MODELING OF CLIMATE CHANGE IMPACTS ON AGRICULTURE, FORESTRY AND FISHERY

B. K. Bala*, M. A. Munnaf**, F. Y. Ruma*** and M. S. Alam****

ABSTRACT

Changes in climate affect agriculture, forest and fisheries. This paper examines the climate change impacts on crop production, fishery and forestry using state-of-the-art modeling technique. Crop growth model InfoCrop was used to predict the climate change impacts on the yields of rice, wheat and maize in Bangladesh. Historical climate change scenario has little or no negative impacts on rice and wheat yields in Mymensingh and Dinajpur but IPCC climate change scenario has higher negative impacts. There is almost no change in the yields of rice and maize for the historical climate change scenario in the Chittagong, Hill Tracts of but there is a small decrease in the yields of rice and maize for IPCC climate change scenario. A new statistical model to forecast climate change impacts on fishery in the world oceans has been developed. Total climate change impact on fishery in the Indian Ocean is negative and the predictor power is 94.14 % for eastern part and 98.59 % for the western part. Two models are presented for the mangrove forests of the Sundarbans. Total bole volumes of the pioneer, intermediate and climax are simulated for three different logging strategies and the results have been discussed in this paper.

Keywords: *Climate Change, Crop Production, Forestry, Fishery, Modeling, Simulation, Adaptation, Management Strategies.*

1. INTRODUCTION

Many studies have been reported on modeling of forest growth, management strategies and climate change (Bossel, 1991; Bossel and Kreiger, 1991; Huth and Ditzer, 2000; Ito and Oikawa, 2002; Phillips, et al., 2003; Masera, et al., 2003; Wallman et al., 2004; Köhler and Huth, 2004; Tietjen and Huth, 2006; Fyllas et al., 2007 and Drouet and Pages, 2007). Bala, et al., (2003, 2004 & 2008) adopted the process based cohort model of Kohler (2000) and Kohler and Huth (1998) to simulate the mangrove forest growth of the Sundarbans and also applied the aggregate model CO2FIX (Masera, et al., 2003).

2. MODELING AND SIMULATION

2.1 Modeling of Climate Change Impacts on Crop Growth

Computation of climate change impacts on crop yields are based on the crop growth model, InfoCrop, developed by Aggarwal, et al. (2006 a & b). Computation of canopy photosynthesis from the incoming photosynthetically active radiation forms the central part of the crop-growth simulation models. The crop development and growth processes and their relationships with the crop growth model, InfoCrop, are shown in Figure-1, where light and temperature are the independent variables, and photosynthetic parameters are constants. Rectangles represent quantities (state variables), valve symbols indicate flows (rate variables), circles are auxiliary variables (converters), full lines are flows of material, and dashed lines are flow of information. 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:

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

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

Under favorable growth conditions, light, temperature, and the crop characteristics for phenological, morphological, and physiological processes are the main factors determining the growth rate of the crop on a specific day. 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 increase 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. The model follows a daily calculation scheme for the rates of dry matter production of the plant organs, the rate of leaf area development, and the rate of phenological development (growth stages). By integrating these rates over time, dry-matter production of the crop is simulated throughout the crop growing season and the yield of the crop is computed. Radiation use efficiency changes for the changes in temperature and CO_2 concentrations in the atmosphere as a result of climate

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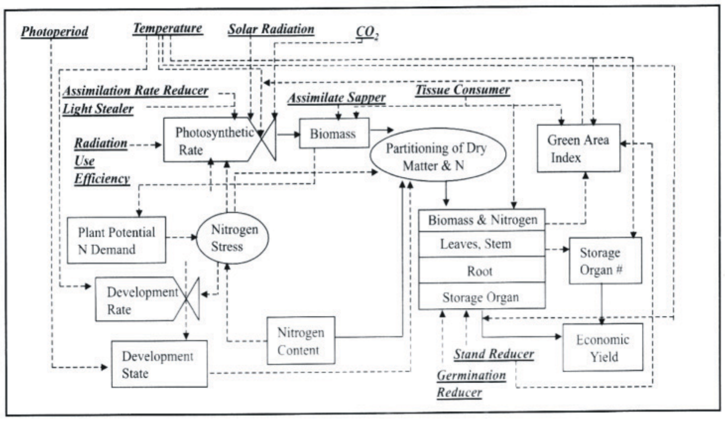

Figure - 1: Simple representation of crop growth model

change and these changes are incorporated in the crop growth model to compute the climate change impacts on crop productions.

