

Modeling of Ecological Footprint and Climate Change Impacts on Food Security of the Hill Tracts of Chittagong in Bangladesh

B. K. Bala · M. A. Hossain

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Abstract This paper presents an integrated and dynamic model for the management of the uplands of the Hill Tracts of Chittagong to predict food security and environmental loading for gradual transition of shifting agriculture land into horticulture crops and teak plantation, and crop land into tobacco cultivation. Food security status for gradual transmission of shifting agriculture land into horticulture crops and teak plantation, and crop land into tobacco cultivation is the best option for food security, but this causes the highest environmental loading resulting from tobacco cultivation. Considering both food security and environmental degradation in terms of ecological footprint, the best option is gradual transition of shifting agriculture land into horticulture crops which provides moderate increase in the food security with a relatively lower environmental degradation in terms of ecological footprint. Crop growth model InfoC-crop was used to predict the climate change impacts on rice and maize production in the uplands of the Hill Tracts of Chittagong. Climate change impacts on the yields of rice and maize of three treatments of temperature, carbon dioxide and rainfall change (+0 °C, +0 ppm and +0 % rainfall), (+2 °C, +50 ppm and 20 % rainfall) and (+2 °C, +100 ppm and 30 % rainfall) were assessed. The yield of rice decreases for treatment 2, but it increases for treatment 3. The yield of maize increases for treatments 2 and 3 since maize is a C₄ plant. There is almost no change in food security at upazila (sub-district) level for the historical climate change scenario, but there is small change in the food security at upazila levels for IPCC climate change scenario.

Keywords Food security · Ecological footprint · Climate change impacts · Rice · Maize · Hill Tracts of Chittagong

1 Introduction

Chittagong Hill Tracts (CHT) is the only extensive hill area in Bangladesh, and it is located in the southern eastern part of Bangladesh between 21°25'N to 23°45'N latitude and 91°54'E to 92°50'E longitude. The area of the Chittagong Hill Tracts is about 13,184 km², of which 92 % is highland, 2 % medium highland, 1 % medium lowland and 5 % homestead and water bodies. Total population of CHT is 1,331,996, of which about 51 % is tribal people.

Agriculture is the main source of livelihood of these populations. Non-farm income opportunities are very limited and in some areas non-existent. The tribal populations here are the most disadvantaged group of populations in Bangladesh. Shifting agriculture, locally known as *jhum*, is still the cultivation system in this region with little impact of different plans and programs to promote the agricultural land use patterns. As a result the tribal populations are suffering from food insecurity, and the shifting agriculture has led to indiscriminate destruction of forest for food resulting in ecological degradation.

Promoting sustainable development in uplands of Chittagong Hill Tracts poses important challenges. These upland areas are remote and are mostly inhabited by many ethnic minorities. The majority of the ethnic minorities are Chakma (48 %) and Marma (28 %). The incidence of poverty is very high. To meet the livelihood needs, upland farmers often use unsustainable land use practices. Uplands are essentially caught in a vicious cycle of poverty, food insecurity and environmental degradations. Land use practices in uplands not only cause severe losses of soil and essential plant nutrients and degradation of the resource base but also negatively impact on the livelihoods and resources base

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downstream. Wider environmental impacts also occur in the form of reduced biodiversity, reduced ability of the ecosystem to regulate the stream flow and reduced carbon sequestration.

Food security is a worldwide problem that has called the attention to governments and the scientific community. It particularly affects developing countries. The scientific community has had increasing concerns for strategic understanding and implementation of food security policies in developing countries, especially since the food crisis in the 1970s. The process of decision-making is becoming increasingly complex due to the interaction of multiple dimensions related to food security [21].

FAO [18, 19] defined the objective of food security as assuring to all human beings the physical and economic access to the basic food they need. Food security is a social sustainability indicator, and most commonly used indicators in the assessment of food security conditions are food production, income, total expenditure, food expenditure, share of expenditure of food, calorie consumption and nutritional status etc. [38]. Accounting tools for quantifying food security are essential for assessment of food security status and also for policy planning for sustainable development.

Several studies have been reported on food security in terms of per capita food availability in Bangladesh [13], pattern of household food consumption and causes of food insecurity [36], and access and utilization of food and the issues of food and nutritional security [32]. These studies give a descriptive statistics of the food security. Recently Bala and Hossain [6, 7] reported a quantitative method of computation of food security.

Ecological footprint is an ecological stability indicator. The theory and method of measuring sustainable development with the ecological footprint was developed during the past decade [15, 43]. The ecological footprint is a measurement of sustainability illustrating the reality of living in a world with finite resources, and it is a synthetic indicator used to estimate a population's impact on the environment due to its consumption. It quantifies total terrestrial and aquatic area necessary to supply all resources utilized in a sustainable way and to absorb all emissions produced always in a sustainable way. Apart from analyzing the present situation, ecological footprint provides framework of sustainability planning in the public and private scale.

Several studies have been reported on applications of ecological footprint during the past decade to address environmental sustainability [5–7, 16, 29, 33, 34, 42, 45]. This technique has been applied to wine production [34], regional level [6, 7, 45], national level [5, 16, 29], and national and global level [42]. The ecological footprint has been jointly used combining energy analysis to evaluate ecological footprint for regional level [45] and national level [16] as well as to assess ecological footprint and biocapacity [5, 29, 33].

Agricultural systems are vulnerable to variability in climate, and they can be viewed as a function of the sensitivity of agriculture to changes in climate, the adaptive capacity of the system and the degree of exposure to climate hazards [23]. The productivity of food crops from year to year is sensitive to variability in climate, and it affects the food security. Furthermore, Bangladesh is the most vulnerable to the impacts of climate variability and change. In the last two decades, there has been rapid development of crop models that can simulate the response of crop production to a variety of environment and management factors. With such models, it is feasible to assess the variations in yields for different crops or management options under a given climatic change.

Climate changes include both rapid changes in climatic variables such as temperature, radiation and precipitation, as well as changes in the atmospheric concentration of greenhouse gases. Soil water and nutrient cycling and climate changes affect food security. Predicted climate change impacts are essential to design plans and programs to adapt for future conditions. For proper understanding and implementations of the plans and programs of the adaptation strategies of the climate change impacts, the climate change impact systems must be modeled and simulated. Simulation models can assist in examining the effect of different scenarios of future development, and climate change impacts on crop production and several crop models are available.

Several studies have been reported on climate change impacts on rice [3, 17, 24, 40, 44], wheat [1, 2, 4, 22, 26, 27, 35] and maize [27, 28, 31]. Farmers have proved highly adaptable in the past to short- and long-term variations in climate and their environment. Also key to the ability of the farmers to adapt to climate variability and change is the access to relevant knowledge and information [14]. Farm level analyses have also shown that large reductions in adverse impacts from climate change are possible when adaptation is fully implemented [30]. Adaptation practices require extensive high quality data and information on climate and on agricultural, environmental and social systems affected by the climate.

Bala and Masduzzaman [10] developed a system dynamics version of crop growth model based on the Wageningen Agricultural University crop growth model to predict the potential yield and yield under water stress of wheat. Bala et al. [11] also adapted this model to project crop production (rice and wheat) in Bangladesh. More recently Rosenzweig et al. [39] reported preliminary outlook for effects of climate change on Bangladeshi rice, and this study shows that aus crop is not strongly affected and aman crop simulations project a highly consistent production increase.

Shifting agriculture is still the cultivation system in this region with little impacts of different plans and programs for increased food security, and also tobacco cultivation is

Table 1 Selected upazilas from the Hill Tracts of Chittagong

District	Upazila
Bandarban	Sadar, Ali kadam and Ruma
Rangamati	Sadar, Barkal and Kaptai
Khagrachhari	Sadar, Mahalchhari and Dighinala

expanding rapidly which demands rapidly expanding amounts of fuelwood for tobacco kilning, which causes environmental degradation. This study presents an integrated and dynamic model to assess the environmental degradation in terms of ecological footprint and food security for different policy options and also addresses the climate change impacts on food security of the Chittagong Hill Tracts of Bangladesh.

2 Materials and Methods

2.1 Field Level Sample Survey

The Hill Tracts of Chittagong consists of three districts: Bandarban, Rangamati and Khagrachhari. The sampling framework consisting of primary sampling unit of district and ultimate sampling unit of upazila (sub-district) is shown in Table 1. Nine upazilas were randomly selected from each of the three districts, and these districts are shown in Fig. 1. Two sets of questionnaire were developed with emphasis on traditional crop production system (*jhum*) and environmental degradation and also food security and environmental degradation at upazila levels. Two sets of questionnaire were pre-tested, and necessary improvement was made.

