

## Supplemental material for

“Collaborative Modeling and Simulation to Mitigate High-Elevation Rangeland Degradation in Eastern Bhutan”, by Tayan Raj Gurung, Christophe Le Page, and Guy Trébuil, published in *Mountain Research and Development* 42(4), 2022. (See <https://bioone.org/toc/mred/42/4>)

**APPENDIX S1** History of the Sheytimi rangeland conflict and past unsuccessful interventions.

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## **APPENDIX S1 History of the Sheytimi rangeland conflict and past unsuccessful interventions**

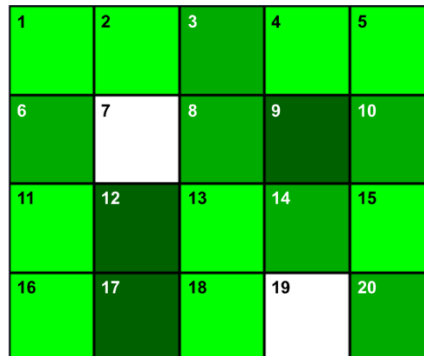
Until 1959, the Sheytimi was a government owned rangeland for dairy cattle. It was closed in the 1960s and the land offered for sale. The then Thrompon of Trashigang (who later became Home Minister) bought the rangeland and it is reported that 1200 acres of pasture land is registered under his widow Aum Sonam Chenzom's name. Bowshey and Lhamshisa pastures were used by the owner, Sheytimi proper leased out to 13 Merak herders (and then 14 according to Tenzing et al in 2018), Daktsi leased out to 6 Radips farmers, Tongling leased out to 4 Merak herders and Kolaphu used by Radips herders. The rent of using the rangeland land was as follows: 1 kg butter for 3 milking cows, Nu. 1 (Nu.73 = 1 USD) per head of other animals (later increased to Nu. 3 then to Nu. 5), free labour contribution for camp shifting of owner, Nu. 2000 each from Merak and Radi herders as lump sum compensation.

The contestation for grazing land has led to overexploitation of resources and irreversible degradation of the area with the cause of conflict associated to encroachment of pasture land by either group. During this switch over and in absence of the other community herders, the one using their designated pasture let their cattle in other's pasture land and even sever fodder trees indiscriminately to supplement fodder. The practice of trespassing has built up into severe antagonism over the years. Reports mention of people injuring and killing cattle of another community, and several cases of death of domestic animals were settled by the payment of hefty fines. To add to the complexity, herders from Radi have discontinued paying grazing rent for many years. In the meantime, the landowner had filed a case against 6 herders from Radi in Dzongkhag court in Trashigang for encroachment. In the past, land-use contracts used to be established with 6 Radips and 12 (then 9) Brokpas herders. Among several instances of reports, negotiations and verification, the most important was the visit by Trashigang Dzongdag and People's representative in January 1981 on Royal Command following a petition several Radips herders, with no legal access to the pasture, to His Majesty the King by Radi people in December 1980 for grant of grazing rights in Sheytimi. Investigation recognized the shortage of grazing area for Radips but concluded that the existing pasture in Sheytimi was just enough for the landowner herds and grazing rights was denied to Radi people. As differences persisted, the owner and Radips decided to establish a legal lease agreement and consulted Dzongkhag Court in Trashigang but learned that pasture land cannot be leased out and that it would be unlawful to enter into such agreement. Since then herders from Merak and Radi have indiscriminately grazed the area blaming one another for widespread degradations in the rangeland, Radips and Brokpas herders accusing each other of trespassing the boundaries of their (legal or not) dedicated grazing areas and of being the source of land degradation.

The loss of arable land, livestock, property and life due to land slips attracted more high-level concerns. The visit of His Majesty the King in February 1998 was followed by a Royal Command to implement remedial actions to stabilize areas prone to mass movements. An integrated watershed development program triggered tree plantation with diverse species and provided fencing materials to restore degraded areas, especially in the Tongling pasture (Figure 1). Tashi and Wangchuk (2006) stated that the enduring conflict is mainly due to the evolution of the lease agreements between the owner and the herders from both communities, to encroachment of Radips' cattle on parts of the rangeland allocated to other parties, and to repeated cantankerous litigations in courts during 2002-2006. Following several legal disputes, cases of physical attacks of domestic animals from each side and destruction of landmarks, the two communities hardly talk to each other to improve a situation characterized by unclear and evolving user rights over the rangeland. Indiscriminate and inequitable use of limited grazing land in the Chongdiri catchment is the outcome of this user rights conflict.

