Supplementary Material

We listed the full edition of ODD + D protocol which is used to describe our agent-based modeling of consumption for grassland ecosystem supply service. We answered the 52 guiding questions in detail separately.

1. Overview

1.1. Purpose

1.1.1. What is the Purpose of the Study?

The model is used to simulate the ecosystem services consumption process of the local people with changes to the economy, society and environment, explore the strategies for sustainable management of pasture ecosystem, identify reasonable ecosystem services consumption pattern for the grassland in the research region and provide decision support for the promotion of the sustainable development of the social-ecosystem in Inner Mongolia.

1.1.2. For Whom is the Model Designed?

The model predicts the evolution of ecosystem pressure, livestock scale and herder's living level under four pasture management scenarios and provides decision support for farmland managers and regional policy makers to exploring the possible win-win strategies of sustainable grassland management and improved herders living level.

1.2. Entities, State Variables and Scales

1.2.1. What Kinds of Entities are in the Model?

Agents and the land are main entities. There are two types of agents in our model, including individual agent and household agent. Each household consists of multiple individuals.

1.2.2. By What Attributes (i.e., State Variables and Parameters) are These Entities Characterised?

Individual agents are characterized by the state variables: coordinates, age, gender, education, living consumption, pasture income (the herding income of individuals), maxAge (the longevity of individuals), work income (the migrant work income of individuals), occupationState (the occupation states of individuals).

Household agents are characterized by the state variables including family structure, household land state, household livestock state, production and comsumption of NPP, household income and NPP pressure index (Table 1).

Table 1. state variables of household agents

Category	Variables	Explanation
Family structure	amountofFamilyM	the number of family members in each household
	individualAgent array	the array of family members
	children	the number of children in the family
	elder	the number of elders in the family
	parent	the role of parent in one family
	herders	the number of herders in the family
	outworkers	the number of workers out of the hometown in the family
Livestock	sheepofCurrentYear	the number of sheep that the family is raising in the current year

breeding	sheepofCurrentYearmiddler	the number of sheep that the family is raising in the middle of the current year
	sheepofLastYear	the number of sheep that the family raised in the last year
	sheepofLastYearmiddle	the number of sheep that the family raised in the middle of last year
	NPPsheepofCurrentYear (gC/(m²·a))	the NPP (net primary productivity) consumed by sheep herding in the family in the current year
	NPPsheepofLastYear (gC/(m²·a))	the NPP consumed by sheep the family herding in the last year
Household income	cashofCurrentYear (Chinese Yuan (CNY))	wage earnings by the outworkers in the family in the current year
	earnedofCurrentYear (CNY)	the sum of all of the earnings (off-farm income and herding income) in the family in the current year
	cashofLastYear (CNY)	wage earnings by the outworkers in the family in the last year
	earnedofLastYear (CNY)	the sum of all of the earnings (off-farm income and herding income) in the family in the last year
Owned grassland	amountofLand	the number of grassland plots that each household had
	familyLand array	the array of farmland plots planted by each household, stored information of each plot
	NPPproduceofCurrentYear (gC/(m²·a))	the NPP produced by the family in the current year
	NPPpeopleofCurrentYear (gC/(m²·a))	the NPP consumed by the family members in the current year
	NPPproduceofLastYear (gC/(m²·a))	the NPP produced by the family in the last year
	NPPpeopleofLastYear (gC/(m²·a))	the NPP consumed by the family members in the last year
	NPPEofCurrentYear (gC/(m²·a))	the real NPP pressure index in the current year

1.2.3. What are the Exogenous Factors/Drivers of the Model?

The exogenous factors of the model mainly refer the natural conditions, including land use type and Net Primary Productivity (NPP) which represents the primary source from ecosystem for human consumption in the form of food, fiber (including fabrication), and wood-based fuel products.

1.2.4. If Applicable, how is Space Included in the Model?

The space information is included in this model as the basic context. Landscape cells are characterized by the state variables: coordinates, land use type, NPP, land owner (household family) and ecosystem pressure (the value of ecosystem press of the cell).