Fig. 1 Map of Bangladesh

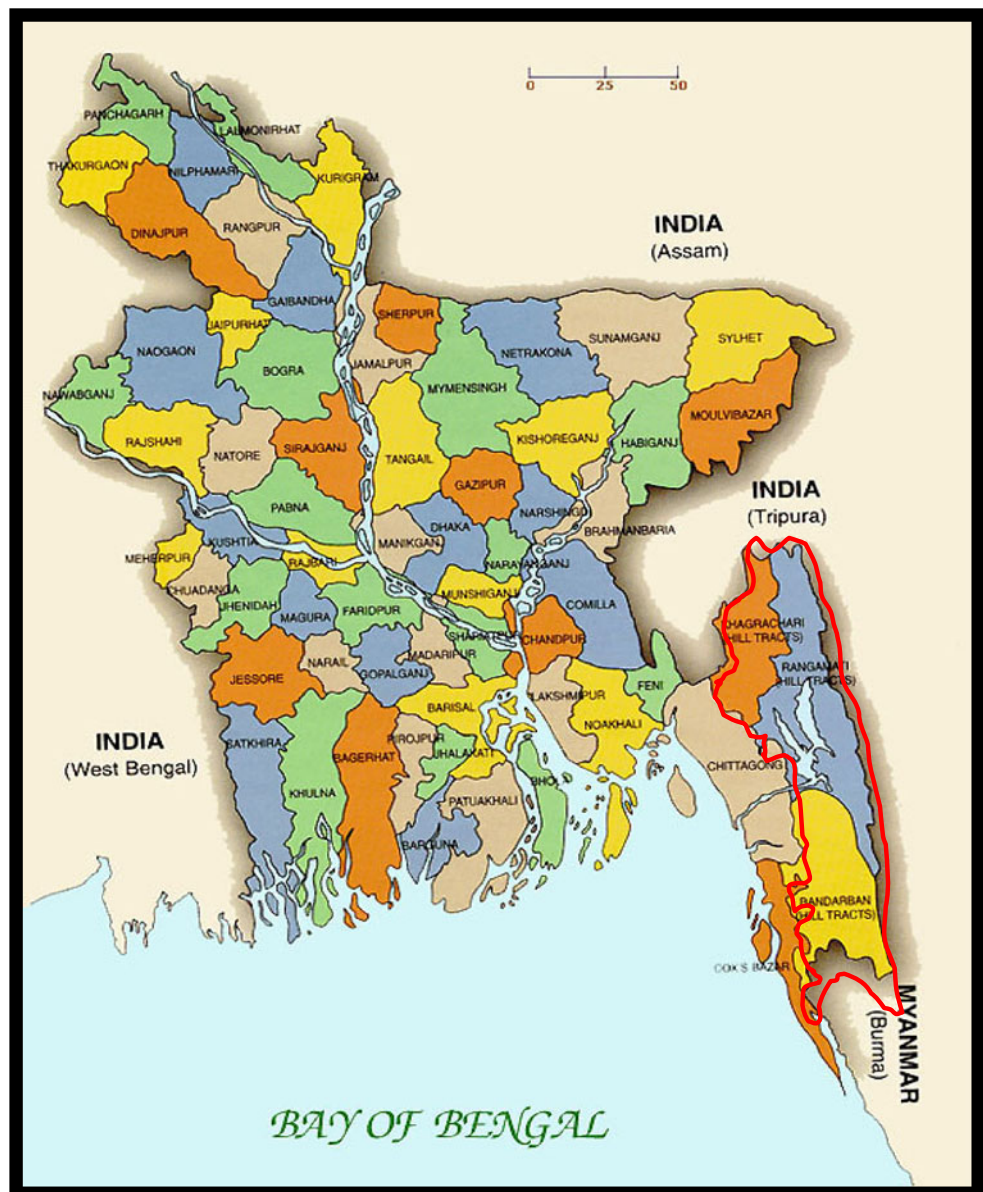
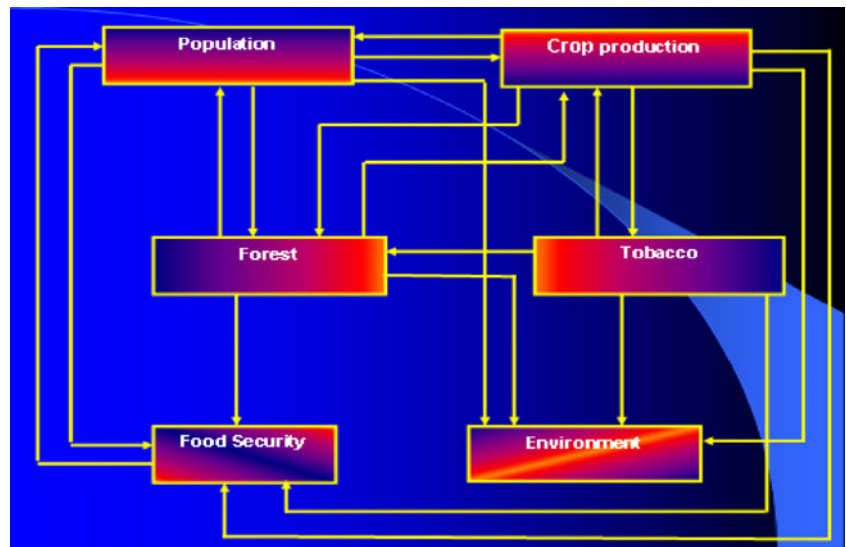


Fig. 2 Interrelationships of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong



2.2 Data Collection and Analysis

Data on population, crop, tobacco, livestock and forestry were collected to estimate the present status of food security and ecological footprint at upazila levels in the Hill Tracts of

Chittagong in Bangladesh from upazila offices of Government Department of Statistics, Agriculture, Forestry, Fishery and Livestock. In addition, a Focus Group Discussion was held with the sub-assistant agricultural officers of ten blocks of Khagrachhari sadar upazila on *jhum* cultivation on 16 April

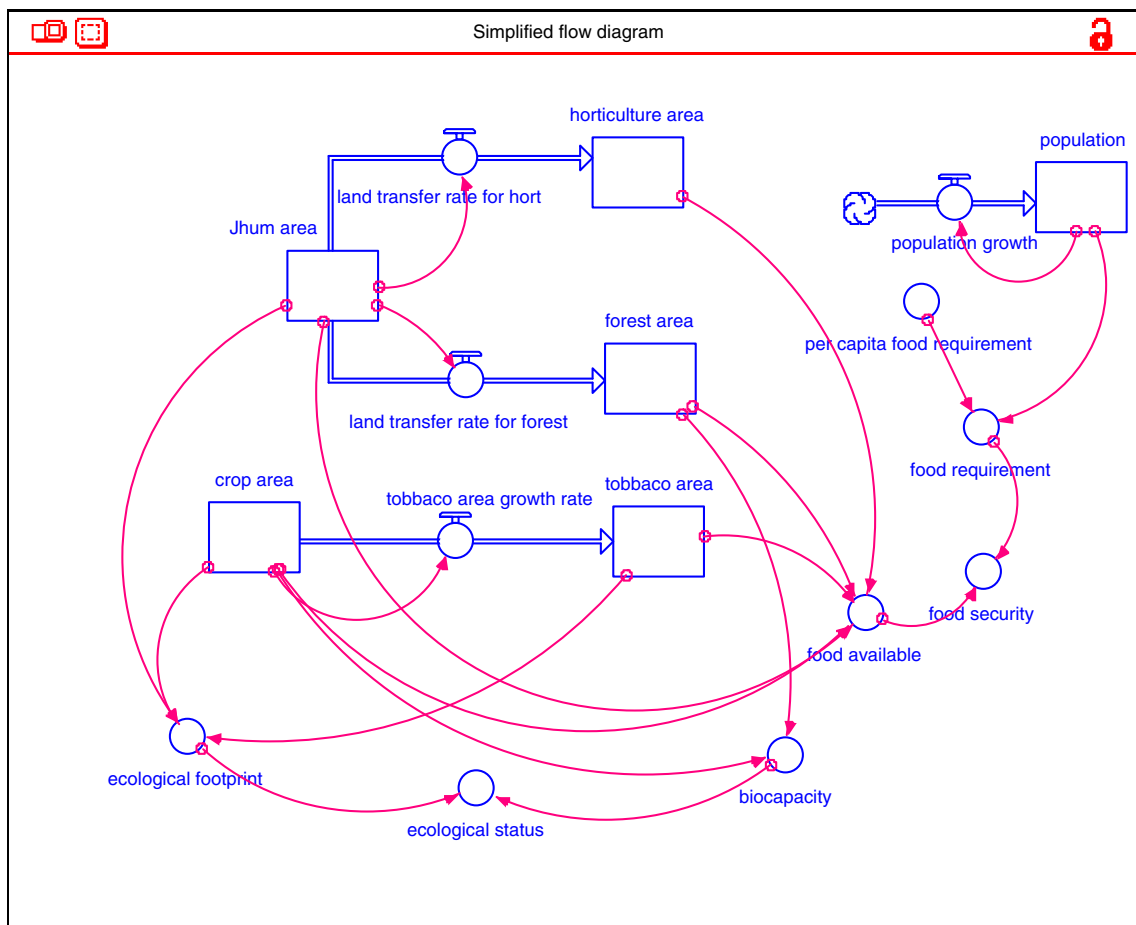
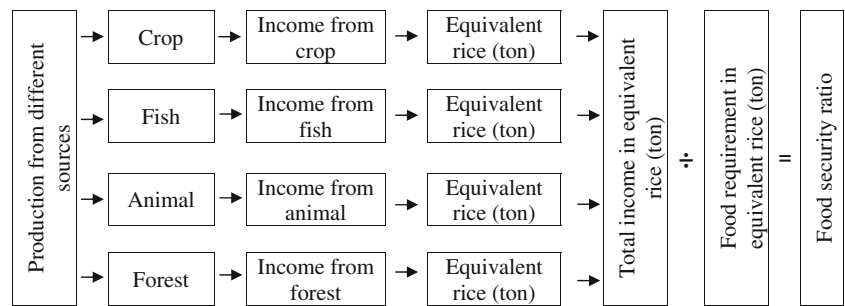


Fig. 3 Simplified flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong

Fig. 4 Structure of food security computation



2009 in the Khagrachhari upazila agricultural extension office. Collected data and information were compiled, edited, summarized and analyzed, and these are available in Bala et al. [12].

