distribution graph and time series. Parameters can be controlled in the right column.

Agents of our ABM are residents of five regions (circles in Fig. 1). Residents take their initial locations (patches at $t = 0$) as their hometowns and form social ties with people from the same hometown due to their cultural background (social factor). Water availability is also an important factor in migration decisions (natural factor). Each resident has different levels of social and natural factors in deciding whether to stay or to leave their current locations. A resident calculates a migration probability based on factor levels and parameters for his/her migration decision-making (equations for the migration probability are given in the later section and parameters are illustrated in Table 1).

Table 1. Descriptions, units, and values of parameters used in the model.

Par	Descriptions	Units	Values
m	Mean of available water for five regions. This input is directly related to the amount of water supply over five regions.	$[W]$	100
s	A slope of water availability over five regions. Related to how equally/inequally water is distributed in five regions.	$[-]$	-10
$\beta_1^{(1)}$	Weight of natural factor (water availability) in calculating first-stage migration probability. Controls a shape of logistic function for the first-stage probability (flat curve versus steep curve).	$\left[\frac{1}{W/N}\right]$	4
$\beta_1^{(2)}$	Weight of social factor (cultural affinity) in calculating first-stage migration probability. Controls a shape of logistic function for the first-stage probability (flat curve versus steep curve).	$[-]$	4
$\alpha^{(1)}$	Increase/decrease the probability of a resident to leave the current location (control degrees of first-stage probability) with respect to water availability.	$\left[\frac{W}{N}\right]$	0.3
$\alpha^{(2)}$	Increase/decrease the probability of a resident to leave the current location (control degrees of first-stage probability) with respect to cultural affinity.	$[-]$	0.3
$\beta_2^{(1)}$	Weight of natural factor (water availability) in calculating second-stage migration probability. Controls a shape of logistic function for the second-stage probability (flat curve versus steep curve).	$\left[\frac{1}{W/N}\right]$	4
$\beta_2^{(2)}$	Weight of social factor (cultural affinity) in calculating second-stage migration probability. Controls a shape of logistic function for the second-stage probability (flat curve versus steep curve).	$\left[\frac{1}{N}\right]$	4
$\beta_2^{(3)}$	Weight of distance factor in calculating second-stage migration probability. Controls a shape of logistic function for the second-stage probability (flat curve versus steep curve).	$\left[\frac{1}{patch}\right]$	4

This ABM is built in the artificial world that the units and scales are not based on real-world measures. In Table 1, "$[W]$" is an artificial unit related to the water amount, "$[N]$" is a unit for the number of residents, and "$[patch]$" represents a distance between regions.

Table 2. Descriptions and initial values of state variables used in the model

State variables	Descriptions	Initial values
p_j	Count a population size in Region j	100
D_j	Identify how well cultural groups are mixed in region j	1

Process overview and scheduling

Every time step, the followings are done:

1. First-stage migration decision making

Each resident decides whether to stay or leave the current location. He/she first identifies the current levels of natural and social factors in the current region.

- Natural factor $x^{(1)}$: Water availability per resident in the current Region j ($x^{(1)} = w^j/p^j$)
- Social factor $x^{(2)}$: Strength of social ties in Region j stemming from the same cultural background. ($x^{(2)} = p_k^{\boldsymbol{j}}/p^j$; $p_k^{\boldsymbol{j}}$ is the population in region j from hometown k)

He/she calculates a staying probability at the current location o ($\mu_o(t)$)with these factors and parameters in Table 1. An equation of staying probability depends on the first-stage factor configuration (F_1).

- $F_1 = \text{ADD}$: $\mu_o(t) = \frac{e^{\beta_1^{(1)}\left(\alpha^{(1)}-x^{(1)}\right)+\beta_1^{(2)}\left(\alpha^{(2)}-x^{(2)}\right)}}{1+e^{\beta_1^{(1)}\left(\alpha^{(1)}-x^{(1)}\right)+\beta_1^{(2)}\left(\alpha^{(2)}-x^{(2)}\right)}}$
- $F_1 = \text{AND}$: $\mu_o(t) = \left(\frac{e^{\beta_1^{(1)}\left(\alpha^{(1)}-x^{(1)}\right)}}{1+e^{\beta_1^{(1)}\left(\alpha^{(1)}-x^{(1)}\right)}}\right)\left(\frac{e^{\beta_1^{(2)}\left(\alpha^{(2)}-x^{(2)}\right)}}{1+e^{\beta_1^{(2)}\left(\alpha^{(2)}-x^{(2)}\right)}}\right)$
- $F_1 = \text{OR}$: $\mu_o(t) = 1 - \left(\frac{1}{1+e^{\beta_1^{(1)}\left(\alpha^{(1)}-x^{(1)}\right)}}\right)\left(\frac{1}{1+e^{\beta_1^{(2)}\left(\alpha^{(2)}-x^{(2)}\right)}}\right)$

Then, the resident rolls a random dice between 0 and 1. If the dice value is smaller than $\mu_o(t)$, he/she stays in the current location. Otherwise, he/she decides to leave the current region and proceeds to the second-stage decision-making to select where to go.