2.2 Modeling of Climate Change Impacts on Fishery in the Oceans

Several studies reported that fishing in the oceans is affected by surface water temperature. Greenhouse and other effects contribute to global warming and the global warming in turn affects the fish catches. A knowledge of the impact of the temperature on fish catches in world fishery is essential for sustainable management of the world fishery resources, and a new method for prediction of climate change impact in the world oceans is described as follows.

Two categories of data were analyzed and processed to assess the dynamics of spatial temperature distribution and fish catches for the oceans of the fishery resources. The predictor is a rule, in accordance with which the dynamics of fish catch w(t) for the future, i.e. for new values of m1,...,m4 (moments of a future temperature distribution) can be predicted. Assuming that the values of w(t) (both for previous years and for future) can be presented in the form:

$$w(t) = \sum_{k=1}^{4} \alpha_k m_k(t), t = 1,...,n \tag{2}$$

With n=32>>4, system can be considered as an over-determined linear algebraic system with respect to α_k which can be solved by the Gauss method (the method of least squares (Hoel, 1966).

Now assuming that the solution of Equation (2) is: {α_k; k=1,2,3,4}. It is obvious that :

$$u(t) = \sum_{k=1}^{4} \alpha_k^* m_k(t) \neq w(t), t = 1,...,n \tag{3}$$

Where u(t) is the relative deviation of predicted total fish catch.

Finally, the decision rule with the predictor s power is that:

> if u(j) > 0, then the fish catch would be higher than the amount predicted by the curve of the mean growth (climate change has a positive influence); this statement is true with probability P^+;
> If u(j) < 0, then the fish catch would be lower than predicted by the curve of the mean growth (FF has a negative influence); this statement is true with probability P^-.

The details of the construction of the predictor and predictor power are given by Biswas, et al. (2005).

2.3 Modeling of Mangrove Forest

The tree geometry and canopy development of mangrove forests are not well defined and are highly variable. Based on critical reviews on previous efforts on modeling and search for a simple but realistic model, two approaches of modeling of the mangrove forests are considered and these are aggregate modeling and individual based growth modeling. The aggregate model consists of three successional tree species of Keora (Sonneratia apetala), Gewa (Excoecaria agallocha) and Sundari (Heritiera fomes). The individual based growth curve model proposed by Chen and Twilley (1998) is adapted for modeling of the