1.2.5. What are the Temporal and Spatial Resolutions and Extents of the Model?

In the model, 1 time step represents 1 year (the time resolution), the spatial resolution is 100m × 100 m and the length of period is 30 years. In China's mainland, the rural land property rights institution is a family-contract responsibility system, and the household is the basic unit of land management. This responsibility system remained unchanged for 30 years, so our simulated length of period is 30 years. The study area is 400km^2(20km× 20km).

1.3. Process Overview and Scheduling

What Entity does What, and in What Order?

At the beginning of each simulation, all herder household agents are randomly allocated with different spatial plots. One household has multiple pasture plots, and one individual agent corresponds to 24 pasture plots (360mu, or 24ha). Once the plots distribution is finished, the number of plots owned by one herder family agent remains unchanged. However, a household may hire plots from other household agents. At each time step, the household agent was executed first to drive its individual agents to update age, and to run the individual status transferring sub-model for determining the occupation and education for each individual agent. Secondly, the land-use decision sub-model is executed to determine the type and number of livestock. Thirdly, the Ecosystem services consumption sub-model is executed to compute ecosystem services consumption of the household and the ecosystem pressure of plots owned by the household. After all the household agents were executed, spatial environment sub-model was executed to show the service consumption pressure index visually on the land-use map. Within the model, the execution sequence for each time step is fixed, same as that described above.

2. Design Concepts

2.1. Theoretical and Empirical Background

2.1.1. Which General Concepts, Theories or Hypotheses are underlying the Model's Design at the System Level or at the Level(s) of the Sub-model(s) (Apart from the Decision Model)? What is the Link to Complexity and the Purpose of the Model?

This model links the supply and consumption of grassland ecosystem service by calculating ecosystem's NPP supply and households' NPP consumption. Reasonable ecosystem NPP consumption is defined as the human consumed NPP for satisfying substantial livelihood without producing excessive pressure to the ecosystem. The maximum NPP consumption carry capacity is the actual NPP supply of ecosystem; the living NPP consumption refers to the NPP consumed for obtaining the necessary food (including grains, vegetables, meat, milk, and products, etc. "necessary food" in this paper means the amount and type of the daily food intake regulated in the Chinese standard of dietary nutrition balance.).

NPP supply and consumption: The NPP supply is calculated by the product of estimated ecosystem NPP from remote sensing model and the proportion utilized by the livestock. According to the previous study in the meadow grassland, the NPP available for livestock is 14%. The NPP consumption consists of livestock's production consumption and herders' living consumption. Livestock production-consumption means NPP consumed by the forage that is needed for livestock raise. Therefore, livestock production consumed NPP is calculated by the following equation:

$$\text{ConsumedNPP}_g = \text{NUM} \times \text{GW} \times \text{GD} \times (1 - \text{MC}) \times \text{Fc}, \quad (1)$$

Where NUM is the number of livestock raised by the household agent; GW is the quantity of hay consumed per livestock per day; GD is the annual hay-consuming days, which is 365 days for non-marketed livestock and 180 days for marketed livestock; MC is the water content of hay, which is 15% in this research; and FC is the converting factor from plant biomass (g) to carbon content (gC), and FC is 0.45 in this research.

Since the living NPP consumption for a herder family to obtain an equal amount of livestock production income varies among the regions and production patterns, the NPP consumption for the equal amount of living consumption is also different. We developed a price equivalent parameter of NPP consumption (ϱ), which measures the quantity of NPP consumed per RMB income derived from different livestock production modes in different regions. Therefore, living NPP consumption could be estimated by the product of the ϱ value and the expenditure on food of the household.

