Appendix A: Overview of the Design, Concepts, and Relevant Details of the Coastal Aquaculture Spatial Solutions (CASS) Model

Overview

1. Purpose

The aim of the agent-based model Coastal Aquaculture Spatial Solutions (CASS) is to create a simulation tool for the analysis of land use change and (shrimp) farmers’ decision-making under the influence of social, policy, economic, and bio-physical drivers (Figure A.1). The agent-based model is parameterized with empirical data and calibrated through role-playing games. The model also uses a GIS (Geographical Information System)-based cadastral map and outputs of hydrological modeling to estimate spatial suitability of plots for different shrimp production systems.

The aim of the model is to i) explore policies for coastal aquaculture management, ii) investigate future production results of shrimp farming based on different policies, economic settings and bio-physical context, iii) integrate new drivers influencing farmer’s decision at the farm level and understand their impact at a larger scale (commune and district) on spatial land use changes.

This spatially explicit agent based model aims to be a decision making support tool for policy makers and planners. Using such a tool may support their discussion about coastal aquaculture planning.

1.1 State Variables and Scales

Coastal Aquaculture Spatial Solutions (CASS) was developed in Gama 6.0. The model is based on the cadastral map of eight (8) communes in Dam Doi district, a coastal district of Ca Mau Province in the Mekong Delta, Vietnam. The cadastral map is composed of more than 20,000 plots, each plot representing one shrimp farm or one forest plot.

Two types of entities are found: farms and plots. Agents represent farmers that manage their plots and each farm is composed of one single plot. The attributes of farms and plots are given in Tables A.1 and A.2.
### Table A.1. Attributes of farm entities

<table>
<thead>
<tr>
<th>Farm Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of plots</td>
<td>Number of plots in the farm (equal to 1)</td>
</tr>
<tr>
<td>Total land area</td>
<td>The area of the farm, loaded from the GIS file</td>
</tr>
<tr>
<td>Household size</td>
<td>Household size randomly determined based on a Gaussian distribution ($5 \pm 1.7$)</td>
</tr>
<tr>
<td>Household expense</td>
<td>Household expense to sustain farm family living: the amount relates to the household size, the crop revenue, and the production system.</td>
</tr>
<tr>
<td>Maximum loan</td>
<td>Maximum loan an agent can borrow, correlated to the land size and production system type</td>
</tr>
<tr>
<td>Available loan</td>
<td>Amount of loan available to the agent, based on previous loans contracted and the maximum loan.</td>
</tr>
<tr>
<td>Household loan</td>
<td>Current loan contracted by the agent.</td>
</tr>
<tr>
<td>Household loan history</td>
<td>Records loans contracted by the household in the past cycle.</td>
</tr>
<tr>
<td>Household bank account</td>
<td>Summarizes the current savings and loans of the agent, including the different revenues, costs, and loans involved.</td>
</tr>
<tr>
<td>Probability to shift</td>
<td>Probability for agent to shift to a specific production system. This is updated at each cycle and for each production system if the agent has enough capital to make the shift. The updated probability integrates bio-physical and social actors.</td>
</tr>
<tr>
<td>Household’s 2nd income</td>
<td>Represents the revenue of the household from activities other than shrimp farming, randomly determined on a Gaussian distribution and varies according to production system.</td>
</tr>
<tr>
<td>PES</td>
<td>Payment for Ecosystem Services, or the amount of subsidies received when farmers plant mangrove trees in their farm.</td>
</tr>
</tbody>
</table>

A plot is characterized by its type of production system, area, suitability for each type of land use, potential yield, risk of virus, and economic characteristics (operational cost). Four production systems are possible: Extensive (EXTS), Improved Extensive (IES), Intensive (INTS) and Integrated Mangrove Shrimp System (IMS). Plot agents also can be hybrid plots with an Intensive system area and an Extensive system area (or Improved Extensive and Extensive) within the same plot. The descriptions of the attributes are given in Table 2.
Table A.2. Attribute of plot entities