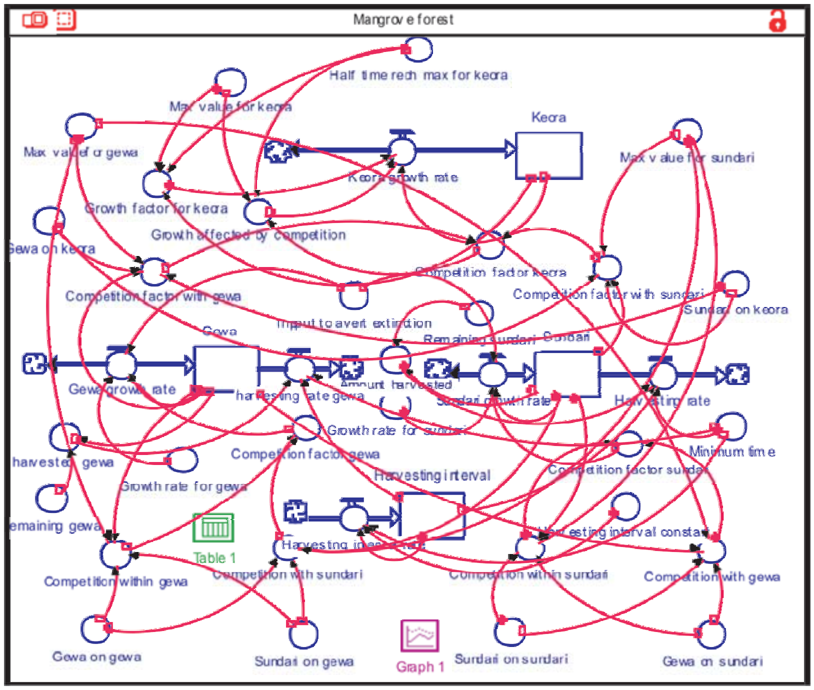

Figure-2: STELLA Flow Diagram for Forest Growth Model with Logging Operations

mangrove forests of the Sundarbans incorporating the salinity multiplier, temperature multiplier, and dominance effect or basal area multiplier. The aggregate model is based on a system of three coupled equations, which describe the stem volume changes of the three successional groups of Keora, Gewa and Sundari for every time step. The model in STELLA flow diagram is shown in Figure-2 and these equations are solved using Runge Kutta method of order 4.

There are few individual based ecological simulation models describing the structural and functional characteristics of mangrove forests. The FORMAN model based modifications of the JABOWA and FORET models (Shugart, 1984; Botkin, 1993) was developed to simulate demographic processes of mangroves in a 0.05 ha plot. This model is adapted for mangrove forest of the Sundarbans and the growth equation of the mangrove forest is as follows:

$$\frac{dD}{dt} = \frac{GD(1 - DH / D_{\max} H_{\max})}{(274 + 3b_2 D - 4b_3 D^2)} \times A \qquad (4)$$

Where A= $(SALT) * N(NUT) * T(DEGD) * D(BA)$
and
D = Diameter at breast height, m;
H = height, m;
t = Time, year;
G, b_2 and b_3 are constants.

Furthermore, the height of the tree is related to the diameter at breadth height as follows:

$$H = 197 + b_2 D - b_3 D^2 \qquad (5)$$

The SIMILE flow diagram of the individual based growth curve model is shown in Figure-3.

3. RESULTS AND DISCUSSIONS

3.1 Climate Change Impacts on Rice, Wheat and Maize Production

As the global warming continues, the weather parameters are also changing in conjuncture, gradually creating a new unacquainted ambient environment for the field crops. What will be the yield, duration and spatial dispersion of the field crops in the changing scenarios of climate change, are the burning issue to the global intellectual community.

The simulated climate change impacts on the yields of rice and wheat in Mymensingh and Dinajpur for historical and IPCC trends of the temperature and CO_2 changes for a period of 2020-2050 are shown in