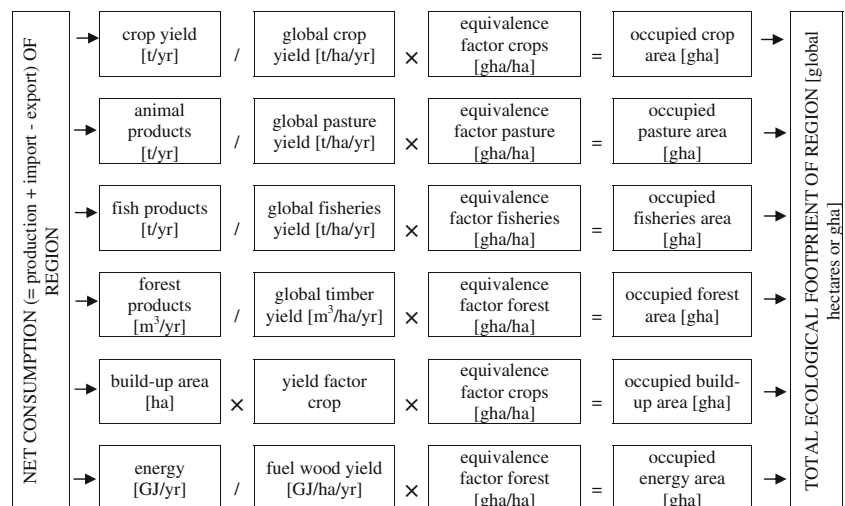
2.3 Modeling of Upland Agricultural Systems

Planning of integrated management of the uplands of the Hill Tracts of Chittagong has to address several interdependent issues such as food security and environmental degradation (ecological footprint) of the uplands of the Hill Tracts of Chittagong to find out the leverage points and also to explore management scenarios of the uplands of Chittagong for sustainable socio-economic development. The integrated management of the uplands of the Hill Tracts of Chittagong is a complex, dynamic and multi-faceted system depending not only on available technology but also on economic and social factors. Experimentation with an actually existing upland management system containing economic, social, technological, environmental and political elements is totally unrealistic. Simulating an integrated upland management system by a computer model, one can conduct a series of experiments. Computer models clearly are of great value to understand the dynamics of such complex systems [9]. Owing to the intrinsically complex nature of the upland management problems, it is advantageous to implement integrated upland management policy options only after careful modeling analyses. Forrester’s

system dynamics methodology provides a foundation for constructing computer models to do what the human mind cannot do that is rationally analyze the structure, the interactions and mode of behavior of complex socioeconomic, technological and environmental systems [9, 20]. Hence, the system dynamics approach is the most appropriate technique to handle this type of complex problem. A detailed description of the methodology is given in Forrester [20] and Bala [8, 9].

The management system of the uplands of agricultural systems of the Hill Tracts of Chittagong consists of population, crop production, tobacco, forestry and ecological sector. These sub-models are integrated for sustainable development. The system as a whole can be described in terms of interconnected blocks. A block diagram representation of the uplands of agricultural systems of the Hill Tracts of Chittagong is shown in Fig. 2. The major influences to a sector from other sectors and its influences on the other sectors are shown in the diagram. *Jhum* area is converted into horticultural crop area and forest area, and crop area is converted into tobacco area. Major contributions to the food security of the Hill Tracts come from the *jhum* production, crop production, horticultural production, tobacco production and forest production, and the environmental degradation i.e. ecological footprint comes from mainly *jhum* production, tobacco production and soil erosion. The simplified flow diagram of integrated farming/

Fig. 5 Structure of ecological footprint computation



agricultural system is shown in Fig. 3. The building blocks of the model are stock and flow. The stock is a state variable, and it represents the state or condition of the system at any time t . The stock is represented by a rectangle. The flow shows how the stock changes with time, and it is represented by a valve symbol. The flow with arrow towards the stock indicates inflow, and the flow with arrow outwards indicates outflow. The lines with arrow are influence lines, and the direction indicates the direction of information flow. The variable/factor at the starting point indicates the variable/factor affecting the variable/factor at the terminating point, and this in essence shows how one variable/factor influences other variable/factor with direction of information flow. In Fig. 3 $jhum$ area is a stock variable, and land transfer rate for hort is outflow from the stock— $jhum$ area. The line starting from the population to population growth with arrow towards the population growth indicates that population level depends on population growth. Fundamental equations that correspond to major state variables shown in Fig. 3 are as follows:

$$\text{horticulture area}(t) = \text{horticulture area}(t - 1) + \text{land transfer rate for hort} \times \Delta t \tag{1}$$

$$\text{tobacco area}(t) = \text{tobacco area}(t - 1) + \text{tobacco area growth rate} \times \Delta t \tag{2}$$

$$\text{population}(t) = \text{population}(t - 1) + \text{population growth rate} \tag{3}$$

The USDA evaluated food security based on the gap between projected domestic food consumption and a consumption requirement [41]. Bala and Hossain [6] developed a quantitative method to compute the food security based on this concept. All food aid commodities are converted into grain equivalent based on economic returns (price). Based on this concept the food security is computed as [6, 7]:

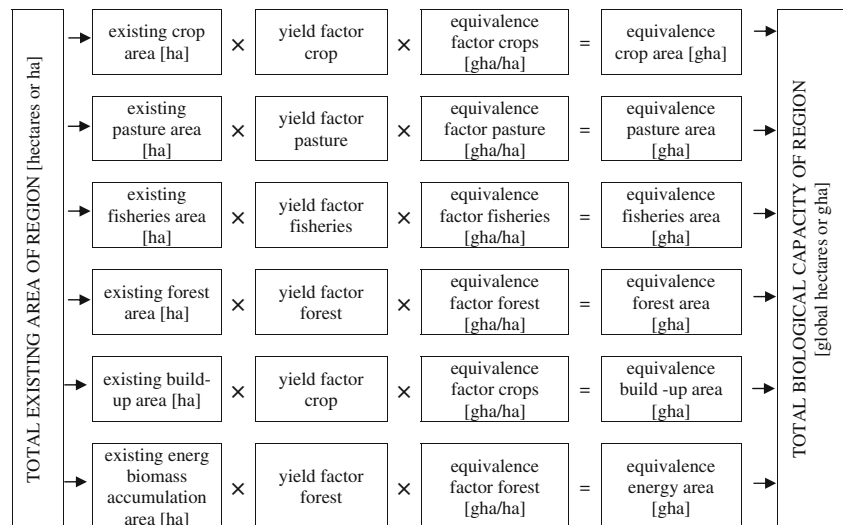
$$\text{Food Security} = \frac{\left(\begin{array}{l} \text{Food available from crops including tobacco} \\ + \text{Food available from aquaculture and equivalent food from income of aquaculture} \\ + \text{Food available from livestock and equivalent food from income of livestock} \\ + \text{Food available from forestry and equivalent food from income of forestry} \end{array} \right) - \text{Total food requirement}}{\text{Total food requirement}} \tag{4}$$

Positive food security means surplus food, and negative food security means shortage in food supply to lead healthy life. The structure of food security computation is shown in Fig. 4.

The ecological footprint calculation is based on the average consumptions data, and these are converted into

uses of productive lands. The bioproductive land is divided into six categories according to the classification of the World Conservation Union: (1) cropland, (2) grazing land, (3) forest, (4) fishing ground, (5) build-up land and (6) energy land.