$$ConsumedNPP_l = \rho \times EXP_l, \tag{2}$$

Where, ConsumedNPPl is the NPP consumed for living consumption, ϱ is the price equivalent parameter of NPP consumption, and EXPl is the economic expenditure (RMB) for herders' food demand. ϱ is calculated as equation (3):

$$\rho = ConsumedNPP_g / PRODg, \tag{3}$$

Income from livestock production (PRODg) is calculated from the number (NUMc) and price (PRc) of various kinds of newborn animals in the year. The yield of wool (WOOLo) and price (WOOLp) is calculated by the following equation (4):

$$PRODg = NUMc * PRc + WOOLo * WOOLp, \tag{4}$$

Food expenditure (FOODex) is calculated from the consumption of grain, meat and milk (FOODe, MEATe, MILKe) and their respective prices (FOODp, MEATp, MILKp), and is calculated using following Equation (5):

$$FOODex = FOODe * FOODp + MEATe * MEATp + MILKe * MILKp, \tag{5}$$

In the above calculation equations, livestock production output data come from the questionnaire survey and the price comes from Inner Mongolia Social Economic Statistical Yearbook of the same year.

Ecosystem Pressure Index (EPI): Ecosystem pressure index means the degree of ecosystem pressure caused by ecosystem consumption in the research area, which is calculated by the ratio of the production-consumption (ConsumedNPPg) to the NPP supply (SupplyNPP).

$$\mathrm{EPI} = \frac{\mathrm{ConsumedNPPg}}{\mathrm{SupplyNPP}}, \tag{6}$$

2.1.2. On what Assumptions Is/Are the Agents' Decision Model(s) Based?

There are two hypotheses in our study. (i) During the model running time, farmland was not reclaimed, and there was no new farmland generated. The households only plant crops on the original farmland plots; (ii) During the simulated years, the running rules of the model remain unchanged. The model parameters of farmland area per capita, migrant work salary, prices of naked oats, the prices of land rent and the yield of farmland are fixed.

2.1.3. Why Is/Are Certain Decision Model(s) Chosen?

We use the surveyed data to analyze the characteristics of individuals and households in the real-world. Using a probability method to get the model running mechanisms can effectively describe agents' characteristics from an overall view.

2.1.4. If the Model/Sub-model (e.g., the Decision Model) is Based on Empirical Data, where do the Data Come from?

Our model is based on empirical data, and this data is collected from first-hand questionnaire surveys on the spot.

2.1.5. At Which Level of Aggregation were the Data Available?

The data is available at yearly aggregation level.

2.2. Individual Decision Making

2.2.1. What are the Subjects and Objects of the Decision-Making? On Which Level of Aggregation is Decision-Making Modelled? Are Multiple Levels of Decision Making Included?

Agents and the land are main entities in the decision making. Two types of agents are in the model, including individual agent and household agent. Each household consists of multiple individuals. The decision-making includes multiple levels. The government decides the subsidy, which influences the livelihood structure of households. The whole town receives the same government policy. The individual agents decide their own occupation states, and this decision influences households' livelihood strategies and structures. The household agents decide their ecosystem services consumption. These decision-makings are modeled on each plot.

2.2.2. What is the Basic Rationality behind Agent Decision-Making in the Model? Do Agents Pursue an Explicit Objective or Have other Success Criteria?

The household agent is the basic unit of the model, and the individual agent who comprises the household agent is the smallest unit of the model. If any individual agent changes its behavior, the household agent's attributes and behaviors will change simultaneously. Herder families would determine the living consumption according to the income from livestock production, they make decisions on the individual agent occupation choice, family livestock production, and family food consumption. Detailed explanation has been showed in section of "Household livelihood decision sub-model".

2.2.3. How do Agents Make Their Decisions?

As individual agents grow older, their occupation states change correspondingly. The changing of individual agent occupation choice, family livestock production, and family food consumption would all affect the decision of household agents on livelihood, such as the marketing rate for livestock. Based on questionnaires interview, for instance, if there is no labor working in livestock production in one family, the raised livestock should be all sold. If yes, normal livestock production can go on. Detailed explanation has been showed in section of "Household livelihood decision sub-model".

2.2.4. Do the Agents Adapt Their Behaviour to Changing Endogenous and Exogenous State Variables? And if Yes, How?

Yes, the household agents adapt the livestock quantity in accordance with the livestock output, policies and labor force in the previous year, and adapt the living expenditure in accordance with the income from livestock in the previous year. The individual agents adapt their occupations in accordance with the average economic income of related possible occupations in the previous year.

