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ARTICLES

Ecosystem vulnerability of China under B2 climate scenario in the 21st century

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This paper applies climate change scenarios in China based on the SRES assumptions with the help of RCMs projections by PRECIS (providing regional climates for impacts studies) system introduced to China from the Hadley Centre for Climate Prediction and Research at a high-resolution (50 km×50 km) over China. This research focuses on B2 scenario of SRES. A biogeochemical model "Atmosphere Vegetation Integrated Model (AVIM2)" was applied to simulating ecosystem status in the 21st century. Then vulnerability of ecosystems was assessed based on a set of index of mainly net primary production (NPP) of vegetation. Results show that climate change would affect ecosystem of China severely and there would be a worse trend with the lapse of time. The regions where having vulnerable ecological background would have heavier impacts while some regions with better ecological background would also receive serious impacts. Extreme climate even would bring about worse impact on the ecosystems. Open shrub and desert steppe would be the two most affected types. When the extreme events happen, vulnerable ecosystem would extend to part of defoliate broad-leaved forest, woody grassland and evergreen conifer forest. Climate change would not always be negative. It could be of some benefit to cold region during the near-term. However, in view of mid-term to long-term negative impact on ecosystem vulnerability would be enormously.

climate change, scenario, ecosystem, vulnerability, China

Global warming has emerged clearly, which impacts on natural ecosystems directly or indirectly. The observed evidence shows that climate change has an impact on different natural and biological systems[1], such as glacier retreat[2], permafrost melt[3−5], and extension of growing season in the middle and high latitude regions[6]. The second article of United Nation Framework for Convention on Climate Change (UNFCCC) is that "the ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"[7]. Clarification of interaction between climatic factors and natural ecosystems at different scales to post response of ecosystems to climate change is one of the most important components of global change studies[8−13]. Assessment of vulnerabilities of ecosystem under the future climate scenarios in China is of great significance to the recognition of problems we are facing in the future and to the sustainable socio-economic development in China.

GEOGRAPHY

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Intergovernmental Panel for Climate Change (IPCC) focuses on the impact of climate change processes resulting from human activities, especially on a series of outcomes caused by global warming trend from increasing of greenhouse gases (GHG). In the IPCC 2000 Special Report on Emissions Scenarios (SRES)[14], different scenarios were designed for determining socio-economic development. Each scenario had a corresponding scenario for GHG emission. Of the scenarios, the B2 scenario is in lower emission of GHG, which is close to mid-to-long term development plan of China. This study focuses on vulnerability of ecosystems under the B2 climate scenario.

There has been much relative research in China: future warming would cause northward shift of most temperature zones of China[15]. Over the arid areas, regional differences in aridity/humidity would decrease and mitigate rapid decreasing trend of moisture from the east to the west[16]. When temperature rises by 4℃, arid areas in China would expand by 8.43×10^5 km^2, and humid areas would shrink by 9.59×10^5 km^2[17]. Continuous drought would influence expansion of desertification[16]. Future warming would cause phenological season to start earlier in most parts of China according to the relationship between earlier and later starts of the phenological season temperature up and down in the last 40 years[6,18]. Future climate change would lead to a northward shift of forest belts, especially the area of defoliated conifer forest would decrease substantially and even move out of China[19,20]. Geographical structure of primary productivity of forest would not change much, but forest productivity would increase to different degrees. However, the incidence of forest diseases and insect pests and enlargement of their affected scope as well as frequent occurrence of forest fire due to climate change[21−24] would by no-means results in increase of fixed biomass of forest[21]. Increasing temperature would make a maximum increase above ground biomass of grassland in Inner Mongolia[25]. Under the scenario of 4℃ rise of temperature and 10% variation of annual precipitation, forest area in the southeastern part of the Tibetan Plateau would increase by 6.4%, but the area of temperate montane desert would increase by 12%[26]. Climate change would affect functions of inland wetland via variations of temperature and precipitation. Meanwhile, functions of coastal wetland would be affected by sea level rise[27,28].

This study, based on future climate (B2) scenario SRES of IPCC, focuses on the impact of climate change caused by socio-economic activities on natural ecosystems of China.