Fig. 6 Structure of biological capacity computation



Total ecological footprint is the sum of the ecological footprints of all categories of land areas which provide for mutually exclusive demands on the biosphere. Each of these categories represents an area in hectares, which is then multiplied by its equivalence factor to obtain the footprint in global hectares. One global hectare is equal to 1 ha with productivity equal to the average of all the productive hectares of the world. Thus, 1 ha of highly

productive land is equal to more global hectares than 1 ha of less productive land. Thus, ecological footprint can be computed as [33]:

$$\text{Ecological footprint (gha)} = \text{Area (ha)} \times \text{Equivalence factor (gha/ha)} \tag{5}$$

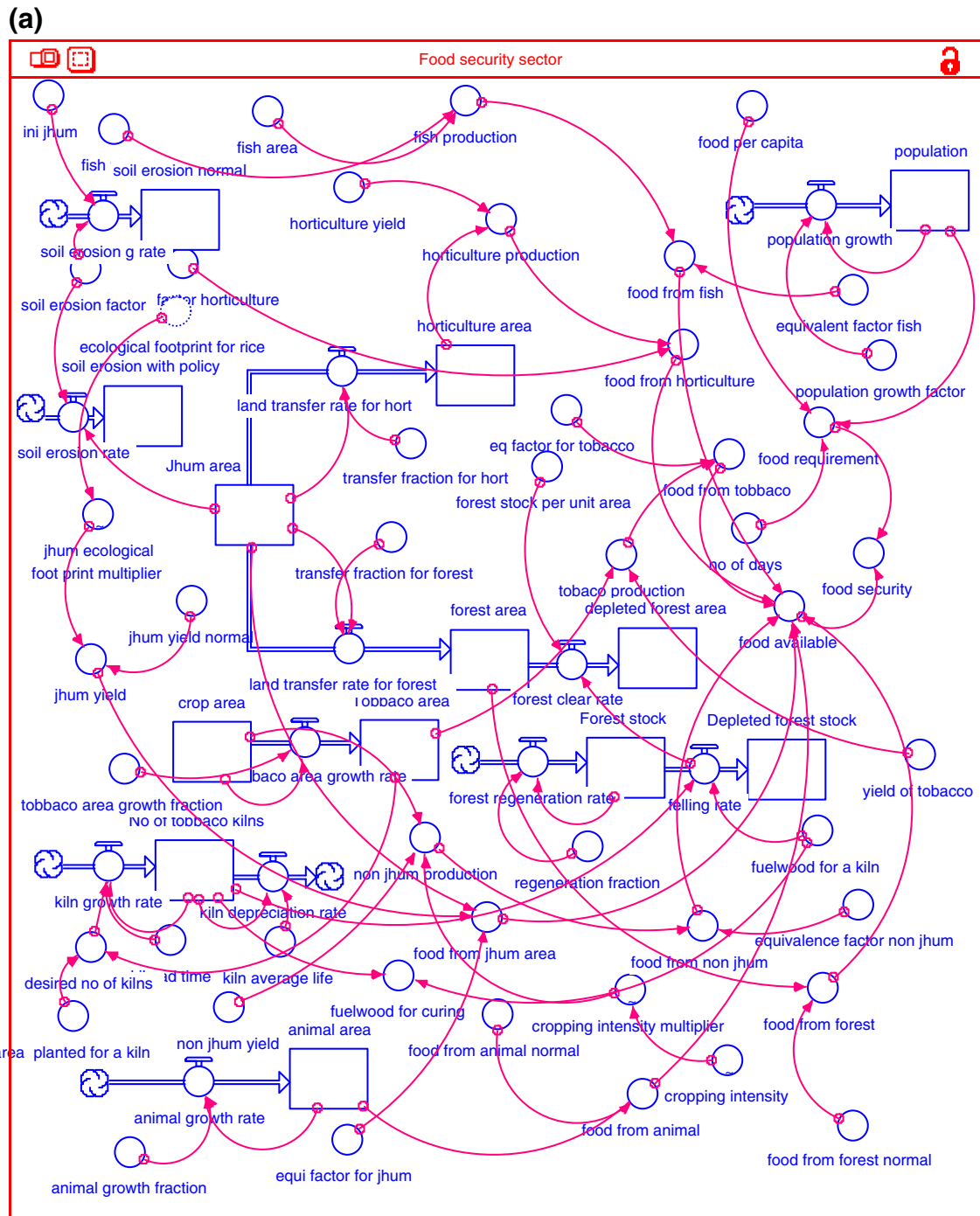


Fig. 7 STELLA flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong

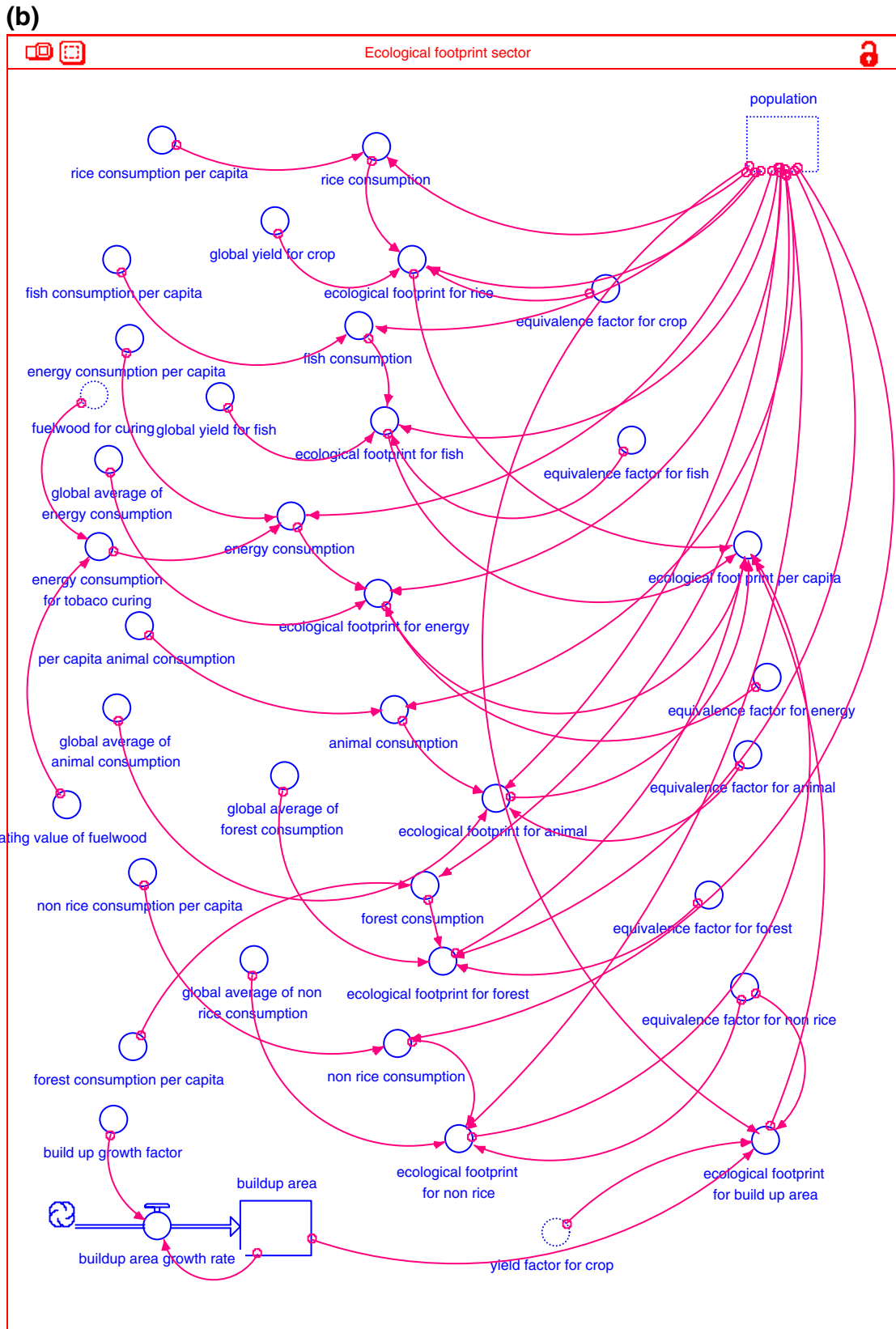


Fig. 7 (continued)