<table>
<thead>
<tr>
<th>Plot Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Id_plot</td>
<td>Plot ID loaded from GIS file.</td>
</tr>
<tr>
<td>Land use certificate</td>
<td>Describes the type of land title of the plot – Green or Red – which determines the possibility to modify land use (Red) or not (Green).</td>
</tr>
<tr>
<td>Production system</td>
<td>Production system of the plot. Four types are possible: Extensive (EXTS), Improved Extensive (IES), Intensive (INTS), and Integrated Mangrove Shrimp System (IMS), as well as a mixed system, IMS_IE.</td>
</tr>
<tr>
<td>Social influence</td>
<td>Influence of the neighboring farm on future land use regarding shifting to INTS or IMS system.</td>
</tr>
<tr>
<td>Failure rate</td>
<td>Risk of virus and loss of crop. The risk varies according to production system.</td>
</tr>
<tr>
<td>Failure history</td>
<td>Records the number of crop failures in the past. A high number of consecutive failures in an INTS production system triggers change towards EXTS production system or the abandonment of the plot.</td>
</tr>
<tr>
<td>Land use history</td>
<td>Records the number of cycles with the same land use. Agents applying INTS and IMS cannot change production systems after one production cycle, even if they incur loss.</td>
</tr>
<tr>
<td>Crop yield</td>
<td>The yield is based on a Gaussian distribution for each type of production system and is randomly determined for each agent in each cycle. The yield of the crop is determined by the presence or absence of virus.</td>
</tr>
<tr>
<td>Crop cost</td>
<td>Crop cost determines the operational cost of the crop per hectare for each production system based on a Gaussian distribution and randomly determined for each agent in each cycle.</td>
</tr>
<tr>
<td>Crop revenue</td>
<td>Represents the economic results of the farm based on the yield and selling price minus the operational cost.</td>
</tr>
<tr>
<td>Plot suitability for mangrove</td>
<td>The suitability factor is between 0 and 2 and corresponds to the suitability of the area for planting mangrove and developing an Integrated Mangrove Shrimp system. The suitability is based on water salinity during the year and flood level (mean monthly water level).</td>
</tr>
<tr>
<td>Plot suitability for INT and IE systems</td>
<td>The suitability factor is between 0 and 2 and corresponds to the suitability of the area for developing Intensive and Improved Extensive shrimp farming systems based on water salinity during the year and flood level (mean monthly water level).</td>
</tr>
<tr>
<td>Policy IE</td>
<td>Corresponds to the influence of government policy to promote the Improved Extensive system in specific locations. The factor ranges between 1 and 1.6 and influences the probability to shift to an Improved Extensive system.</td>
</tr>
<tr>
<td>Ie_factor, ext_factor, Int_factor</td>
<td>Plots may not be fully converted into Intensive or Improved Extensive system. This factor (a random number between 0.3 and 1) is multiplied to the plot area to determine the INTS area or IES area of the plot, which is further managed as an EXTS system.</td>
</tr>
</tbody>
</table>