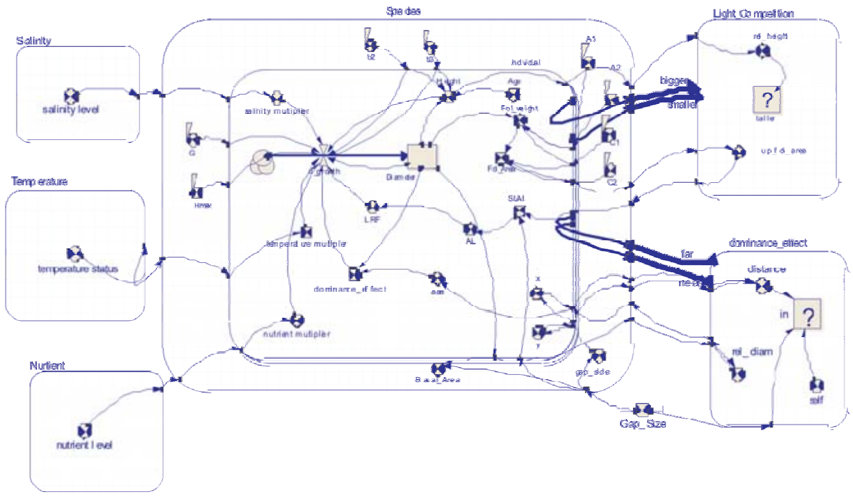

Figure-3: SIMILE Flow Diagram of the Mangrove Forest

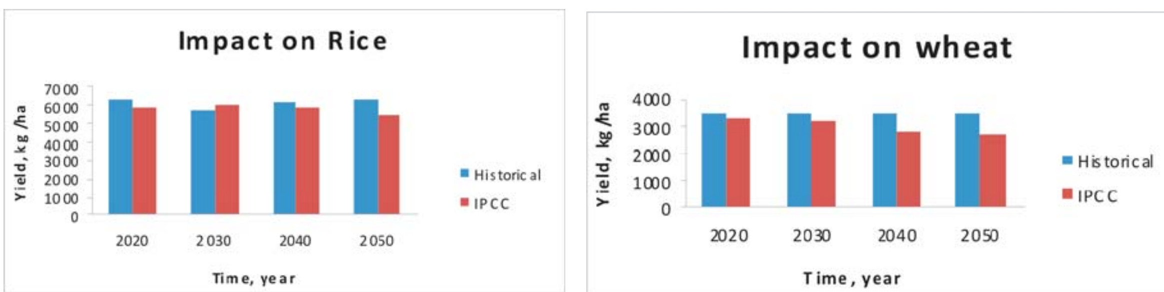

Figure-4(a): Changes in the Yields of Rice & Wheat for Historical & IPCC Climatic Scenarios (Mymensingh)

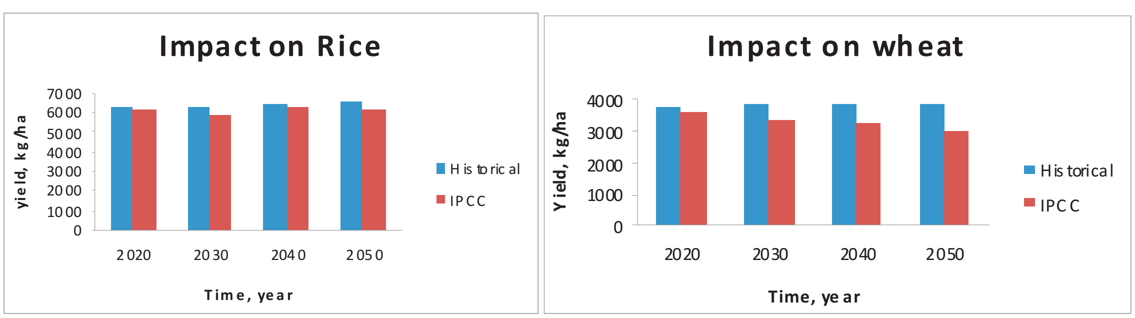

Figure-4(b): Changes in the Yields of Rice & Wheat for Historical and IPCC Climatic Scenarios (Dinajpur)

Figure-4. From the simulation studies, it is clear that there is almost no change in the yields of rice and wheat for the historical climate change scenario, but there is small decrease in the yields of rice for IPCC climate change scenario. Rice yield decreases from 5,780.9 kg/ha to 5,449.3 kg/ha and from 6,222.1 kg/ha to 6,110.8 kg/ha in Mymensingh and Dinajpur, respectively, and wheat yield decreases from 3,263.8 kg/ha to 2,648 kg/ha and 3,573.9 kg/ha to 2,933 kg/ha in Mymensingh and Dinajpur, respectively. Climate change impacts are more effective for wheat yields than the rice yields. Rice yields will be more affected by the climate change in Mymensingh in comparison to Dinajpur, while wheat yields will be more affected by climate change in Dinajpur in comparison to Mymensingh. The simulated results in Figure-5 show

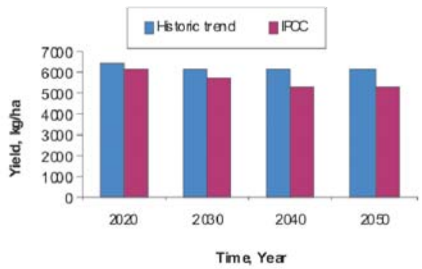

Figure-5(a): Changes in the Yields of Rice for Historical and IPCC Climate Scenarios

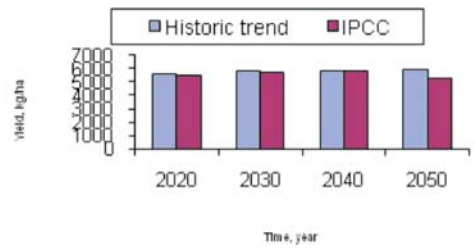

Figure-5(b): Changes in the Yields of Maize for Historical and IPCC Climate Scenarios