## APPENDIX S2 Description of the *CherIng* role-playing game

The game is based on the representation of a portion of territory represented by a board composed of 20 numbered squares, each of which contains a quantity of biomass of a plant resource expressed by a number of units varying between 0 and 3. Figure S2.1 shows the initial configuration of this virtual territory on which 30 biomass units are heterogeneously distributed. One round of the game represents one harvest season. A gaming session ends after 5 rounds of play. The game has been calibrated for a total number of 20 harvesters. In order to respect this constraint, the number of players  $j$  present at the time of starting a game is divided into  $n$  families of  $m$  members so that:  $\sum_{i=1}^n m_i = 20$ , with  $n \leq j$



**Figure S2.1.** The CherIng game board made of squares numbered from 1 to 20. The colours correspond to the initial biomass levels of the plant resource: 0 in white (squares 7 and 19), 1 in light green, 2 in medium green and 3 (the maximum) in dark green (squares 9, 12 and 17).

Each harvester, who is able to harvest a maximum of 2 units of biomass per year, must contribute to the self-subsistence of his family (one unit of biomass per member per season). When there are several harvesters on the same square, a random distribution is made (1 or 2 units to the first, 1 unit to the second if there are any left, nothing to the others). The renewal of the plant resource depends on an undisclosed dynamic that the players will try to discover during the gaming session. This renewal depends on the number of harvesters present on a square and, if this is zero, on the number of previous rounds without harvesting (see Table S2.1).

$B_t$	$B_{t+1}$	0	1	2	3
0		$H_t > 0$ $H_t = 0 \ \& \ H_{t-1} = 0$	$H_t = 0 \ \& \ H_{t-1} > 0$		
1		$H_t > 1$ $H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} = 0$	$H_t = 1$ $H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} > 0$	$H_t = 0 \ \& \ H_{t-1} > 0$	
2		$H_t > 1$	$H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} = 0$	$H_t = 1$ $H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} > 0$	$H_t = 0 \ \& \ H_{t-1} > 0$
3		$H_t > 2$	$H_t = 2$	$H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} = 0$	$H_t = 1$ $H_t = 0 \ \& \ H_{t-1} > 0$ $H_t = 0 \ \& \ H_{t-1} = 0 \ \& \ H_{t-2} > 0$

**Table S2.1.** Renewal rules for plant biomass. Each cell gives the transition conditions from a biomass state in the current year ( $B_t$ , in rows) to a biomass state in the next year ( $B_{t+1}$ , in columns). The conditions are based on the number of harvesters present in a given square in the current year ( $H_t$ ) and the two previous years ( $H_{t-1}$  and  $H_{t-2}$ ). Shaded cells indicate impossible transitions, white cells indicate that the biomass level is maintained, yellow, orange and red cells indicate a decrease of 1, 2 and 3 units respectively

These rules, while not referring to any particular plant species, reflect the following principles:

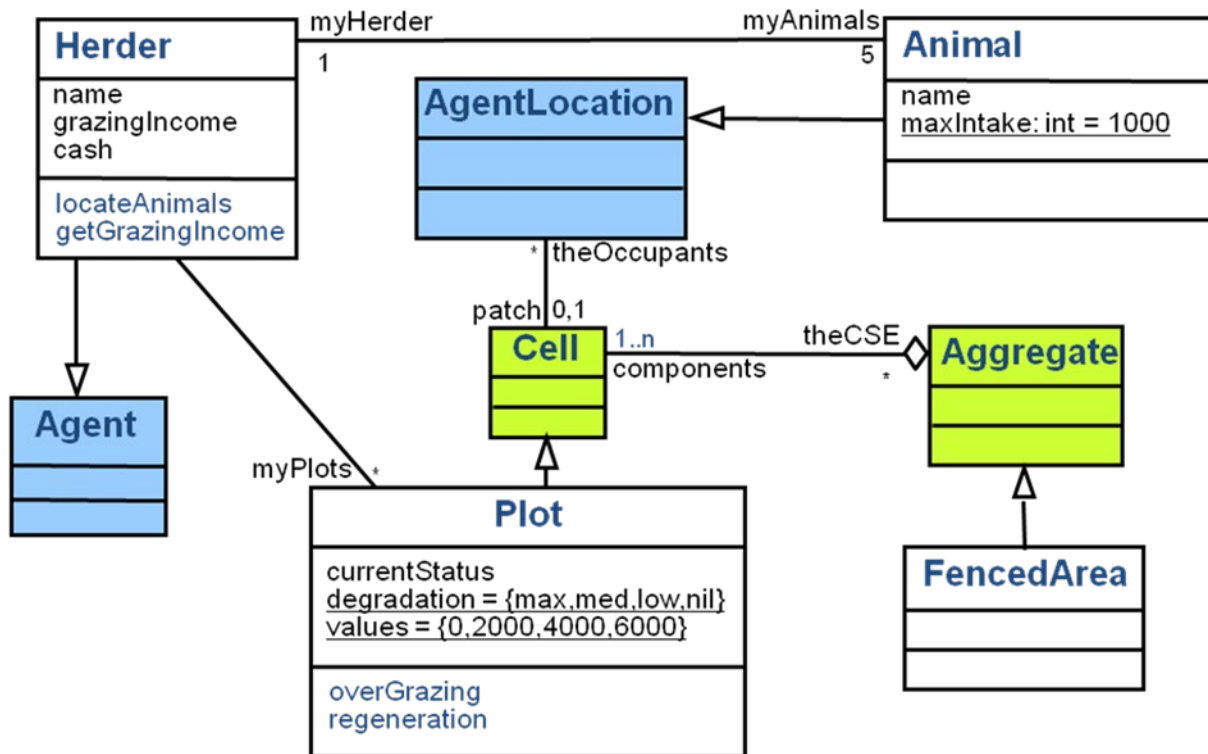
- There is a sustainable level of exploitation (1 harvester per square) for which renewal equals harvesting; beyond this threshold, overexploitation has a strong impact on the resource (orange and red cells in Table S2.1);
- A season without harvesting allows the resource to increase its biomass level by one unit (green cells in Table S2.1);
- A longer period of non-use leads to a stagnation (at the second occurrence, cf. second rows of the white cells in Table S2.1) and then to a decline (from the third season onwards, cf. yellow cells in Table S2.1) of the biomass level. This last principle, which is counter-intuitive, is justified by the fact that in some plants, such as reed, mowing and harvesting preserve the conditions that favour the growth.