2.2.5. Do Social Norms or Cultural Values Play a Role in the Decision-Making Process?

No. The social norms and cultural are just the context of the behavior in this region, which reflected in the interview but not played an explicit role in the decision-making process.

2.2.6. Do Spatial Aspects Play a Role in The Decision Process?

Yes, spatial aspect plays a role in the decision process. The regional NPP is calculated by the product of estimated ecosystem NPP from spatial remote sensing model.

2.2.7. Do Temporal Aspects Play a Role in the Decision Process?

Yes, time aspect plays a role in the decision process. As individual agents grow older, they will change their occupation states, and their family livelihood structures will be changed correspondingly.

2.2.8. To Which Extent and How is Uncertainty Included in the Agents' Decision Rules?

The individual member structure of household agents is created proportionally according to the household survey, the plot locations of each household are distributed stochastically in the model. The agents' behaviors are all changed randomly within certain interval ranges. Thus, the model includes uncertainty.

2.3. Learning

2.3.1. Is Individual Learning Included in The Decision Process? How Do Individuals Change Their Decision Rules over Time as Consequence of Their Experience?

Both household agents and individual agents could improve their ability to achieve objectives by learning from the decision-making behaviors and effects of other agents. Through learning, the household agents are able to improve the decision-making in livestock breeding for the pasture protection and higher living level. Through learning, the individual agents could increase their income and improve their ability of livestock breeding.

2.3.2. Is Collective Learning Implemented in the Model?

Collective learning is implemented in the model. households with the same agent occupation state, family livestock production, and family food consumption will share the same rules of decision making.

2.4. Individual Sensing

2.4.1. What Endogenous and Exogenous State Variables are Individuals Assumed to Sense and Consider in Their Decisions? Is the Sensing Process Erroneous?

Individuals are assumed to sense and consider their own ages, occupations and economic development. Households are assumed to sense their livelihood structure, economic development and consumption pattern. These sensing processes are correct.

2.4.2. What State Variables of Which other Individuals Can an Individual Perceive? Is the Sensing Process Erroneous?

An individual cannot perceive state variables of other individuals. However, both household agents and individual agents could improve their ability to achieve objectives by learning from the decision-making behaviors and effects of other agents, which are mostly based on the data from individual interviews.

2.4.3. What is the Spatial Scale of Sensing?

The spatial scale of sensing is the grid cell. At this scale the plots state can be sensed. The resolution of spatial is 100m × 100 m and the study area is 400km^2(20km× 20km).

2.4.4. Are the Mechanisms by Which Agents Obtain Information Modelled Explicitly, or Are Individuals Simply Assumed to Know These Variables?

All other variables are just known by the agents.

2.4.5. Are the Costs for Cognition and the Costs for Gathering Information Explicitly Included in the Model?

The costs for cognition and the costs for gathering information are not included in the model.

2.5. Individual Prediction

2.5.1. Which Data do the Agents Use to Predict Future Conditions?

Based on the interviewed data and the aging of individual agents in the new year, agents would decide which kind of career to choose, based on the occupation states of one household, the family livestock production would be decided. For instance, if there is no labor working in livestock production in one family, the raised livestock should be all sold. Otherwise, normal livestock production can go on; the marketing rate of livestock production is affected by the policy, environment, and family labor force; and the herder families would determine the living consumption according to the income from livestock production.

2.5.2. What Internal Models are Agents Assumed to Use to Estimate Future Conditions or Consequences of Their Decisions?

Ecosystem Pressure Index (EPI) that reflect the degree of ecosystem pressure caused by ecosystem consumption in the research area, through which, agents could obtain whether the ecosystem consumption is beyond the ecosystem supply.

2.5.3. Might Agents Be Erroneous in the Prediction Process, and How Is It Implemented?

The behavior of individual agents and household agents is stochastics to some extent, but the whole result and the spring up phenomenon is definite.

2.6. Interaction

2.6.1. Are Interactions among Agents and Entities Assumed as Direct or Indirect?

The interactions between households and plots are direct. The interactions between individuals and plots are indirect, and individuals have to interact with plots with the help of the household they belong to.