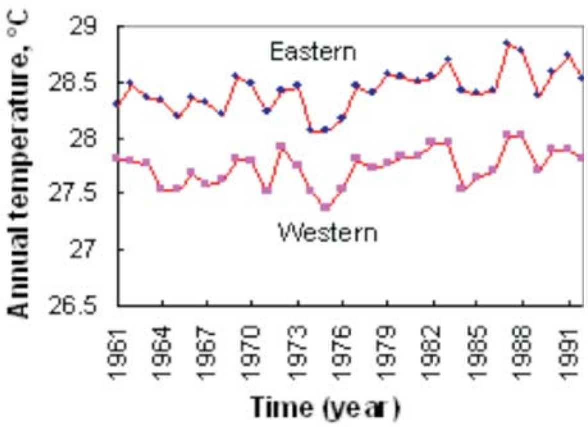

Figure-6(a): Temperature Changes in the Western and Eastern Parts of the Indian Ocean.

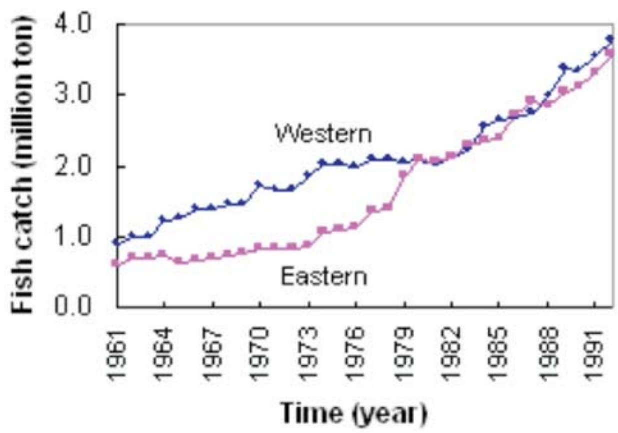

Figure 6(b). Fish Catch in the Western and Eastern Parts of the Indian Ocean.

that there is almost no change in the yields of rice and maize in the Chittagong Hill Tracts for the historical climate change scenario, but there is small decrease in the yields of rice and maize for IPCC climate change scenario. The predicted climate change impacts on rice yields in Bangladesh by different researchers vary considerably and it is as high as 50 %. This might be due to difference in climate change scenario considered and hence climate change scenario predicted by GCM or IPCC should be considered for consistency in the prediction of climate change impacts. More recently, Rosenzweig, et al. (2010) reported preliminary outlook for effects of climate change on Bangladeshi rice, and this study shows that Aus rice crop is not strongly affected and Aman rice crop simulations project highly consistent production increase.

3.2 Climate Change Impacts on Fish Catch In the Oceans

Temperature changes and fish catch in Indian Ocean, from the years 1961-1992, are shown in Figure-6. Based on these data, the dynamics of fish catch w(t) for next time, i.e. for new values of m1,..,m4 (moments of a future temperature distribution), are predicted and the solutions of equation (2) are also obtained for computing the u(t)-values.

The model CLIMBER-2 (CLIMate-BiospheRE model), developed by Petoukhov, et al. (1998) is applied for prediction of the future temperature changes. The future temperature differences of every 10-year interval are taken from the CLIMBER-2 Simulated Sea Surface Temperature Anomalies 2000-2100 for the Indian Ocean and these differences also increase for every interval. From these data, the future average of Indian Ocean are calculated. The predicted temperature and u(t)-values from the years 2000-2100 are shown in Figure-7. Figure-7(b) shows that the u(t)-values for the eastern part of the Indian Ocean decreases with time from positive to negative values, and the u(t) values for the western part of the Indian Ocean also decreases with time (totally negative values). This means that the global climate change will negatively influence fish catch in the Indian Ocean from the year 2005 to 2100 and also the influence of

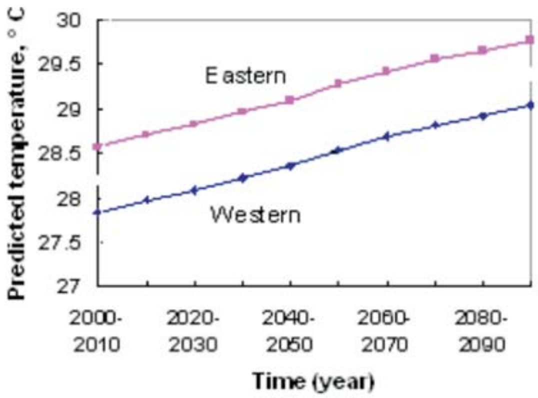

Figure-7(a): Predicted Temperature in the Western and Eastern Parts of the Indian Ocean.