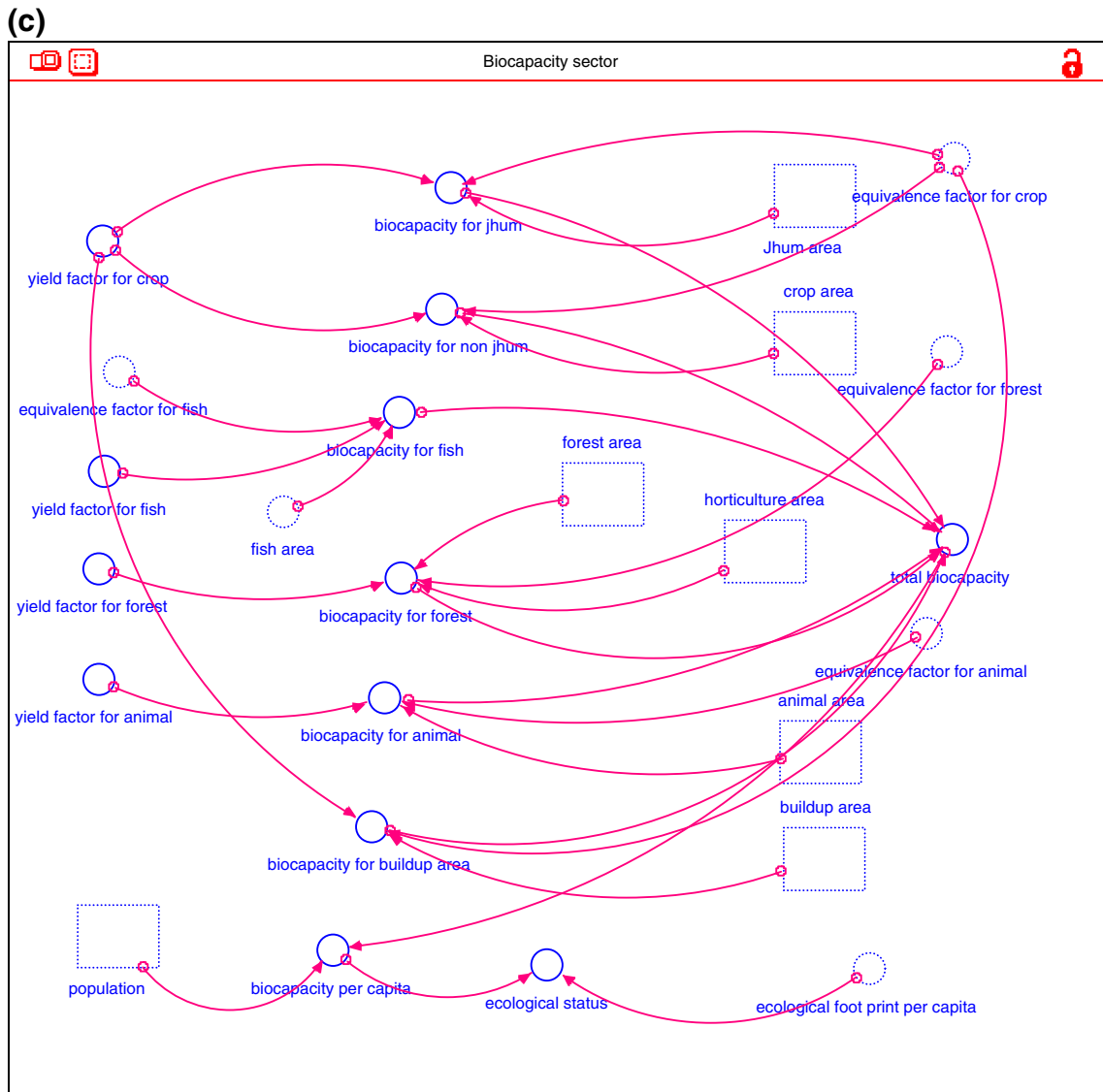


Fig. 7 (continued)

where

Area (ha) = all categories of land areas in hectares
 Equivalence factor = world average productivity of a given bioproductive area/world average potential productivity of all bioproductive areas.

Specially, equivalence factor is the quantity of global hectares contained within an average hectare of cropland, build-up land, forest, pasture or fishery. The structure of the computation of ecological footprint is shown in Fig. 5.

An important part of the ecological footprint analysis of a region or zone is represented by the calculation of its biological capacity (biocapacity) that takes into account the surfaces of ecologically productive land located within the area under study. Biological capacity represents the ecologically productive area that is locally available, and it indicates the local ecosystem’s potential capacity to provide natural resources

and services. Biological capacity is the total annual biological production capacity of a given biologically productive area. Biological capacity can be expressed as [33]:

$$\text{Biocapacity (gha)} = \text{Area (ha)} \times \text{Equivalence factor (gha/ha)} \times \text{Yield factor} \quad (6)$$

where yield factor = local yield/global yield.

Total biocapacity is the sum of all bioproductive areas expressed in global hectares by multiplying its area by the appropriate equivalence factor and the yield factor specific to that country/locality. The structure of the computation of biocapacity is shown in Fig. 6. Biological capacity can be compared with the ecological footprint, which provides an estimation of the ecological resources required by the local population. The ecological status is expressed as the difference between biocapacity and ecological footprint. A

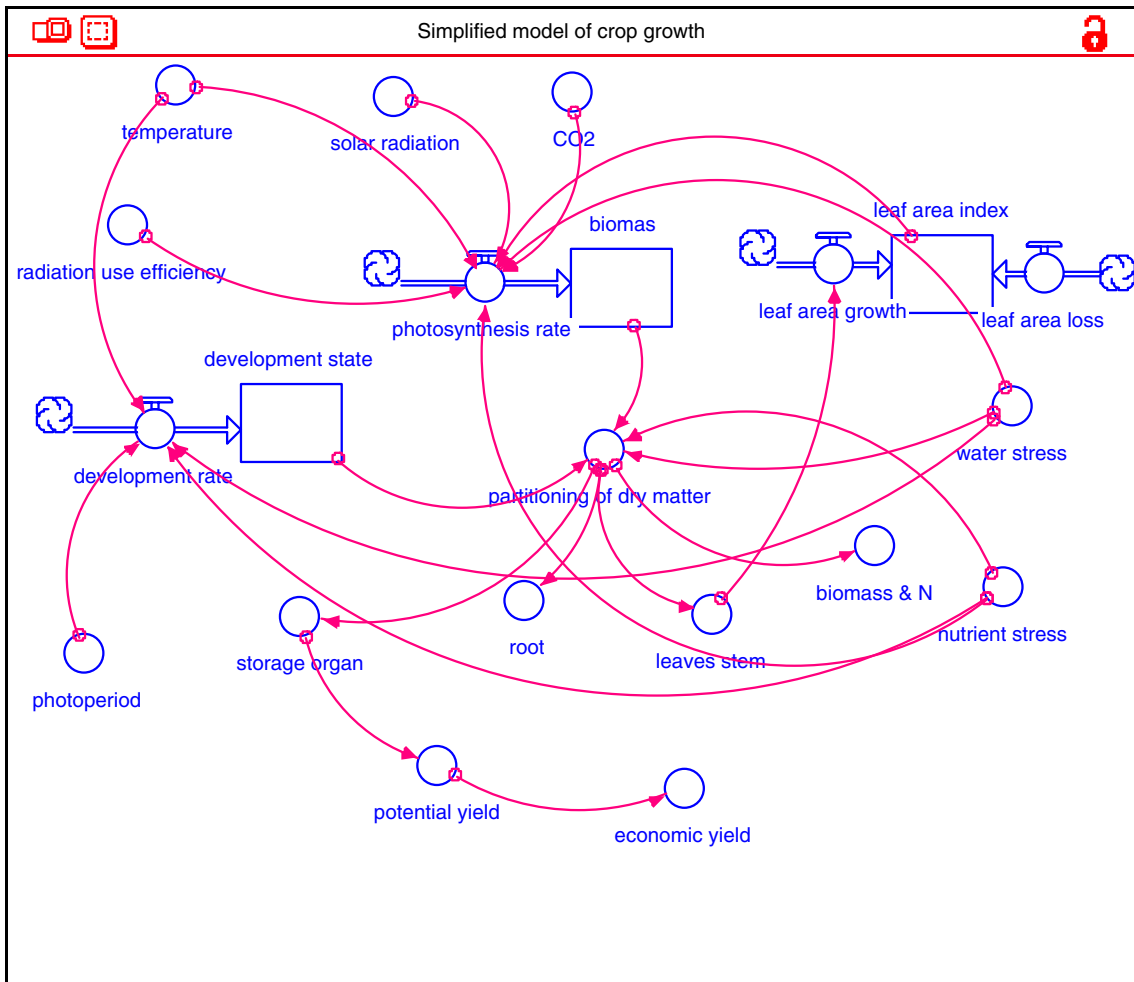


Fig. 8 Crop growth model

negative ecological status ($BC < EF$) indicates that the rate of consumption of natural resources is greater than the rate of production (regeneration) by local ecosystems [37]. Thus,

an ecological deficit ($BC < EF$) or surplus ($BC > EF$) provides an estimation of a local territory's level of environmental sustainability or unsustainability. This also

Fig. 9 Simulated crop, horticulture, jhum, tobacco and depleted forest areas of Bandarban sadar