A first gaming session without any possible communication between the families serves as a "warm-up" which allows the players to get used to the game features and rules. Then a second session starts, this time with a 5-minute time-slot at the beginning of each round for free discussion between families. Depending on how these discussions are conducted, competition gives way to coordination and the results obtained are more or less significantly improved.

A workshop ends with a collective debriefing to draw some lessons from what happened during the gaming sessions.

## APPENDIX S3 Structure of the Sheytimi conceptual model

The entities of the model are represented as rectangular boxes in the UML class diagram below. The upper part shows the name of the entity, the intermediate part displays its characteristics (attributes) while the lower part lists its operations (methods). When underlined, an attribute represents a parameter of the model: its value is constant. When not underlined, an attribute represents a state variable. Lines across entities represent associations between them. Symbols (triangle, diamond) at the end of an association indicate a specific semantics (respectively generalization and composition). The coloured boxes represent generic classes of the [Cormas simulation platform](#) that was used to implement a computerized version of the RPG



**APPENDIX S4 Second (top row) and third (bottom row) gaming sessions in action at Radi site**



## **APPENDIX S5 Guidelines for individual interview of the participants in the Sheytimi gaming sessions held at Radi Block Office**

### **Restating the objectives of the interviews**

Focus is on the second day (more realistic) gaming sessions

- To clarify the observations made during the game sessions.
- To better understand some of the decisions made during the games.

- 1. What do you think about the game: could you comment on the representation of (easy/difficult to understand, most adapted?)**
  - a. The space/the environment? Understanding of the grid & its heterogeneities?
  - b. The land (the resource) & its different states?
  - c. And the process of land degradation (morning) & regeneration (in the afternoon)?
  - d. The animals: about their number? The use of coloured pins?
  - e. The annual incomes?
  - f. Time in the games, the sequences / turns?
  - g. What is the kind of actual access to pasture resources that could explain your decision making in the games?
  - h. Would you say that the game dynamics & results were similar to reality / were realistic?
- 2. Your role and decisions in the first morning group wise game (without management options & without regeneration)**
  - a. How was the discussion organized in your group of players?
  - b. How was the decision-making process organized in your group?
  - c. Were you satisfied with the results of this first game?
- 3. Your role and decisions in the second early afternoon group wise game with management options & with regeneration**
  - a. How was the discussion organized in your group of players?
  - b. How was the decision-making process organized in your group?
  - c. Were you satisfied with the results of this first game?
- 4. Your role and decisions in the afternoon collective game with management options & regeneration**
  - a. How was the discussion organized in your group of players?
  - b. How was the decision-making process organized in your group?
  - c. Were you satisfied with the results of this first game?
  - d. About what the other players were doing: were you surprised by some of their decisions? If yes, who made it and why?
- 5. Conclusion & evaluation**
  - a. Among the three games played yesterday, how would you rank them according to your preferences?
  - b. What knowledge about pasture land did you share with others during these games?
  - c. Did you learn something from these games?
  - d. For what purpose these games could be used in the Geog?
  - e. Are you willing to play similar games about the grazing problem again in the future?
  - f. Who else do you think should play this game?
  - g. Was the venue of this workshop the most appropriate one? Is there a better place to organize similar events?
  - h. After participating in this workshop, what are the three most important information you will pass on to people back in your village?