2.6.2. On What do the Interactions Depend?

The interactions between households and plots depend on the individual agent occupation choice, family livestock production, and family food consumption.

2.6.3. If the Interactions Involve Communication, How Are Such Communications Represented?

These interactions do not involve communication.

2.6.4. If a Coordination Network Exists, how does It Affect the Agent Behaviour? Is the Structure of the Network Imposed or Emergent?

No coordination network exists in our simulation.

2.7. Collectives

2.7.1. Do the Individuals form or Belong to Aggregations that Affect and Are Affected by the Individuals? Are These Aggregations Imposed by the Modeller or do They Emerge during the Simulation?

The household agent is the basic unit of the model, and the individual agent who comprises the household agent is the smallest unit of the model. The household emerges during the simulation, but the characteristics of household is imposed by modeler.

2.7.2. How are Collectives Represented?

By counting family members in each household, this model allocates the same number of plots to each household. The plots that planted by the same household are distributed adjacently.

2.8. Heterogeneity

2.8.1. Are the Agents Heterogeneous? If Yes, Which State Variables and/or Processes Differ between the Agents?

The individual agents and household agents are heterogeneous. The occupation states are different from individual agents, and the production and consumption are different between household agents.

2.8.2. Are the Agents Heterogeneous in Their Decision-Making? If Yes, Which Decision Models or Decision Objects Differ between the Agents?

The individual agents and household agents are heterogeneous in their decision-making. The occupation states of individual agents are different, and the ecosystem services consumption of households are heterogeneous during their decision-making process (for more detail, see Section "Descriptions of Sub-models").

2.9. Stochasticity

What Processes (Including Initialisation) Are Modelled by Assuming They are Random or Partly Random?

The individual member structure of household agents is created proportionally according to the household survey, it ensures the consistency of family structures on age, gender, occupations, and so on between modeled proportion and the actual survey proportion. The plot locations of each household are distributed stochastically in the model. During the processes of production decisions of household agents and the occupation selection of individual agents, the agents' behaviors are all changed stochastically within certain interval ranges.

2.10. Observation

2.10.1. What Data Are Collected from the ABM for Testing, Understanding and Analyzing It, and How and When Are They Collected?

The output from the simulation includes the living consumption NPP per capita, livestock numbers in the middle and at the end of the year per capita, ecosystem consumption pressure and the total population in the region.

2.10.2. What Key Results, Outputs or Characteristics of the Model Are Emerging from the Individuals? (Emergence)

The desired emergence includes the reasonable living level for the people due to proper utilization of pasture ecosystem, reasonable ecosystem NPP consumption, and normal ecosystem pressure.

3. Details

3.1. Implementation Details

3.1.1. How Has the Model Been Implemented?

This model is developed with Java language and RePast simulation platform. Considering the existence of random parameters in the model, each scenario would be simulated for 50 times and the average values of the 50 times would be taken as the model output data.

3.1.2. Is the Model Accessible, and if so Where?

The model is accessible. If readers want to see the source code of this model, you can send email to us.

3.2. Initialisation

3.2.1. What is the Initial State of the Model World, *i.e.* at Time t = 0 of a Simulation Run?

The initial state of the model was determined according to the household survey and social economic statistical data. The agents running space is a two-dimension grid with land use information as background. The spatial resolution of land use data is 100m. Model initializations include spatial environment initialization, household agents initialization, and individual agents initialization. The initialization of the household agents includes structures of ages, labor and family members. The initialization of the individual agents includes the initializations of the occupations, education status, and genders of each herder individual; the initialization of running space includes the allocation of plots for each household.

3.2.2. Is the Initialisation Always the Same, or Is It Allowed to Vary among Simulations?

The initialization is not always the same. With the stochastically of the individual member structure of household agents, the plot locations of each household and the occupation selection of individual agents, the initialization are different each time.

3.2.3. Are the Initial Values Chosen Arbitrarily or Based on Data?

In our model, the initial values are chosen based on on-the-spot questionnaires survey, remote sensing data and census data.

3.3. *Input Data*

Does the Model Use Input from External Sources such as Data Files or other Models to Represent Processes that Change over Time?