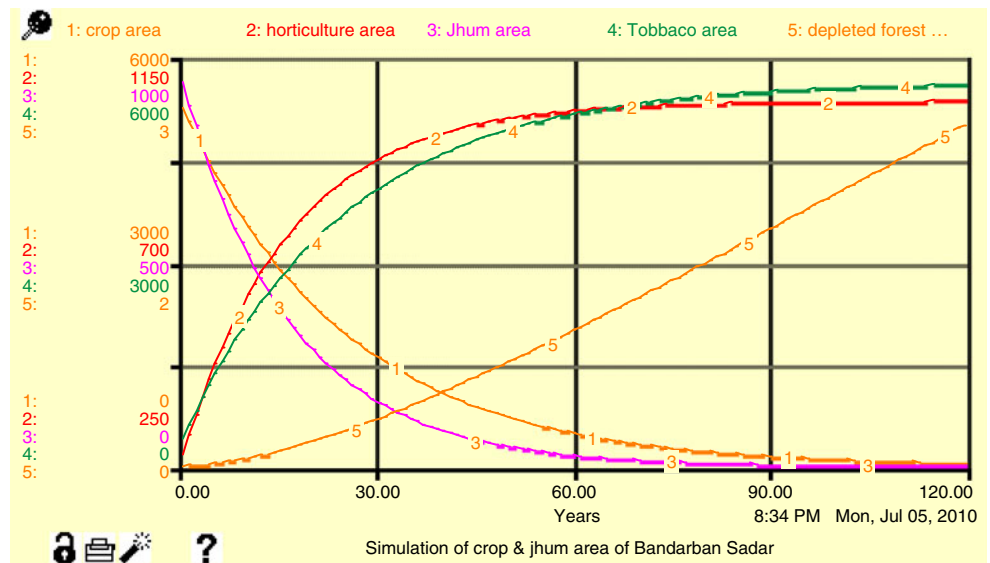
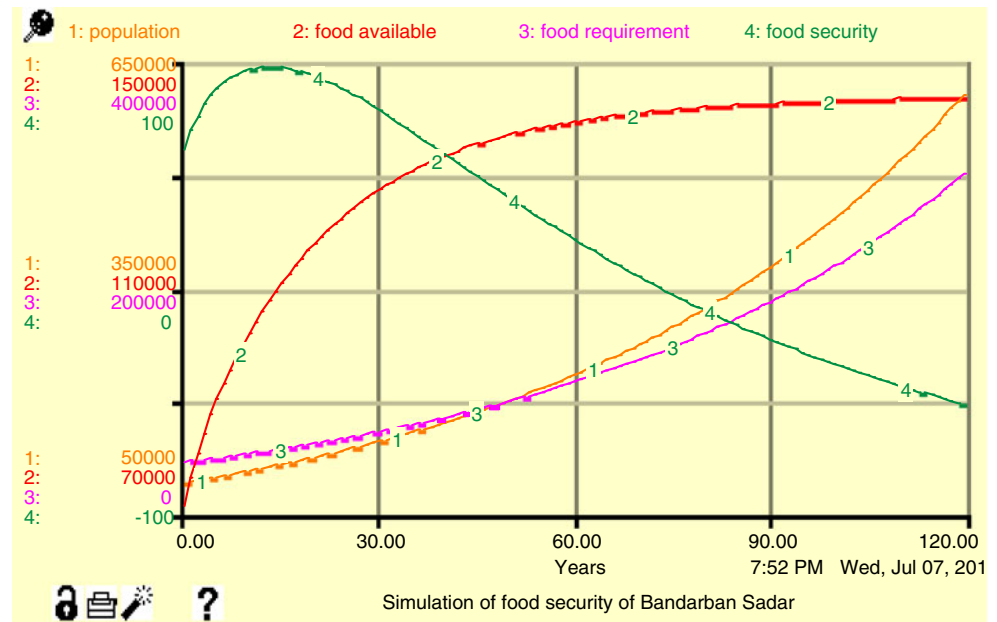


Fig. 10 Simulated population, food available, food requirement and food security of Bandarban sadar upazila



indicates how close to sustainable development the specific area is.

The STELLA flow diagram of the detailed integrated and dynamic model is shown in Fig. 7. Since soil erosion and loss of biodiversity are the major causes of environmental degradation in CHT and the population density is also low (100 persons/km²), it is assumed in this model that environmental degradation does not affect population growth. This model is essentially a detailed mathematical description of the system, and it is a system of finite-difference integral equations. This system of equations is solved using the Runge–Kutta 4th order method.

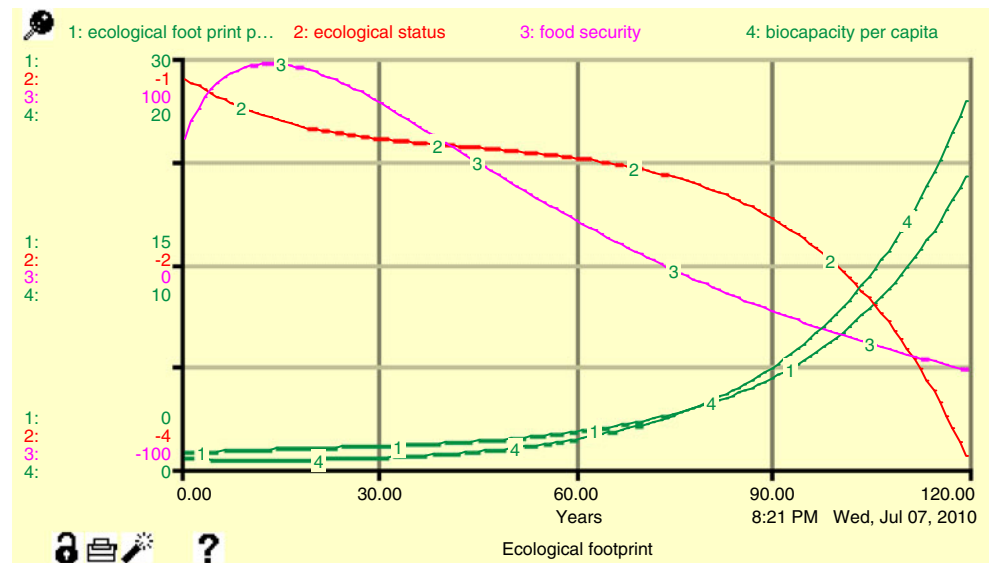
In this study three policy options are considered: (i) gradual transfer of crop (rice) area into tobacco area and *jhum* area into

horticultural area, (ii) gradual transfer of *jhum* area into horticultural area and (iii) rice plus *jhum* area. The climate change impacts on food security are assessed incorporating the changes in yields of rice and maize due to the climate change scenarios of the historical trend and IPCC predictions, and the yield changes due to climate change are computed from the crop growth model discussed in the next section.

2.4 Climate Change Impacts

Computation of climate change impacts on crop yields is based on the crop growth model InfoCrop developed by Aggarwal et al. [1, 2]. Computation of canopy photosynthesis from the incoming photosynthetically active radiation forms the central

Fig. 11 Simulated ecological footprint, ecological status, food security and biocapacity per capita in the Bandarban sadar upazila



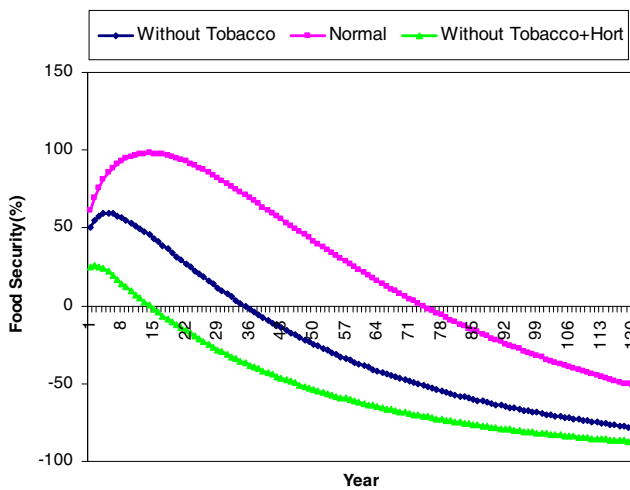


Fig. 12 Simulated food security for different scenarios of land use patterns

part of the crop growth simulation models. The crop development and growth processes and their relationships for the crop growth model InfoCrop are shown in Fig. 8, and these development and growth processes are dry matter production, dry matter partitioning, leaf area growth and phenology.