2. Second-stage migration decision making

Each resident who decided to leave in the first stage chooses which region to migrate to. He/she first identifies the levels of natural, social, geographical factors in the other four regions.

- Natural factor $\Delta x_{jo}^{(1)}$: Difference of water available per resident between origin o and destination j ($\Delta x_{jo}^{(1)} = w^j/p^j - w^o/p^o$)

- Social factor $\Delta x_{jo}^{(2)}$: Difference of populations from the same cultural background between origin o and destination j ($x^{(2)} = (p_k^j - p_k^o)/\sum_{i=1}^{5} p_k^i$, where Region k is the hometown of a focal resident)
- Geographical factor $\Delta x_{jo}^{(3)}$: Distance between origin o and destination j

He/she calculates a second-stage ($\theta_{j\leftarrow o}(t)$) probability with these factors and parameters in Table 1. An equation of migration probability depends on the second-stage factor configuration (F_2). Geographical factor always has an inverse relationship to natural and social factors.

- $F_2 = \text{ADD}$: $\theta_{j\leftarrow o}(t) = C_{ADD} \frac{e^{\beta_2^{(1)}\Delta x_{jo}^{(1)} + \beta_2^{(2)}\Delta x_{jo}^{(2)}}}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)} + \beta_2^{(2)}\Delta x_{jo}^{(2)}}} / e^{\beta_2^{(3)}\Delta x_{jo}^{(3)}}$
- $F_2 = \text{AND}$: $\theta_{j\leftarrow o}(t) = C_{AND} \left(\frac{e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}} \right) \left(\frac{e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}}{1+e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}} \right) / e^{\beta_2^{(3)}\Delta x_{jo}^{(3)}}$
- $F_2 = \text{OR}$: $\theta_{j\leftarrow o}(t) = C_{OR} \left\{ 1 - \left(\frac{1}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}} \right) \left(\frac{1}{1+e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}} \right) \right\} / e^{\beta_2^{(3)}\Delta x_{jo}^{(3)}}$

C_{ADD}, C_{AND}, and C_{OR} normalize the probabilities ($\sum_{j\neq o} \theta_{j\leftarrow o}(t) = 1$).

Then, the resident rolls a random dice between 0 and 1 (independent from the previous one). If the dice value is in the range of $\theta_{j\leftarrow o}(t)$, he/she chooses Region j as the destination.

3. Migration

Residents who decided to leave in the first stage migrate to the destination selected in the second stage. Residents who decided not to leave in the first stage just stay in their current region.

4. Update social and environmental properties

After the migration process is finished, the model newly updates natural and social factors.

Shock scenario

At $t = 2001$, we drop 50% of water availability in Region 1 to explore how the system responds to the shock in different factor configurations. This drop is kept until the end of the simulation ($t = 3000$).

Design concepts

Basic principles. This model is a proof-of-concept ABM which simplifies environmentally induced migration to test the effect of factor configuration. Though many drivers exist in this problem (e.g., economic, political, demographic) (Black et al., 2011), we focus on natural (related to water availability), social (related to cultural affinity), and geographical(related to the distance) factors.

Emergence. Two key outputs of our ABM are the spatial distribution of populations and the mixing of cultural groups. The former explains how populations are spread over five regions, and the latter illustrates how much each region is culturally homogeneous/heterogeneous. For the cultural mixing, we use Simpson's diversity index (D_j) from ecology to quantify a level of how well Region j is culturally mixed.

Adaptation. In our model, migration decision-making is divided into two stages, as in some migration models (Champion et al., 2003; Rees et al., 2006; Stillwell, 2005). First, a resident decides whether to stay in the current region. Once the resident decides to leave, he/she chooses which region to go in the second stage. Decision-making is based on the probabilistic process rather than an adaptive process. A resident rolls dice with U[0, 1] and behaves depending on the relationship between the probability value and dice value.

Objectives. An agent's objective is to pursue a higher level of natural and social factors. Therefore, a resident may leave the current location and move to a new place with a better situation. Yet, different configurations between these factors affect the decision-making of the agent. For example, a low level of one factor can be replaced by another factor under ADD factor configuration and satisfy a resident to stay at his/her current location regardless of insufficiency.

Sensing. An agent is assumed to know how many people from the same hometown stay in one region and how much water can be supplied in each region (full information).

Interaction. The interactions are indirect in our model. The migration of residents affects the water availability of each resident. Migration also changes the strength of social ties in each region.

Stochasticity. In general, most of the processes in the model are probabilistic. Decision-making of an agent depends on the random dice rolls. Migration patterns still have deterministic behaviors, which are more explained in our ongoing work (Carmona Cabrero et al., In prep.).

Collectives. People form social ties with others from the same hometown due to the same cultural background. Social ties play a significant role in migration decision-making.

Initialization

At $t = 0$, each region has 100 residents who take initial locations as their hometowns. Five regions are all culturally homogeneous with $D_j = 1$. Water allocated to each resident is 1.2, 1.1, 1.0, 0.9, and 0.8 from Regions 1-5.

References

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