The input data obtained from the social survey and spatial data. Social survey data including population distribution of households, the age distribution of farming or livestock family members and occupation status distribution of farming or livestock family members. Spatial data including land-use data and NPP data of grassland.

3.4. *Sub-models*

3.4.1. What, in Detail, Are the Sub-models that Represent the Processes Listed in 'Process Overview and Scheduling'?

The model includes three sub-models: individual status transferring sub-model, households' livelihood decision sub-model, and ecosystem pressure sub-model.

3.4.2. What are the model parameters, their dimensions and reference values?

The framework of the EcoC-G model has been shown in Figure 2. The individual status transferring sub-model outlines the transition between different individual states, and the individual agents' behaviors include choosing their occupation type and consumption pattern. The household livelihood decision sub-model mainly simulates family livestock production and family consumption. Different consumption patterns will intake different types of food and then generate different NPP consumptions. The household agents' behaviors include choosing the livestock amount, grassland use, and computing their income, payments, and NPP consumption. The ecosystem pressure sub-model would compare the supply NPP of the ecosystem and the consumption NPP by individuals and livestock, resulting in the ecosystem pressure of its grassland.

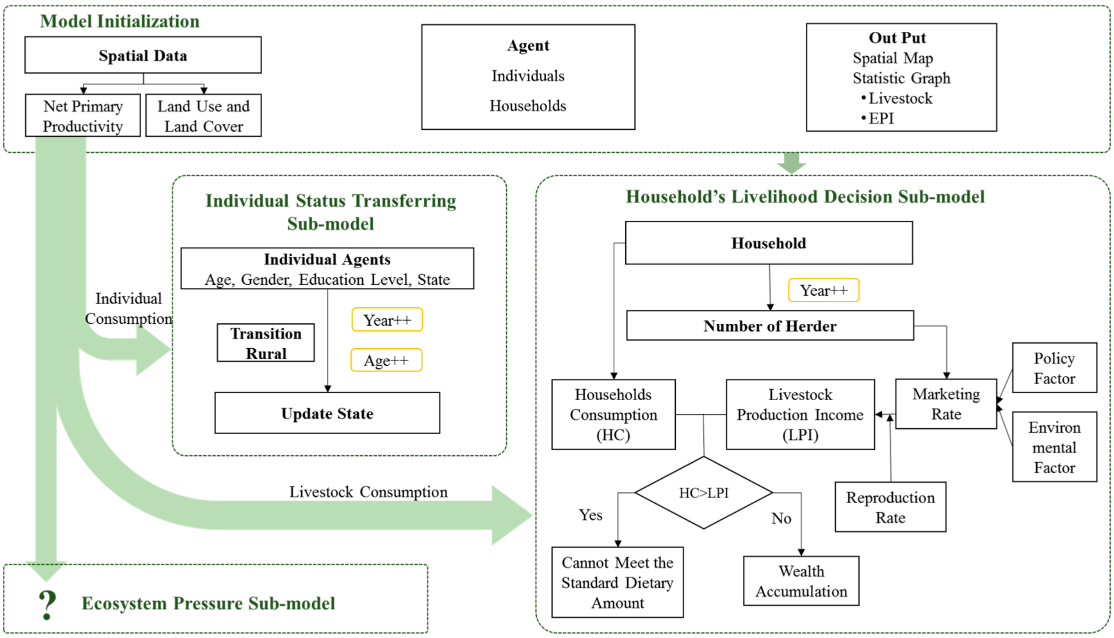

Figure 2. The framework of Reasonable Consumption Model for Grassland Ecosystem

3.4.3. How Were the Sub-models Designed or Chosen, and How Were They Parameterised and then Tested?

(1) Individual status transferring sub-model

There are 7 individual states according to the education and employment situation of surveyed households, namely: (1) The fostered state, meaning that the agent is in infancy or in primary or middle school; (2) the educated state before employment, meaning the agent is accepting vocational training or university education; (3) the herder state, meaning the agent is working as a herder; (4) city worker with odd job state, meaning the agent is a migrant worker in an urban area and engages in odd jobs; (5) city worker state with permanent employment, meaning the agent is working in a state-owned enterprise or government in the city; (6) the rural dependent state, meaning the agent has lost the ability to work or live in a rural village; and (7) the retired state, meaning the agent has retired from being a city worker and is sustained by a retirement pension. According to the analysis of survey data, the transitional relationship for individual agent state is shown in Figure 3, where S represents the state of individual agents and Rij represents the rules that should be followed while transitioning from status i to status j. The transition rules between different individual states were derived from the questionnaire survey data and are listed in the Appendix.