1 Data and methodology

1.1 Data

Climate scenario data were from the Climate Research Group of Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences[29,30]. The group introduced PRECIS (Providing Regional Climates for Impacts Studies) system[31] to China from the Hadley Centre for Climate Prediction and Research in 2003 to develop the high-resolution (50 km×50 km) climate change scenarios under SRES[14] over China for the period of 1961—2100[29,30]. The results show that temperature rise would occur in most parts of China compared with baseline period (1961—1990). Under the B2 scenario, mean temperature would rise by 1.16℃, 2.20℃ and 3.20℃, and the precipitation would increase by 3.7%，7.0% and 10.2% during the periods of 2011—2020, 2041—2050 and 2071—2080, respectively[29]. Vegetation was divided into 14 types: evergreen coniferous forest, evergreen broad-leaved forest, defoliated coniferous forest, defoliated broad-leaved forest, coniferous/broad-leaved mixed forest, woody grassland, grassland, alpine meadow, closed shrubland, open shrubland, cropland, crop intermingled natural vegetation, desert steppe, and barren or sparse vegetation[32]. Soil texture was grouped into 12 grades: gravel, sand, coarse sand, fine sand, silty sand, sandy silt, silt, silty clay, silty loam, loam, loamy clay, and clay[33].

1.2 Methodology

Time was sliced according to IPCC definition: baseline period of 1961—1990, near-term of 1991—2020, mid-term of 2021—2050, and long-term of 2051—2080. Each term was discussed according to the average of 30 years.

Status of ecosystems under the future climate scenario was simulated by the biogeochemical model, the Atmosphere Vegetation Integrated Model (AVIM2)[34,35]. The model consists of three sub-models: a) land surface physical process sub-model which describes radiation, moisture and heat exchanges among vegetation, atmosphere and soil; b) physiological sub-model based on vegetation physiological processes, which includes photosynthesis, respiration, and allocation of assimilation; and c) soil organic carbon sub-model which describes the transformation and decomposition of soil organic carbon.

While the climate, vegetation and soil variables were inputted into the physical process sub-model, canopy temperature and moisture were outputted to the plant growth module, and then the vegetation began to grow. The morphological characters of vegetation would be changed in the process of growth, and then the leaf area index (LAI) would feed back to the physical process sub-model. The soil temperature and moisture outputted from the physical process sub-model as well as the litter fall outputted from physiological sub-model were inputted into the soil organic carbon sub-model, and then the heterotrophic respirations were calculated. The net ecosystem productivity (NEP) would be given by using net primary productivity (NPP, $gC/m^2 \cdot a$) from physiological sub-model minus the heterotrophic respiration from soil organic carbon sub-model. The three sub-models are fully coupled in AVIM2. The changes in climatic variations in AVIM2 will influence both soil condition and vegetation growth. Meanwhile the changes of soil condition have effects on both vegetation growth and transformation and decomposition of soil organic carbon. The time steps of input data for physical sub-model are every 30 min, and those for vegetation physiological and soil organic carbon sub-model are every one hour and one day, respectively. Previously, AVIM was used to simulate the exchanges of carbon in various ecosystems, such as semi-arid grassland in Inner Mongolia[35,36], forests in Changbai Mountains[33], and crops in North China[37], and the results of all these approaches were satisfactory. AVIM has also been applied to simulating NPP in regional scale as in Tibetan Plateau[38−40] and in global scale[41] as well. The simulated NPP generally agreed well with the observation result.

In terms of assessing vulnerability of ecosystems to climate change, threshold of impact of climate change on ecosystem was firstly defined as: adaptation and adjustment capability of an ecosystem to climate change can only operate under certain conditions. If the range of climate change is too great, intimidation duration is too long or the intensity of short period interference is too high, which exceed the resilience (adjustment and restoration capability) of the ecosystems, the structure, function and stability of the ecosystems will be damaged to lead to completed damage by climate change (irreversible succession). This critical limitation is "threshold of impact of climate change on ecosystems" [42]. Vulnerability of an ecosystem depends on damage degree of an ecosystem, which is indicated by decrease of NPP of the ecosystem. The vulnerability is set up by comparing status of the ecosystem to that of global average of the ecosystem (eco-baseline). Damage of ecosystems is ranked into light (40% NPP less than eco-baseline), moderate (60% less), severe (80% less), and complete (over 80%) damage. Criteria are established accordingly[42,43]. Ecosystem vulnerability assessment model is established based on artificial neural network model and degree of membership in fuzzy mathematics. In light of the above-mentioned, assessment model was built to assess the ecosystem status simulated in AVIM2 model[42,43]. The assessment was focused on NPP of the ecosystems with environmental background.