The model includes also global variables that influence agents and their decision-making. The list of global variables is given in Table A.3.
Table A.3. Attributes and descriptions of global variables used in the CASS model (mVND: Million Vietnam Dong)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum investment</td>
<td>Lowest investment required to shift from EXTS to IMS (13.3 mVND/ha)</td>
</tr>
<tr>
<td>Chance for higher loan</td>
<td>Probability to get a loan that is higher than usual (20%) for IES, EXTS and IMS farms</td>
</tr>
<tr>
<td>Fail factor</td>
<td>Minimum amount of capital required to continue INTS or IES farming, expressed as a percentage of the crop cost (20% of the operational crop cost).</td>
</tr>
<tr>
<td>Investment cost of INTS/EXTS/IMS system</td>
<td>Amount required transforming the pond into a new production system, including the cost of equipment. Investment cost is provided per hectare: INT (165 mVND /ha); IE (90 mVND /ha); IMS (12 mVND /ha).</td>
</tr>
<tr>
<td>Social distance</td>
<td>The distance corresponding to the radius around a plot center used to calculate the influence of neighbors on the possible change to INT (500m) or IMS (1,000m).</td>
</tr>
<tr>
<td>Base probability to shift</td>
<td>The base level of the probability for a farmer to shift from one system to another. It includes all the different possibilities to shift. Those probabilities are based on local trends and are calibrated during focus group discussion and role-playing.</td>
</tr>
<tr>
<td>PES influence</td>
<td>Factor, depending on local policy (subsidies), that increases the probability to shift to IMS</td>
</tr>
<tr>
<td>Organic premium</td>
<td>Percentage of premium price added to the shrimp’ selling price if the organic standards are applied (10%)</td>
</tr>
<tr>
<td>Organic influence</td>
<td>Factor, depending on local policy (organic premium), that increases the probability to shift to IMS</td>
</tr>
<tr>
<td>Policy influence</td>
<td>Factor, depending on local policy to focus extension service in certain area, that increases the probability to shift to INTS or IES</td>
</tr>
<tr>
<td>Price fluctuation</td>
<td>Shrimp price is randomly determined every cycle, between a lower and upper boundary.</td>
</tr>
<tr>
<td>Intensification Ratio</td>
<td>Ratio of Intensive shrimp area / Total shrimp area</td>
</tr>
<tr>
<td>Virus outbreak</td>
<td>Probability to have a virus outbreak in the region, which increases with the level of intensification of the farm. This probability is updated before every cycle and determines the level of risk for the run.</td>
</tr>
<tr>
<td>Additional risk</td>
<td>A 30% increased risk for all farms during one cycle of a disease outbreak due to virus. This risk depends on probability of a virus outbreak, and translates to the cyclic appearance of new disease agents or of more virulent varieties of existing viruses or bacteria.</td>
</tr>
</tbody>
</table>

Since the model is designed to simulate changes across time, economic variables such as market prices are dynamic enough so as to represent fluctuations and developments in the shrimp market. The increases in shrimp price, operational cost, investment cost, and returns defined by the participants within the scenario are transformed into an increment per cycle, and are added to the variable cost for every new cycle (Table A.4). Those increment values are derived from literature (Kam et al., 2010) and workshops with experts of the shrimp sector in Ca Mau.
### Table A.4: Increment of model variables per cycle.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>+ 1.4% per cycle</td>
</tr>
<tr>
<td>Minimum investment</td>
<td>+ 0.63 mVND /ha per cycle</td>
</tr>
<tr>
<td>Investment cost of Intensive/Improved Extensive/Integrated Mangrove Shrimp Systems</td>
<td>INTS: + 1.66 mVND /ha per cycle</td>
</tr>
<tr>
<td></td>
<td>IES : + 0.65 mVND /ha per cycle</td>
</tr>
<tr>
<td></td>
<td>IMS : + 0.27 mVND /ha per cycle</td>
</tr>
<tr>
<td>Crop cost: Intensive/Improved Extensive/Integrated Mangrove Shrimp / Extensive Systems</td>
<td>INTS: + 3.33 mVND /ha per cycle</td>
</tr>
<tr>
<td></td>
<td>IES : + 0.57 mVND /ha per cycle</td>
</tr>
<tr>
<td></td>
<td>IMS : + 0.16 mVND /ha per cycle</td>
</tr>
<tr>
<td></td>
<td>EXT : + 0.10 mVND /ha per cycle</td>
</tr>
<tr>
<td>Failure rate: Intensive/Improved Extensive/Integrated Mangrove Shrimp / Extensive Systems</td>
<td>INTS: + 0.27% cycle</td>
</tr>
<tr>
<td></td>
<td>IES : + 0.27% cycle</td>
</tr>
<tr>
<td></td>
<td>IMS : + 0.17% cycle</td>
</tr>
<tr>
<td></td>
<td>EXT : + 0.17% cycle</td>
</tr>
</tbody>
</table>

One time step (or cycle) corresponds to 6 months (1 shrimp crop). At each step, success or failure of the shrimp crop is calculated for each plot (agent) and the economic results of the farm agent are updated accordingly. Farm agent characteristics and spatial representation of the farms and plots are based on local and current situation of shrimp farming in Dam Doi district and from empirical data collected during an on-farm survey (Ha, 2012) completed with focus group discussion and role playing with farmers.

Plot suitability for developing an IMS farm and an INTS farm is derived from hydrological modeling of the flood and water salinity (Dat et al., 2011) and translated into a suitability index.