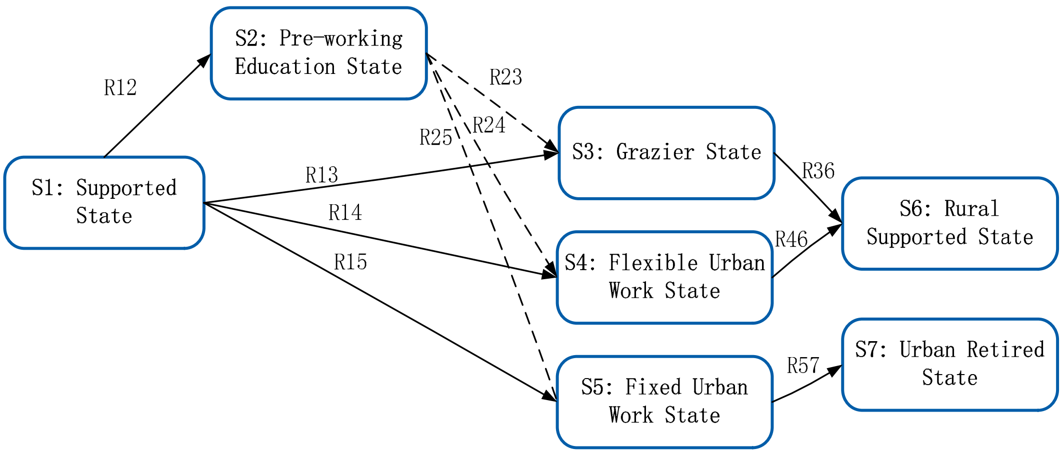

Figure 3. Status and transition of individual agents.

For the natural (birth/death) and social (emigration/immigration) population changes in the model, we firstly initializing the individuals and households. Different households initially consist of different kinds of individuals (specific structure could be found in Appendix, Table A2). We assumed that if there are young couples with the most suitable ages for childbearing (20–23), and they also have a good economic condition (the household income for the year is more than 10,000 CNY), then a new baby will be born, and the total population will increase by one. If the age of the individual is in the range of 60–100, then there is a random probability of death. In this model, we didn't consider the emigration/immigration from regions beyond the study region. The population of herders is changed with income. When the average income of outworkers is lower than the average income of farmers, the outworkers would return to farmland and become a herder, and vice versa.

(2) Household's livelihood decision sub-model

The household livelihood decision sub-model is mainly used to simulate the individual agent occupation choice, family livestock production, and family food consumption.

In the model, the first decision is about the career choices for the individual agents, and the second decision is about family livestock production. If there is no labor work in livestock production for one family, the raised livestock should all be sold. If yes, normal livestock production can go on. The livestock quantity of the herder family can be calculated by the reproduction rate (β) and marketing rate (μ), which are respectively defined as follows:

$$\beta = (\text{NUM-MID}i - \text{NUM-END}_{i-1})/\text{NUM-END}_{i-1} \quad (1)$$

$$\mu = (\text{NUM-MID}i - \text{NUM-END}_{i-1})/\text{NUM-MID}i \quad (2)$$

wherein $\text{NUM}-\text{MID}_i$ is the livestock number in the middle of the ith year; and $\text{NUM}-\text{END}_{i-1}$ is the livestock number at the end of the (i−1)[th] years.