2 Results and analysis

Figure 1(a)—(d) shows the NPP pattern of ecosystems of China simulated by AVIM2 in different periods. NPP of different periods subtracted that of baseline period (1961—1990) are displayed in Figure 2(a)—(c), indicating that impact of climate change is more serious in eastern China than in western China.

By the ecosystem simulation and vulnerability assessment methodology described above, vulnerability of China's ecosystems due to climate change was assessed. Under B2 scenario, ecosystem status of baseline period (Figure 3(a)) shows that Northwest China and Tibetan Plateau are likely to be vulnerable and some parts of Northeast and South China are likely to be moderately vulnerable, which agrees basically with the reality vulnerable situation of China[44]. Figure 3(b) shows the result of the near-term vulnerability assessment under B2 scenario, indicating that there is not much change in Northwest China and Tibetan Plateau, but the situation changes significantly in Northeast and South China.

Figure 3(c) is the result of the mid-term vulnerability assessment under B2 scenario, which shows that the damage degree of the ecosystems in Northwest China and Tibetan Plateau intensifies and slight to moderate damage areas are likely to occur again in Northeast and South China. Figure 3(d) is the result of the long term vulnerability assessment under B2 scenario, which shows that damaged ecosystems aggravate in Northwest

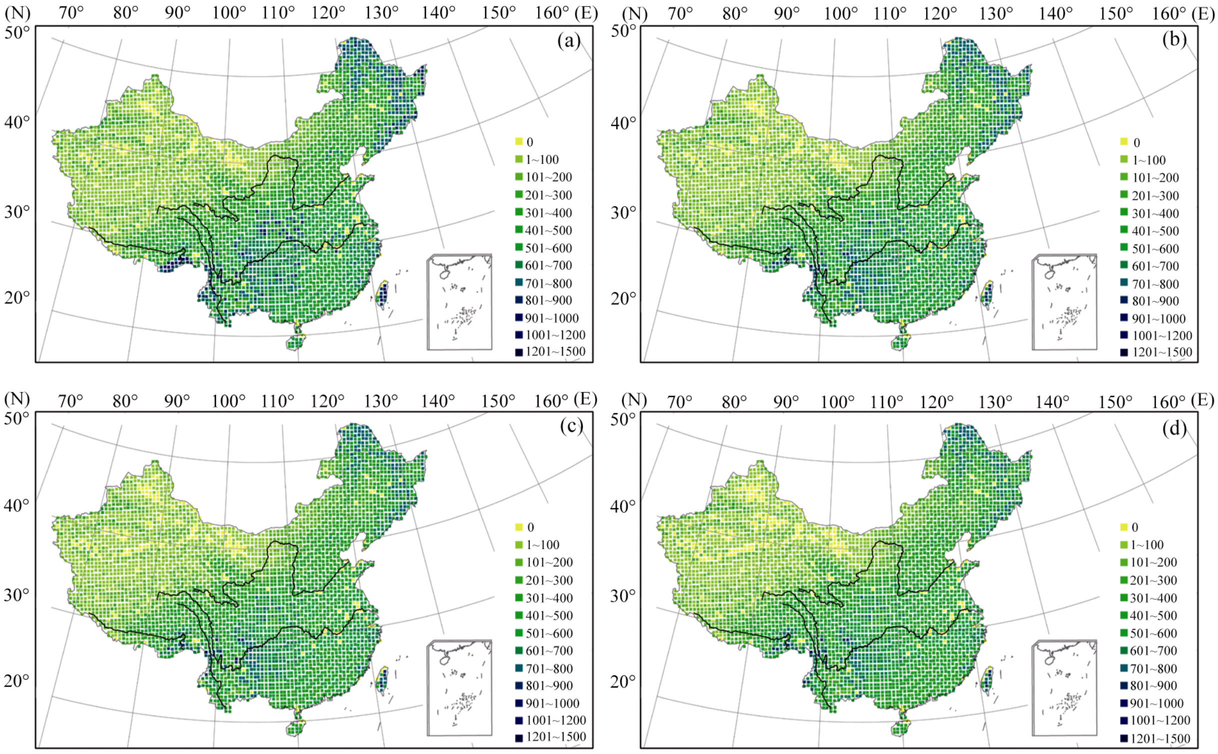

Figure 1 NPP, unit is gC·m^{-2}·a^{-1}. (a) Baseline period; (b) near-term; (c) mid-term; (d) long-term.

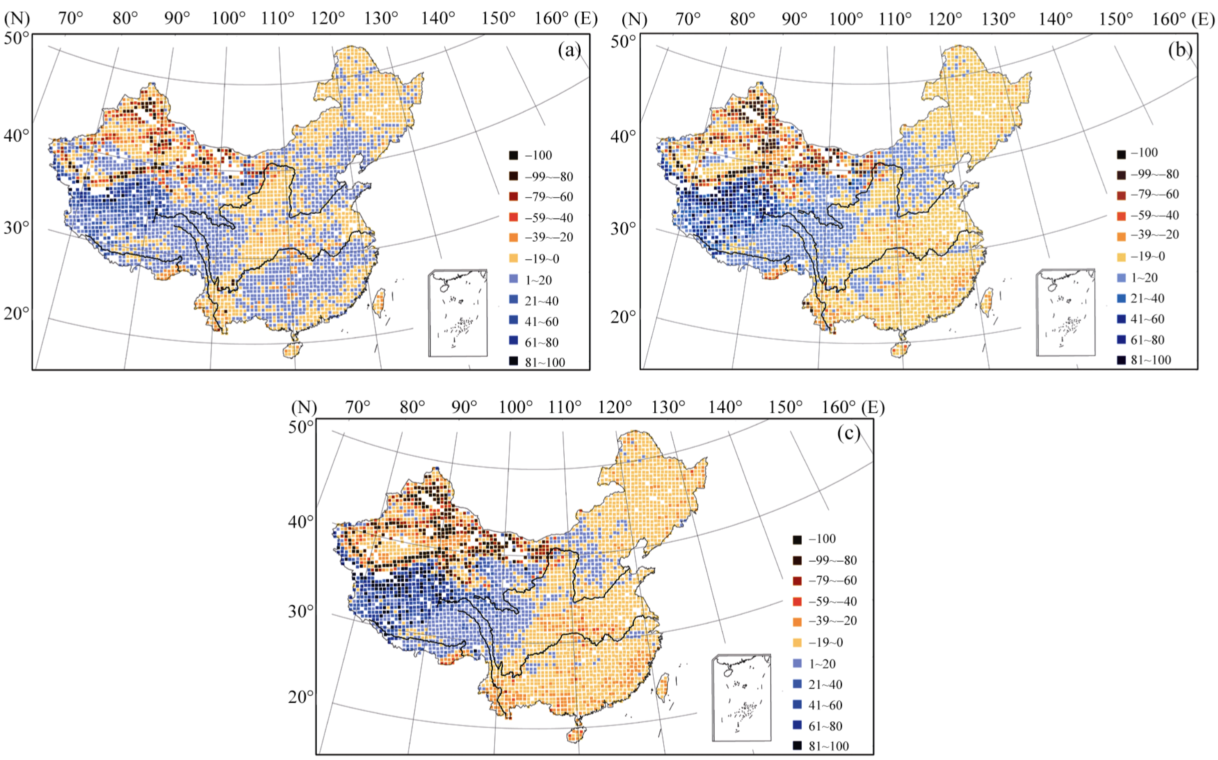

Figure 2 Increase/decrease of NPP, unit is %. (a) Near-term; (b) mid-term; (c) long-term.

China and Tibetan Plateau, and the areas of slight-moderate damage are likely to expend apparently in Northeast, North, South and Southwest China.