### 1.2 Process Overview and Scheduling

At every time step, the “Farm Plot” agents carry out the process in the following order (Figure A.2):

1. Check the land title of the plot (Decision 1). If land title is “Green,” the agent keeps the same production system; if land title is “Red,” the agent estimates its capital for investment (checks its bank account);
2. Check the bank account of the farm agent and see if this is above the minimum threshold (minimum bank account) to invest in another production system.
3. Check the bank account of the farm and see if this is above the investment needed to convert to an Intensive farm. If not, a similar check is done for Improved Extensive (medium threshold) and Integrated Mangrove Shrimp (lowest threshold) farm, in this order.

In case the land title is Green or the bank account of the farm is lower than any threshold (Decision 2), the “Farm Plot” agent keeps its current production system (“No Change”) and “runs a crop cycle” through the following steps:

a) Test the crop for presence of virus, and b) Calculate yield and economic results accordingly before updating its bank account, including loan reimbursement, secondary income, and household expenses.
4. If the bank account is above one of the thresholds (for INTS, IES, or IMS), the agent updates his probability (with influence of policies, and suitability) to shift to this system before testing its probability.

5a) If the tests are successful, the agent calculates the area of each production system in case of a hybrid plot (plot with two production systems such as EXTS and INTS).

5b) If the tests are not successful ("No Change") the agent may test the probability to shift to a less intensive system such as IE or IMS.

5c) Even if the tests are successful, the agent may choose not to change.

6 The agent makes the investment for the crop, tests for presence of virus, and calculates yield and economic results of the production systems before updating his bank account with data on loan reimbursement, secondary income, and household expenses.

2.0 Design Concepts

2.1 Basic Principles

The CASS integrates social and ecological dimensions. The social behaviors of the agent in the system are based on the principle that agents aim to maximize their profit. Social behavior is based on the 1) agent’s investment capacity that includes his past farming results, access to loan, other economic activities, and living expenses; 2) probability of the agent to change to another production system; 3) influence of local policies on this decision; 4) influence of neighbors’ land use on this decision, and 5) biophysical characteristics of the plot under different production systems. The biophysical environment of the model includes a suitability index for each plot to grow mangrove and a suitability index for intensive shrimp farming. Both suitability indices are based on flood level and water salinity during the year.

2.2 Emergence

Interactions of the agents are of two types: 1) influence of the neighbors on land use decision, and 2) influence of the neighboring farms on the risk of virus. When the density of Intensive or Integrated shrimp farms increases in the neighborhood, the agent increases his probability to shift to those systems due to a copycat mechanism observed in the Mekong Delta (Nguyen and Ford, 2010).

For each farm, increased density of intensive shrimp farms increases the risk of virus outbreak increases as follows:

\[
\text{Virus outbreak probability} = 0.05 + \epsilon (2 \times \text{Total INTS farm area} / \text{Total shrimp farming area})
\]
Figure A.2: Agents’ decision tree
2.3 **Adaptation**

Agents want to maximize their profit. The decision about land use depends first on the financial capital. Hard thresholds determine the behavioral strategy an agent uses. In Intensive systems, an agent with enough financial capacity will continue the same production system if: 1) he is successful, and 2) he has enough capital to cover the crop cost, and 3) he has experienced less than three consecutive crop failures due to virus outbreak. In Improved Extensive systems, similar rules are used, but in case the agent is successful and reaches the threshold to invest in Intensive farming, the agent will test the probability of investing in a more intensive and profitable system. The probability to invest in intensive ponds will depend on the neighbors’ influence, the local policy, and plot suitability.

An Improved Extensive or Intensive agent without enough financial capacity to cover his operational cost or with successive past failures of his system will go back to the Extensive system or will abandon shrimp farming. This last option is taken only by smalls-sized Intensive agents (<1ha). Agents with hybrid farms (having both Intensive + Extensive pond or Improved Extensive + Extensive pond) stop their Intensive or Improved extensive pond if they experience successive failures or do not have enough financial resources to cover the operational cost.

Integrated mangrove shrimp and Extensive agents will keep their system even if they experience crop failure.

2.4 **Fitness and Objectives**

The goal of agents is to intensify their production toward Improved Extensive and Intensive systems. At each step, agents owning Red land title are able to change systems and test if they have enough capital to invest in more intensive production systems to maximize their profit.