According to the survey in the research area, a reproduction rate is commonly in the range of (0.4, 0.8). The marketing rate is in the range of (0.4, 0.6) according to the statistical yearbook data in Inner Mongolia. In the decision-making sub-model, the reproduction rate is a random number from the range of (0.4, 0.8). However, the marketing rate (μ) is affected by the policy, environment, and family labor force, which is defined as follows:

$$\mu = \begin{cases} 1 & if\ \ \text{k} = 1 \\ Random(0.4{,}0.6) + k & if\ \ \text{k} \neq 1 \end{cases} \quad (3)$$

wherein k is the impact factor, which is concerned with the policy factor kp, the environmental factor ke, and the labor factor kf.

The respective values of the above three factors are defined as follows:

$$kp = \begin{cases} Random(0, 0.1) & having.policies \\ Random(-0.1, 0) & no.policies \end{cases} \quad (4)$$

In Equation (10), if there are ecological competition policies provided for the households, the value of kp is a random datum and the interval is (0,0.1), which means the marketing rate is increased; otherwise, the interval is (−0.1,0), which means the marketing rate is decreased.

$$ke = \begin{cases} Random(0, 0.1) & if.SupplyNPP_{i-1} < \text{ConsumedNPP}_{gi-1} \\ Random(-0.1, 0) & if.SupplyNPP_{i-1} \geq \text{ConsumedNPP}_{gi-1} \end{cases} \quad (5)$$

In Equation (11), if the SupplyNPP ($gC/(m^2{\cdot}a)$) in the last year is less than the ConsumedNPPg ($gC/(m^2{\cdot}a)$) in the last year, the value of ke is a random data and the interval is (0,0.1), which means the marketing rate is increased; otherwise, the interval is (−0.1,0), which means the marketing rate is decreased.

$$kf = \begin{cases} 1 & if.\text{0 herdsman} \\ Random(0{,}0.1) & if.\text{herdsman decrease.but not be 0} \\ Random(-0.1{,}0) & if.\text{herdsman increase} \end{cases} \quad (6)$$

In Equation (12), if the household agent has no herdsman, the value of kf is 1; otherwise, if the amount of the herdsman in the household agent is decreased and not equal to zero, the value of kf is a random datum and the interval is (0,0.1), which means the marketing rate is increased; otherwise, the interval is (−0.1,0), which means the marketing rate is decreased.

The value of k is defined as follows:

$$k = \begin{cases} 1 & if.kf = 1 \\ kp + ke + kf & if.kf \neq 1 \end{cases} \quad (7)$$

In Equation (13), if the household agent has no herdsman, the value of kf is 1, the value of k is 1, and the value of μ is 1 in Equation (9), which means all of the livestock will be sold because of lacking a herdsman; otherwise, the value of k is the sum of the three parameters.

The value of the marketing rate μ is not only determined by the above formula but is also affected by different simulation scenario conditions, which will be introduced later. The quantity of livestock NUM-MIDi in the ith year is calculated as follows:

$$\text{NUM-MID}i = (1 + \beta i) * \text{NUM-END}i\text{-}1 \tag{8}$$

The number of livestock marketed in the ith year is calculated as follows:

$$\text{NUM-SOLD}i = \mu_i * \text{NUM-MID}i \tag{9}$$

The remaining livestock number at the end of the ith year is calculated as follows:

$$\text{NUM-END}i = (1 - \mu_i)\text{NUM-MID}i \tag{10}$$

The living decision of herder families would determine the living consumption level for the whole year. The herder families would determine the living consumption according to the income from livestock production, as follows:

a. When the income of livestock production is less than the life consumption demand, the livestock production income cannot support the lives of herder families, and all of the livestock production income will be used for the living consumption.
b. When the livestock production income is more than, or equal to, the living consumption demand, the livestock production income is able to support all of the lives of herder families. The whole living consumption of the herder families comes from livestock production; i.e., the consumption is equal to the demand. The living demand is set with a reference to the resident nutrient balanced standard dietary amount.

(3) Ecosystem pressure sub-model

The ecosystem services consumption sub-model simulates the change occurring to the ecosystem services consumption and the EPI. In this study, the supply of the ecosystem service is assumed to be stable and is set to the average NPP value in the past 20 years. The ecosystem services consumption and the EPI are calculated by Equations (1), (2), and (6).