Climate data analysis shows that extreme high temperature is likely to occur in North China and extreme drought is likely to happen in the Changjiang River ba-

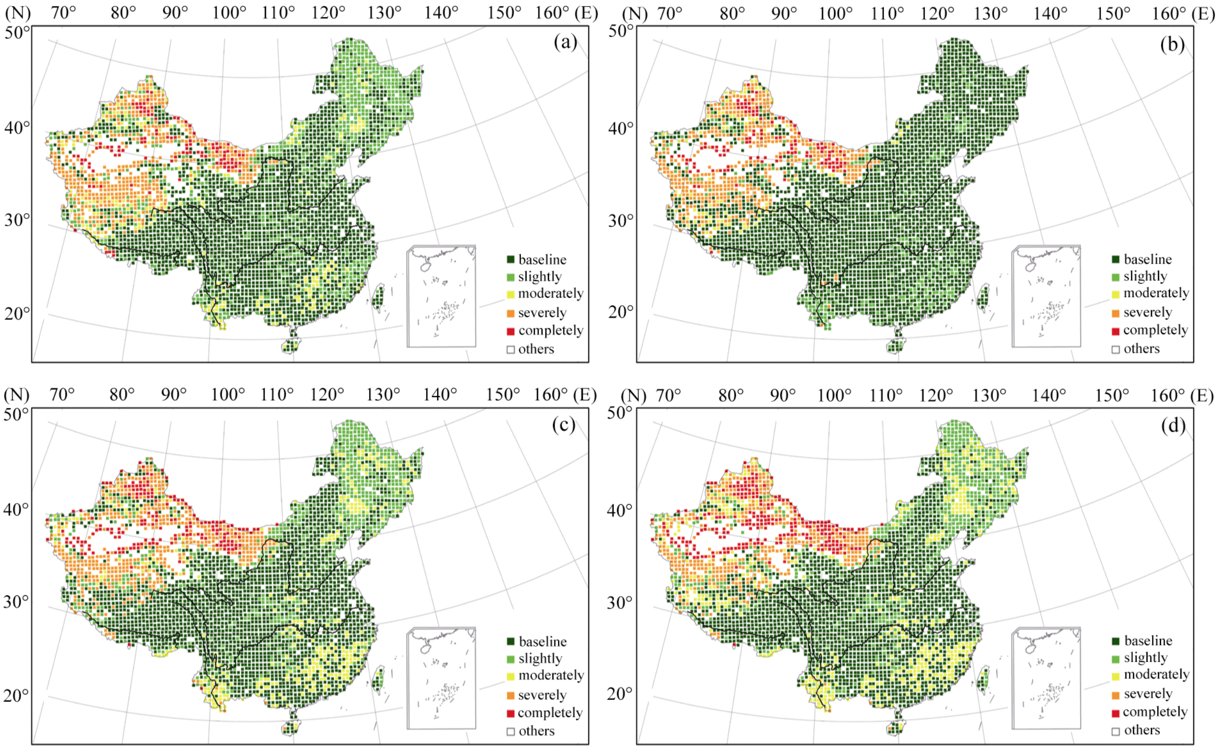

Figure 3 Vulnerability of ecosystems. (a) Baseline period; (b) near-term; (c) mid-term; (d) long-term.

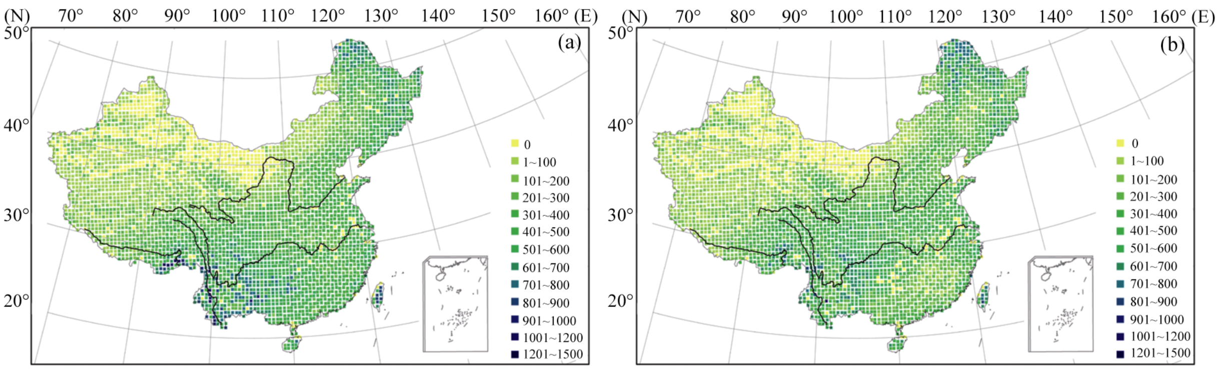

Figure 4 NPP of the extreme climate year, unit is $gC \cdot m^{-2} \cdot a^{-1}$. (a) In 2084; (b) in 2092.