The growth rate of the crop is calculated as a function of radiation use efficiency, photosynthetically active radiation, total leaf area index and a crop/cultivar specific extinction coefficient. The growth rate of the crop is calculated as follows:

$$GCROP = RUE * PAR * (1 - EXP(-KDF * LAI)) \quad (7)$$

where

- GCROP = net crop growth rate
- RUE = radiation use efficiency
- PAR = photosynthetically active radiation
- KDF = extinction coefficient
- LAI = leaf area index

Fig. 13 Simulated environmental loading for different scenarios of land use patterns

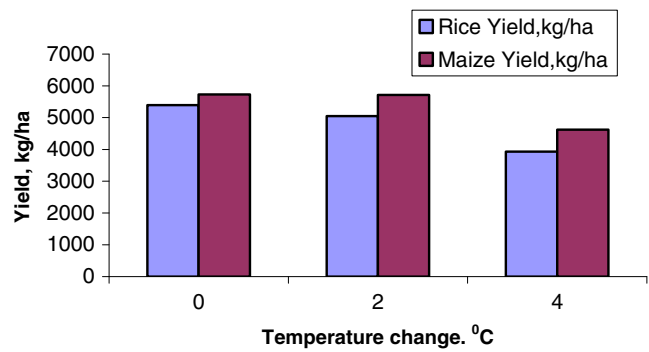
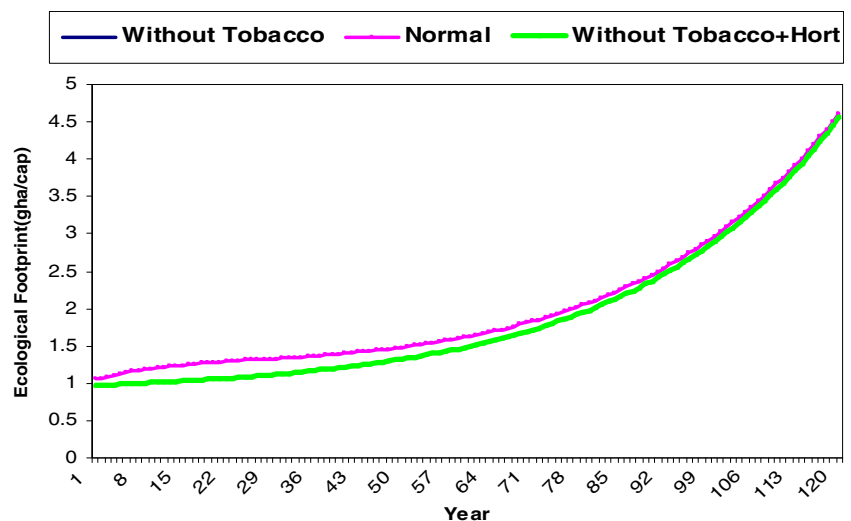


Fig. 14 Changes in the yields of rice and maize for changes in temperatures

The net dry matter available each day for crop growth is partitioned into roots, leaves, stems and storage organs as a crop-specific function of development stage. Allocation is made first to roots, which gets increased in case the crop experiences water or nitrogen stress. The remaining dry matter is allocated to the above ground shoot from which a fraction was allocated to leaves and stems. The balance dry matter is automatically allocated to the storage organs. Allocation to leaves is computed as:

$$RWLVG = GCROP * FSH * FLV - (DLV) \quad (8)$$

where

- RWLVG = net growth rates of leave
- GCROP = net crop growth rate
- FSH = fraction allocated to shoots
- FLV = fraction allocated to leaves
- DLV = dead leaves

Similar procedure is adopted for stems and roots.

The leaf area growth is calculated based on initial leaf area index and its growth rate. The leaf growth rate is estimated

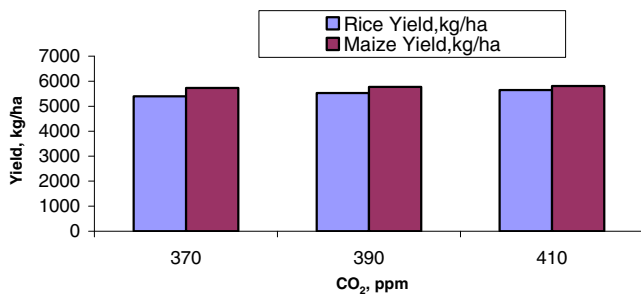


Fig. 15 Changes in the yields of rice and maize for changes in CO₂ concentrations

multiplying the increment in leaf weight by the specific leaf area. Net effective leaf area for photosynthesis and transpiration is the sum of the leaf areas and non-lamina green area after subtracting all losses due to senescence. The net growth rate of leaf area index is calculated as follows:

$$RLAI = LAII + GLAI - DLAI \tag{9}$$

where

- RLAI = net leaf area growth rate
- LAII = initial leaf area index
- GLAI = leaf area growth rate
- DLAI = death rate of leaf area index

Modeling of the development rate is still largely descriptive, and the total development of a crop is quantified on the basis of development stages (DS), a dimensionless variable having a value of 0 at sowing, 0.1 at seedling emergence, 1.0 at flowering and 2.0 at maturity [25]. This was calculated by integrating the temperature-driven development rates of the phases from sowing to seedling emergence, seedling emergence to anthesis, and storage organ filling phases. The rate of crop development is accelerated depending upon the crop/intensity of stress.

$$DRV = HUVG * DAYLC / TTVG \tag{10}$$

where

- DRV = rate of development during vegetative phase
- HUVG = thermal time of the day
- DAYLC = correction factor for the photoperiod-dependent thermal time
- TTVG = thermal time required for entire phase

Table 2 Treatments for climate change impacts on rice and maize

Treatment No.	Temperature change (°C)		CO ₂ change ^a	Rainfall change (%)	Rice yield (kg/ha)	Maize yield (kg/ha)
	Maximum	Minimum				
1	0	0	0	0	5259.60	5692.40
2	2	2	50	20	5191.80	5759.20
3	2	2	100	30	5543.90	5869.50

^a Reference CO₂ level is 340 ppm

Further details are given in Bala et al. [12].

Crop growth model is used to simulate the crop production for climate change conditions. Radiation use efficiency changes for the changes in temperature and CO₂ levels as a result of climate change, and these changes have been incorporated in this crop model to assess the climate change impacts on crop production.

3 Results and Discussion

Initial values and the parameters were estimated from the primary and secondary data. The sensitivity of the important parameters was also estimated. To build up confidence in the predictions of the model, various ways of validating a model such as comparing the model predictions with historic data, checking whether the model generates plausible behaviour and checking the quality of the parameter values were considered. The validated model was used for baseline scenario and policy analysis.

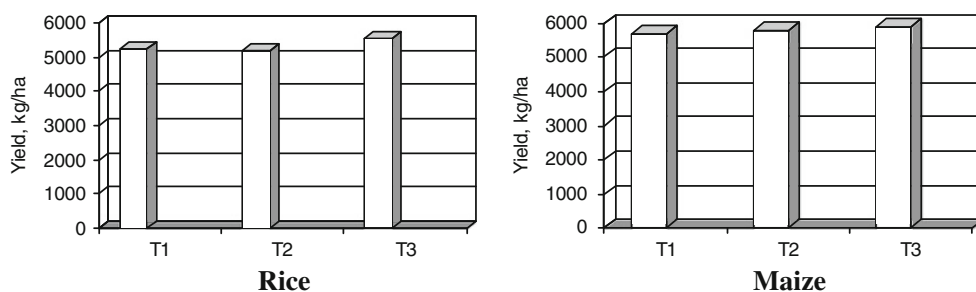
3.1 Simulated Scenarios

An integrated and dynamic model was developed to predict food security and environmental loading for gradual transmission of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation. The simulated results for Bandarban sadar upazila are presented here.

Figure 9 shows the simulated crop area and tobacco area, and *jhum* area and horticultural crop area and depleted forest area. Cropped area is converted into tobacco area at the rate of 1.7 % while *jhum* area is converted into horticultural crop area at the rate of 0.035 %. Simulated results show that the conversion of crop area into tobacco area and *jhum* area into horticultural crop area causes the crop area to be fully converted into tobacco within 110 years while *jhum* area into horticultural crops area within 95 years. This policy of tobacco cultivation causes a total depletion of forest of 12 million tons within 150 years, and this option may lead to total depletion of the forest in the Hill Tracts of Chittagong.

Figure 10 shows simulated population, food available, food requirement and food security in the Bandarban sadar

Fig. 16 Climate change impacts on the yields of rice and maize for different treatments



upazila. Simulated results show that population increases from 90,443 in 2010 to 124,538 in 2130. As a result the food requirement also increases and follows the pattern of population growth. The food availability increases till 95 years and then becomes constant due to the fact that cropped area under different crops reaches the maximum limit. Since crop production becomes stagnant and the population increases, this results in a decrease in food security. Thus, sustainable food security demands population control.

Figure 11 shows the simulated ecological footprint, ecological status, food security and biocapacity per capita in the Bandarban sadar upazila. Simulated results show that ecological footprint initially increases slowly until 60 years, and thereafter it increases exponentially with time and the biocapacity follows the similar pattern. Since ecological footprint is higher than biocapacity, ecological status is negative and it becomes much prominent after 60 years. Food security increases up to 15 years, and then it decreases to zero within 71 years.

Figure 12 shows the simulated food security for (i) crop, tobacco and horticulture (normal), (ii) rice and horticulture (without tobacco) and (iii) rice and *jhum* only (without tobacco and horticulture). Simulated results show that in all the cases the food security decreases in a similar pattern with time, but there is only difference in the time when the food security reduces to zero. It is after 71 years in case of rice, tobacco and horticulture cultivation; after 36 years in case of rice and horticulture and after 15 years in case of crop. Hence, rice, tobacco and horticulture production is the best policy for food security followed by rice and horticulture.