2.5 **Learning and Prediction**

Agents do not learn or adjust their decision-making rules. They do not predict the results of their decision.

2.6 **Sensing (factors influencing agents)**

An agent senses a range of variable values from other agents:
- Relative land use choices of their peers, in the case of Intensive and Integrated Mangrove Shrimp systems. These two land use types indicate the probability of agents to copy each other’s production systems
- Influence of increasing area of Intensive farms because this increases the risk of virus outbreak in neighboring farms.

An agent senses a range of variables from the Global agent. Those variables are related to market and policy:
- Agents sense the influence of local policy to develop Improved Extensive shrimp plots in certain areas. This value is loaded from the GIS file and corresponds to specific areas in the district where local authorities intensify efforts to push for Improved Extensive shrimp farming. This is spatially translated by an increase of the Policy IE factor to 1.6 for plots 750 m around existing clusters of Improved Extensive plots.
- Agents sense the influence of national and regional policy on the development of an organic shrimp value chain and payment for ecosystem service. Those policies increase the probability for Extensive farmers to shift toward an Integrated Mangrove Shrimp system due to two factors: PES influence and Organic influence calibrated during role playing.

An agent senses a range of variables from the local environment. Flood level and salinity are converted into suitability value for Intensive and Integrated Mangrove Shrimp systems.
Suitability for Intensive and Improved Extensive Systems

The Flood suitability for Intensive and Improved Extensive systems is set between 0.4 (mean flood level is 1.4 masl) and 1.4 (mean flood level is 0.3 masl). Communes with a specific policy for developing Intensive and Improved Extensive farms have suitability for those systems increased by +0.2. A similar factor was developed regarding suitability to salinity level. Both flood and salinity and local policy factor have been aggregated to create the suitability index for Intensive shrimp farming. The suitability factor for Intensive shrimp farming is between 0.08 and 1.5.

Suitability for Integrated Mangrove Shrimp System

A similar type of factor for Flood impact has been created for Integrated Mangrove Shrimp farming. This suitability factor integrates mean flood level, mean water salinity, and local policy. Finally, the suitability factor for Integrated Mangrove Shrimp farming is between 0.09 and 2.6.

Climate Change – Sea Level Rise Impact

Scenarios can take into account sea level rise and the increased level of flood. For plots of lowest elevation in the study area, a climate change factor was introduced to reduce the suitability of Intensive shrimp farming (-0.4). This factor will be used when the probability to shift to Intensive and Improved Extensive systems are updated.

2.7 Interaction

Besides the interaction between agents explained earlier in terms of copycat behaviors and the influence of Intensive shrimp farms on overall risk of disease outbreak, the model considers no other specific interaction between agents.

2.8 Stochasticity

In the initialization process, some variables of agents are set randomly to create a heterogeneous population. Those variables are: 1) the Intensive and Improved Extensive areas in the case of hybrid agents; 2) household size; 3) household secondary income; 4) household bank account, and 5) maximum loan. The functions to determine household second income, maximum loan, and household’s bank account vary according to the type of agent (Extensive, Improved Extensive, Intensive or Integrated Mangrove Shrimp). Each uses a different Gaussian distribution. The values are set based on an average value and a standard deviation. The data are sourced from Ha (2012) and additional surveys in the study area.

During the simulation, more agent variables are set randomly at each cycle. Those variables are: 1) household second income; 2) maximum loan; 3) crop cost; 4) crop yield; and 5) gross revenue.

Stochasticity is also found in the global variable selling price of shrimp. The shrimp market is extremely volatile, and is therefore reset at every cycle. At the beginning of each cycle the program (Table 5) randomly assigns a price between an upper and lower value.

2.9 Collectives

There are no collectives in the model. Agents are individuals, with individual decisions within to make on their plot/pond and farm, and no sort of collective farming is developed in the model.
2.10 *Observation*

The graphic user interface provides several types of graphs and maps enabling the modeler to follow the dynamics of the model. The map updates the land use of each farm every cycle. The graph provides visual representation of variables such as: 1) total shrimp production per cycle; 2) production for each type of system; 3) total shrimp area and total area per type of production system; 4) number of farms that are abandoned or Intensive and Improved Extensive agents who have moved back to an Extensive system, and 5) yield per type of production system. The graphic user interface also allows the modeler to modify several agents and global parameters.