sin in 2084. In 2092, extreme drought is likely to happen in North China and the Changjiang River basin. Results of ecosystem status under B2 scenario simulated by AVIM2 are showed in Figure 4(a) for the year 2084 and Figure 4(b) for 2092. Compared with the baseline period, ecosystems are likely to have more impacts (Figure 5(a) and (b)).

In 2084, extreme high temperatures in North China and extreme drought in the Changjiang River basin are likely to affect ecosystems. Large areas' ecosystems in North China are likely to be moderately or severely damaged (Figure 6(a)). Moderately damaged areas are likely to increase. Areas of irreversible evolving ecosystem are likely to expand eastward. In 2092, droughts in North China and middle and lower reaches of Changjiang River basin are likely to cause even more serious impacts on the ecosystems. Situation in Northwest, North and Northeast China is likely to be similar to that in 2084. Vulnerable degrees of ecosystems in the middle and lower reaches of Changjiang River basin and South China are likely to increase definitely. Small parts in hilly areas of South China are even likely to evolve inconvertibly (Figure 6(b)).

With the support of geographical information system (GIS), comparison of the ecosystem vulnerability to land cover shows that the severely affected and irreversible succession ecosystem types are likely to be open shrubland and desert grassland under B2 scenario. In the extreme climate years of 2084 and 2092, seriously damaged ecosystems are likely to extend to parts of defoliated broad-leaved forest and grassland (2084), and parts of wood land and evergreen conifer forest (2092).

Ecosystem vulnerability in different regions under B2 climate scenario in the 21st century could be summarized in Table 1.

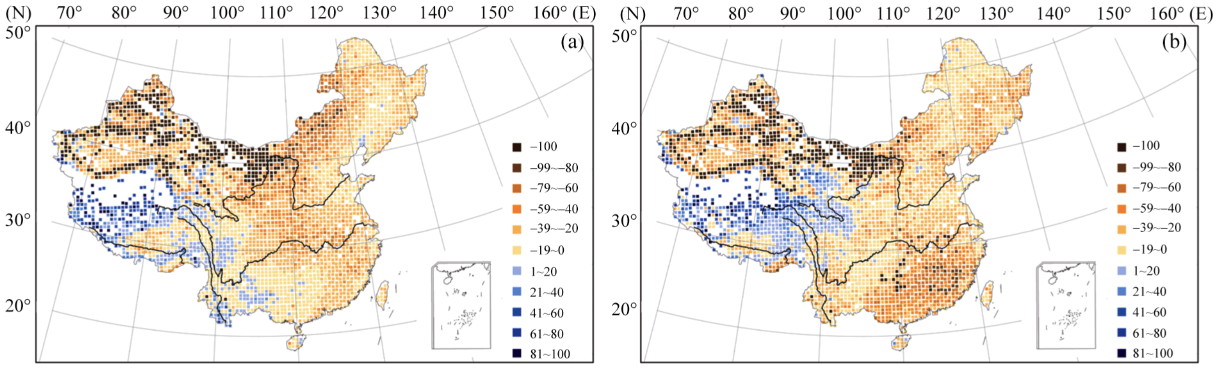

Figure 5 Increase/decrease of NPP, unit is %. (a) In 2084; (b) in 2092.