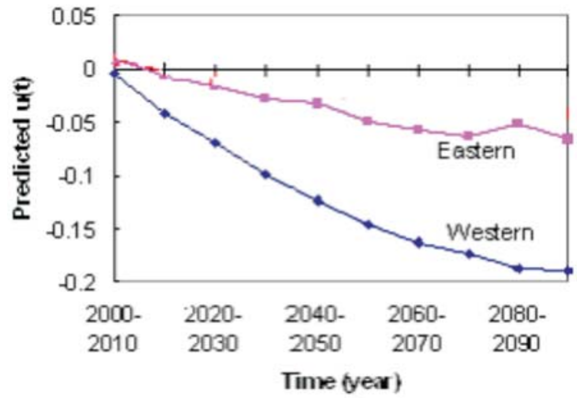

Figure 7(b): Predicted u(t)-values in the Western and Eastern parts of the Whole Indian Ocean.

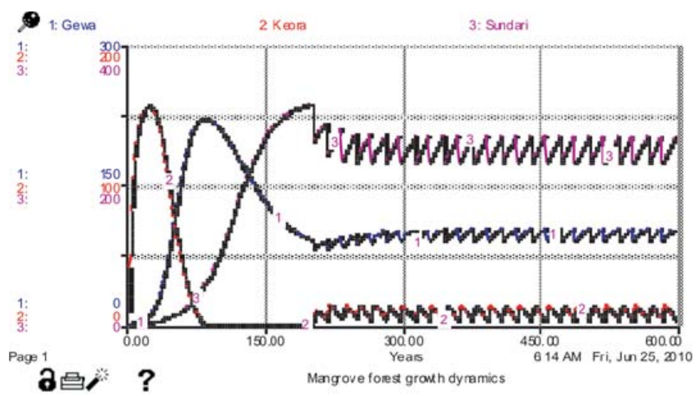

Figure-8: Simulation results For the Development of Volume of Mangrove Forests for 16 Years Logging Cycle.

climate change will be negative for the western part of the Indian Ocean, from the year 2000 to 2005.

Validation of a model is a process by which confidence in the model is to be developed for some particular purpose. In this statistical forecasting model the predictor power is the probability with which the prediction is made. The total climate change impacts on fish catch in the Indian Ocean is negative and the predictor power is 94.14 % for eastern part and 98.59 % for the western part.

3.3 Forest Growth Model

Simulated total bole volumes of pioneer, intermediate and climax tree species for logging cycle of 16 years with time are shown in Figure-8. The first logging is practiced after the forest reached a steady state condition. For the undisturbed forest growth model, the pioneer tree species (Keora) disappears after a certain period due to competition with climax and intermediate tree species, but after a logging operation it reappears. If the logging operation continues at a certain interval, the pioneer species never disappear. The maximum volume of the climax tree species for undisturbed model is 320 m^3/ha but for 16 years logging cycle it cannot reach its maximum volume, rather the volume changes in cyclical manner with a mean volume of 195 m^3/ha, while a maximum volume is 275 m^3/ha.

4. CONCLUSIONS

InfoCrop model based on radiation energy use efficiency in photosynthesis was used to simulate crop growth and to predict climate change impacts on rice, wheat and maize yields. Historical climate change scenario has little or no negative impacts on rice and wheat yields in Mymensingh and Dinajpur, however IPCC climate change scenario has higher negative impacts than historical climate change scenario. IPCC climate change scenario is more negative for wheat yields than rice yield. There is almost no change in the yields of rice and maize for the historical climate change scenario in the Chittagong Hill Tracts, but there is a small decrease in the yields of rice and maize for IPCC climate change scenario. A new method has been applied for prediction of climate change impacts on world fishery. The impacts may be positive or negative depending on the climate scenarios. This model can predict the climate change impacts on fish catch in the different world oceans, at least qualitatively with a probability statement. An individual based gap model using SIMILE has been developed and simulated to address the cutting cycles and further study is underway to refine the model and update data and predict the climate change impacts on mangrove forests for climate change scenarios.

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