Table 3 Historical and IPCC data for climate change

Year	Historical data		IPCC data	CO ₂ (ppm)
	Maximum temperature increase (°C)	Minimum temperature increase (°C)	Average temperature increase (°C)	
2020	0.3	0.3	0.67	409
2030	0.5	0.5	1.09	428
2040	0.7	0.7	1.51	447
2050	0.9	0.9	1.93	466

Figure 13 shows the simulated ecological footprint for (i) rice, tobacco and horticulture (normal), (ii) rice and horticulture (without tobacco) and (iii) rice only (without tobacco and horticulture). Simulated results show that in all the cases the ecological footprint i.e. environmental degradation increases initially slowly and after 70 years it increases rapidly, but during the early periods, environmental degradation under rice, tobacco and horticulture is dominant followed by rice only. Thus, any policy without tobacco is the best policy in terms of reduction of environmental degradation.

3.2 Climate Change

In general, historical weather data at least of 30 years are preferred to represent annual weather variability. Different climate change scenarios can then be assessed using these data records. The simplest approach is to assume a fixed climate change and to modify the data with a constant number, such as an increase or decrease of 1, 2, 3 °C etc. for temperature. Similarly, CO₂ can be changed with a certain percentage, such as an increase or decrease of 10, 20, 30 % etc. These changes are then applied to the crop simulation models.

The model was simulated to assess the effects of temperature change of 2 and 4 °C for rice and maize, and the simulated results are shown in Fig. 14. The model was also simulated to determine the effects of CO₂ changes of 370, 390 and 410 ppm on the yields of rice and maize, and the simulated

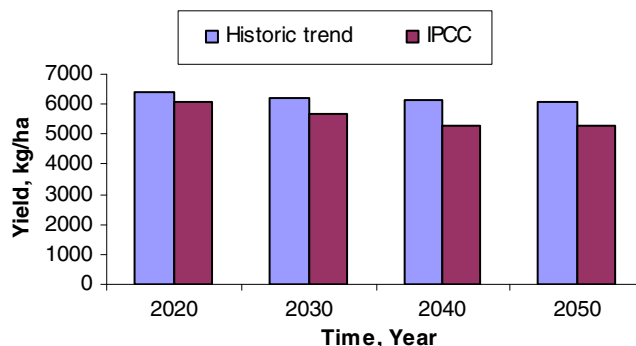
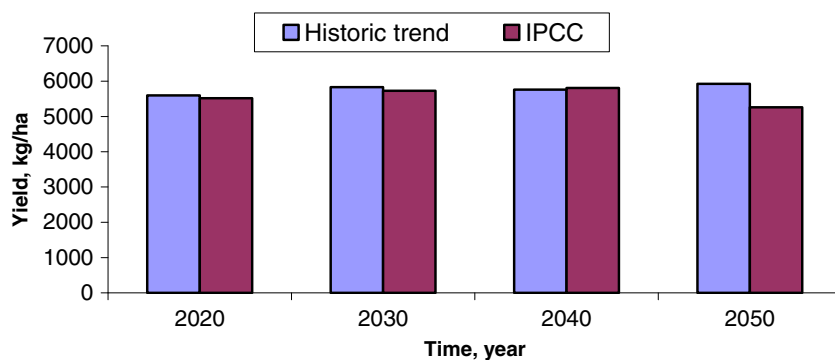


Fig. 17 Changes in the yields of rice for historical and IPCC climate scenarios

Fig. 18 Changes in the yields of maize for historical and IPCC climate scenarios



results are shown in Fig. 15. The simulated results show that the increases in the temperature and CO₂ concentration have negative and positive impacts, respectively, on the yields of rice and maize. However, the impacts of temperature changes are more dominant than that of CO₂ concentration.

The model was simulated to predict the yields of rice and maize for climate change scenarios of temperature, rainfall and CO₂ concentration. Treatments of climate change and their impacts on the yields of rice and maize are shown in Table 2. Figure 16 shows the climate change impacts on the yields of rice and maize for the three different treatments of climate change. The simulated results show that the yield of rice decreases for treatment 2, but it increases for treatment 3. This might be due to the fact that for +2 °C of temperature change and +50 ppm of CO₂ change, the effect of temperature is dominant and negative while for +2 °C of temperature change and +100 ppm of CO₂ change, the effect of CO₂ is dominant and positive i.e. the effect of elevated CO₂ and increased rainfall makes up for the negative effect on the rice yield due to temperature rise. The yield of maize increases for treatments 2 and 3. This might be due to the fact that maize is a C₄ plant and in C₄ plant the effect of CO₂ reduces the severity of the warmer air temperature.

Historical and IPCC trends of the temperature and CO₂ changes are shown in Table 3. The simulated climate change impacts on the yields of rice and maize for historical and IPCC trends of the temperature and CO₂ changes for a

period of 2020–2050 are shown in Figs. 17 and 18, respectively. The simulated results in Figs. 17 and 18 show that there is almost no change in the yields of rice and maize for the historical climate change scenario, but there is a small decrease in the yields of rice and maize for IPCC climate change scenario. More recently Rosenzweig et al. [39] reported preliminary outlook for effects of climate change on Bangladeshi rice. This study shows that aus rice crop is not strongly affected and aman rice crop simulations project a highly consistent production increase.

The simulated climate change impacts on food security of the population of the Hill Tracts of Chittagong for historical and IPCC trends of the temperature and CO₂ changes for a period of 2020–2050 are shown in Figs. 19 and 20, respectively. The simulated results of climate change impacts on food security for historical and IPCC trends of the temperature and CO₂ changes for a period of 2020–2050 show that there are almost no changes in food security at upazila level for the historical climate change scenario, but there is small change in the food security at upazila level for IPCC climate change scenario.

4 Policy Implications

An integrated and dynamic model is developed to predict food security and environmental loading for gradual transmission

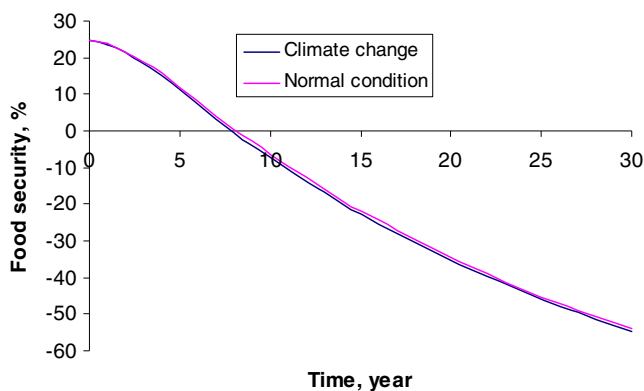


Fig. 19 Changes in food security for historical climate scenario

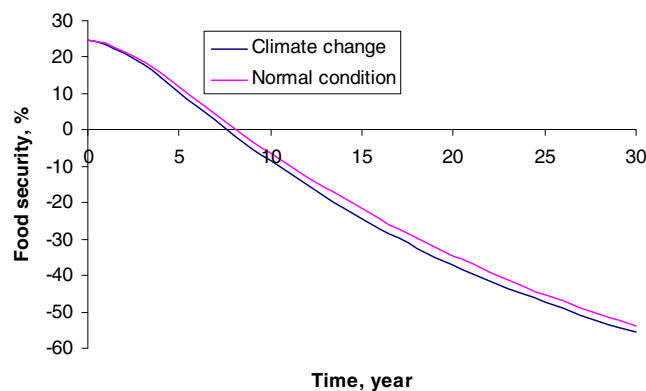


Fig. 20 Changes in food security for IPCC climate scenario

of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation using systems approach. Computer models to predict the climate change impacts on rice and maize production in the upland of Hill Tracts of Chittagong have also been developed. Our findings suggest the following overall policy implications:

- Findings of the simulated studies suggest that fruit trees with other horticultural crops to control soil erosion and landslides, and banning of tobacco cultivation to avoid deforestation need promotion of environmentally sustainable and economically viable agricultural systems.
- Our findings show that climate change has little positive impacts on rice and maize production in the uplands of the Hill Tracts of Chittagong. Adaptation of the crops to changed climatic conditions for increased yields needs promotion.
- Further study using a multi-agent system model with participatory approach for different policy interventions and management strategies at household levels for sustainable development is desirable.

5 Conclusions

An integrated and dynamic model has been developed to predict food security and environmental loading for gradual transition of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation. Food security status for gradual transition of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation is the best option for the food security, but this causes the highest environmental loading resulting from tobacco cultivation. Considering both food security and environmental degradation in terms of ecological footprint, the best option is gradual transition of *jhum* land into horticulture crops which provides a moderate increase in the food security with a relatively lower environmental degradation in terms of ecological footprint.

Crop growth model InfoCrop was used to predict the climate change impacts on rice and maize production in the upland of Hill Tracts of Chittagong. There are almost no changes in food security at upazila level for the historical climate change scenario, but there is small change in the food security at upazila levels for IPCC climate change scenario.

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