3.0 *Details*

3.1 *Initialization*

At the initialization stage of the model, the static variables are assigned values. The global and agent’s variables are set to default values that can be changed by users. The GIS cadastral map of the study area is loaded. From this GIS layer, plots and farm agents are created with their associated variables: production system, area, land use certificate, plot suitability for intensive and mangrove farming, and the influence of local policy on improve extensive farming.

Also at initiation, farm and plot agents are assigned random values for some variable (See Stochasticity). All variables of farm and plot agents production associated with production systems and socio-economy are given values either from random distribution or loaded from the GIS file (See Tables 1 and 2 on all the variables of the agent).

3.2 *Input Data*

External sources were used to prepare the model database:

- The GIS cadastral map was developed by the local authorities, digitized, and updated by the model developer;
- The socio-economic data on the production systems were sourced from Ha (2012) and updated during consultations and role-playing with farmers;
- The baseline probabilities to shift were computed from local trends in shrimp farming and calibrated during the role plays;
- The land suitability for integrated mangrove shrimp and intensive shrimp farms was derived from the hydrological modeling of the Mekong Delta applied to the study area. The water level and salinity concentration along the river network in the Dam Doi district, Ca Mau province were simulated with the Mike 11 model (Dat et al. 2011). This calibrated and validated model simulates the hydrodynamics and the salinity intrusion over the whole delta of the Mekong. Compared with the actual measured salinity and water levels, the simulated ones followed the measured trend and were within an acceptable range of differences. In fact, the study area was close to the downstream boundary conditions of the applied hydrodynamics model (i.e., the measured tidal regimes).

3.3 *Sub Models*

The sequence of events happening during a cycle or when an agent shifts to Intensive farming is listed in Table A.5 below.
Table A.5: Sequence of actions and reflexes during a cycle

<table>
<thead>
<tr>
<th>Reflex/Action</th>
<th>Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reflex</strong></td>
<td></td>
</tr>
<tr>
<td>- Update Price</td>
<td>Global environment</td>
</tr>
<tr>
<td>- Update virus outbreak</td>
<td>Global environment</td>
</tr>
<tr>
<td><strong>Master Rule for testing probability to change to INT</strong></td>
<td></td>
</tr>
<tr>
<td>- Determine loan and available loan</td>
<td>Farm</td>
</tr>
<tr>
<td>- Check land use title</td>
<td>Plot</td>
</tr>
<tr>
<td>- Check minimum bank account</td>
<td></td>
</tr>
<tr>
<td>o Check for Hybrid (ratio of INTS and EXTS plot size)</td>
<td>Plot</td>
</tr>
<tr>
<td>o Check INT economic threshold</td>
<td>Farm</td>
</tr>
<tr>
<td>o Update probability to shift to INTS</td>
<td>Plot</td>
</tr>
<tr>
<td>o Test probability</td>
<td>Plot</td>
</tr>
</tbody>
</table>

Once the production system is decided

Run crop

- Test for virus
- Update failure history
- Calculate yield and economic return

Update secondary income and expense

Update bank account and loans

Update land use

**Master Rule**

The master rule is the main reflex of the model and the backbone of every step or cycle. It applies to every agent and determines a series of actions as follows:

- Determine the Available loan accessible to farm agent;
- Update the cost of the next crop;
- Check if the Land use title is Red (Decision 1 in Figure 1):
  - Check if the Bank account is above the minimum threshold;
  - If the farm agent does not have an Intensive plot, the plot agent checks for the option of a Hybrid farm and determines the areas for Intensive and Extensive production in case it becomes a hybrid Intensive plot:
    - Based on the Intensive area stochastically determined, the plot agent calculates the cost of investment and the cost of one crop necessary to shift to Intensive production;
    - This cost of investment and crop cost is compared with the Household bank account and the Available loan;
    - If the Bank account + Available loan are above the investment +crop cost, the agent updates the probability to shift to Intensive farming and tests this probability.
  - If the agent has only an Extensive plot and does not have sufficient capital to invest in an Intensive plot, a similar process is done for Improved Extensive farming. The agent checks the option for a Hybrid farm to determine the areas for Improved Extensive and Extensive system in case the plot becomes Improved Extensive.
    - Based on the Improved Extensive area stochastically determined, the plot agent calculates the cost of investment and the cost of the crop necessary to shift to Improved Extensive farming.
- This cost of investment + crop costs is compared with the Household bank account and the Available loan.
- If the Bank account + Available loan are above the investment cost, the agent updates the probability to shift to Improved Extensive and tests this probability.
  - If the agent has only an Extensive plot and does not have sufficient capital to invest in Improved Extensive farming, he updates the probability to shift to Integrated Mangrove Shrimp and tests this probability.

**Updating Probability**

The probability to shift to Intensive, Improved Extensive andIntegrated Mangrove Shrimp can be updated. Updating the probability to shift to Intensive plots is done as follows:

- The base probability to shift to Intensive is loaded from the global variable and varies according to the agent’s original land use (Extensive, Improved Extensive, Integrated Mangrove Shrimp);
- The social influence of neighbors is calculated:
  - Calculate the number of Intensive plots within a 500 -radius and generate a ratio between number of Intensive plots/ total number plots if number of Intensive plots is >0;
  - Calculate the social influence for Intensive using this formula:
    \[1 + (0.6 \times (1 - (e^{6 \times \text{intensive plots/ total number plots}}))\]
  - If the number of Intensive plots is = 0, the social Influence Intensive = 0.8;
- The plot suitability for intensive farming is sourced from the GIS file and included in the plot agent’s calculations.
- The updated probability is calculated as follows:
  - Probability to shift to Intensive = base probability X social Influence Intensive X plot suitability for intensive

**Testing Probability to Shift**

Once the probability has been updated, the agent tests its probability.

- If the test result is positive, the agent does the following actions:
  - Update the area of Intensive and Extensive plots (see Check Hybrid);
  - Update his Bank account by withdrawing the investment and crop cost required for Intensive farming on the pre-determined area;
    - If after the update, the bank account is negative, the agent contracts a loan within range of what is available and the bank account is updated as well as the amount loaned.
    - If the bank account is positive, no loan is contracted.

- If the test is negative, the agent will check if he can invest in an improved extensive plot and follow a similar type of procedure by updating the probability and testing the probability to shift to Improved extensive.

**Checking Intensive for Hybrid**

To estimate the investment cost needed to develop an Intensive plot, the agent stochastically determines first the areas for the Intensive and the Extensive ponds. Only agents with a small pond area (less than 0.25 ha) converts their pond to Intensive entirely.
- If the total pond area is between 0.25 and 1 ha, the agent chooses randomly a factor between 0.33 and 1. This factor will be the ratio of the intensive pond area to the total area.
- If the total pond area is between 1 ha and 2 ha, the agent chooses randomly a factor between 0.4 and 1. This factor will be the ratio of intensive pond area to the total area.
- If the total pond area is above 2 ha, the pond agent chooses randomly a factor between 0.3 and 1. This factor will be the ratio of intensive pond area to the total area.

The ratio will be used to calculate the intensive pond area. If the agent decides to invest in an Intensive shrimp pond, he will use the area decided during this process.

A similar process is followed to decide the pond area of Improved extensive (Check Hybrid for IE), but with slightly different ratios.

**Running Crop**

Run crop action is set by the plot agent. It determines the revenue from the crop for every cycle. The action is slightly different according to the production system. In Improved Extensive plots the action is as follows:

- The agent checks if the area for Improved Extensive farming is not null and if the production system is Improved Extensive (=2);
- The failure rate is updated using the failure rate of Improved extensive system + additional risk;
  - The agent tests the probability if the crop is a success or a failure;
  - If the crops is a failure, the agent updates the failure history of the plot (+1), and calculates the yield, gross revenue, and crop revenue.
  - if the crop is a success, the agent sets the failure history to 0, and calculates the yield, gross revenue, and crop revenue.

The yield is determined randomly based on an average yield and a standard deviation for this specific production system.

The gross revenue is equal to the yield x area cultivated x price (failed or success).

The crop revenue is equal to the gross revenue minus the crop cost.

**Updating Secondary Income and Expense**

At every cycle the farm agent updates the Secondary income of the household (income not derived from shrimp farming activity) as well as the Household expenses. Both expenses and secondary income depend on the production system of the agent. An agent following an Intensive production system will have expenses and secondary incomes different than an agent with an Extensive production system.

To update secondary income and expenses, the agent
- Checks the type of production system
  - Assigns randomly a secondary income, based on an average and standard deviation specific for each type of production system;
  - If the crop revenue is positive, the expense is calculated as:
    - a fraction of the crop revenue + correlation of the expense and the household size;
  - If the crop revenue is negative the expense is calculated as:
    - The correlation of the expense and the household size.
**Updating the Bank Account**

At the end of the cycle, the agent will update the bank account, taking into account the yield of the crop, the expenses, the secondary income and the debts, as follow:

- Updated bank account = previous bank account + crop revenue + secondary income - expenses.

If the bank account is negative, then the agent will contract a loan. The amount loaned depends on the loan availability for each agent (See Determining Loan). Agent will contract a loan to have a bank account equal to zero.

If the bank account is positive, the agent will reimburse his loan, partially or totally but will always keep their bank account equal to or above 0.

**Updating Failure History**

Updating the failure history concerns only Intensive and Improved Extensive agents. When the failure history is above 3 or the bank account is less than 20% of the crop operational cost, the agent makes the following decisions:

- If agent has a total plot area of <1 ha, he abandons the plot, and crops and area parameters are set to 0;
- If the agent has a total plot area > 1 ha, he changes production systems and goes back to the Extensive pond, converting the entire plot area to Extensive. Land use history parameter is set to 0.

The improved Extensive agent does not abandon, but only converts to the Extensive system.

**Actions**

**Determining Loan**

At every cycle each agent, before testing the different possibilities of production systems, will determine the amount of money he can borrow.

The agent will first determine the Maximum loan he can take out by testing if he can contract a “normal loan” or a “higher loan”. This is decided by a probability test; an agent has a 20% chance to contract a “higher loan.”

- If the agent contracts a “normal loan,” the Maximum loan he can contract varies according to the production system of the plot. An Intensive agent can borrow a higher amount than an Extensive agent. The amount is randomly attributed based on an average loan and a standard deviation multiplied by the plot area (loans are proportional to the total area).
- In the case of a “higher loan,” the amount loaned is higher than usual for Extensive, Integrated Mangrove Shrimp and Improved Extensive agents, and corresponds to the average loan and standard deviation of the Intensive agent.

The Maximum loan calculated during this action will be used to determine the available loan at the beginning of the cycle. The Available loan is equal to the maximum loan minus the household loan (or the current debts of the household).

**Land Use History**

After every cycle, land use is counted for abandoned plots, Intensive, and Integrated Mangrove Shrimp plots. Thus, the number of cycles with the same production system is recorded.
**Past Changes**

Actions related to Past changes use the Land use history of the plot to decide whether or not Intensive plots or Integrated Mangrove Shrimp plots are allowed to change systems. In fact, once agents decide to shift to an Integrated Mangrove Shrimp system, they have to stay in this system for the next 20 cycles (or steps) to be allowed to harvest their timber. Thus, when the Land use history is 19 or lower, the probability to shift to another system = 0.

A similar rule is defined for Intensive plots, but the number of cycles agents have to follow this system is equal to 2.

**Reflexes**

At every cycle the model operates a series of reflexes that define the global variable.

The reflex ‘price’ determines the farm gate price of shrimp, both from a successful and a failed crop. Both prices are set randomly within a lower and upper boundary.

The reflex ‘disease outbreak’ of the model determines if there is a significant disease outbreak in a cycle that affects the entire region by testing this probability. If realized, this probability, set to 5%, will increase the risk of a virus outbreak in all production system by 30%.

‘Check abandonment’ corresponds to the re-initialization of plots that have been abandoned. After being abandoned, a plot stays abandoned for 4 cycles. After this period a new agent is initialized and the plot follows an intensive production system, and the value of the parameters are set accordingly.

**References**