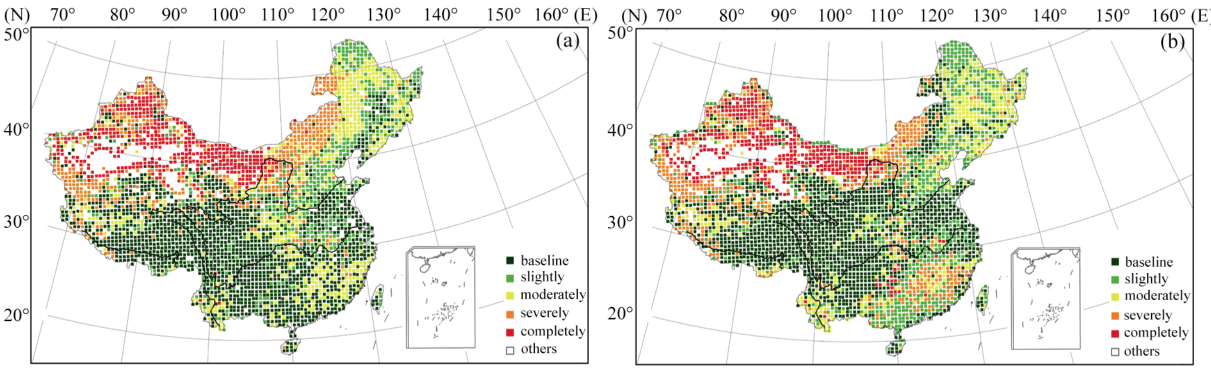

Figure 6 Vulnerability of ecosystems. (a) In 2084; (b) in 2092.

Table 1 Ecosystem vulnerability (inadaptability) in different regions of China under climate change in the 21st century

Vulnerability	Baseline period	Near-term	Mid-term	Long-term	Extreme 2084	Extreme 2092
Eco-baseline	Other parts of China	Apparently expanding in Northeast and South China	Apparently shrinking in Northeast, South and Southwest China	Mainly Central and Southwest China	Mainly Central-east and Southwest China	Mainly Central and Southwest China
Slightly damaged	Northeast and South China	Apparently shrinking in Northeast, South and Southwest China	Apparently expanding in Northeast, South and Southwest China	Apparently expanding in Northeast, South and Southeast China	Large areas of North China; apparently expanding in the middle and lower reaches of the Changjiang River basin and South China	Large areas of North China; apparently expanding in the middle and lower reaches of the Changjiang River basin and South China
Moderately damaged	Northwest and Tibetan Plateau; small areas of Northeast and South China	Northwest and Tibetan Plateau	Increase in Northwest and Tibetan Plateau; apparently expanding in Northeast, South and Southwest China	More serious in Northwest and Tibetan Plateau; apparently expanding in Northeast, South and Southwest China	Most parts of North China	Large areas of North China; apparently expanding in the middle and lower reaches of the Changjiang River basin and South China
Severely damaged	Northwest and Tibetan Plateau	Northwest and Tibetan Plateau	Areas increasing in Northwest and Tibetan Plateau	More serious in Northwest and Tibetan Plateau	Parts of North China	Parts of North China; parts of hilly areas of South China
Completely damaged	Small areas of Northwest and Tibetan Plateau	Small areas of Northwest and Tibetan Plateau	Areas increasing in Northwest and Tibetan Plateau	Areas increasing in Northwest and Tibetan Plateau	Areas in Northwest expanding eastward	Areas in Northwest expanding eastward; occurring in the hilly areas of South China

3 Main conclusions and discussion

(i) Climate change is likely to have a serious impact on natural ecosystems in China.

(ii) Degrees of impact of climate change are likely to become worse in near-term, mid-term and long-term.

(iii) Areas seriously affected by climate change are likely to be the areas with vulnerable ecosystem background such as Northwest China and Tibetan Plateau.

(iv) Some areas with good ecosystem background in Northeast, North, and South China are also likely to be seriously affected.

(v) Extreme climate events are likely to have great impacts on the ecosystems of China, which are likely to cause irreversible succession of the ecosystems even in the hilly areas of South China.

(vi) Under B2 scenario, possible ecosystems of irreversible succession are likely to be open shrubland and desert grassland. For the extreme climate events, such vulnerability is likely to extend to parts of defoliated broad-leaved forest, grassland, wood land, and evergreen conifer forest.

(vii) Generally speaking, impact of climate change on ecosystem in China during the near-term is likely to be slight, in partial areas could even get some benefit. However, in view of the mid and long terms, negative impacts of climate change on natural ecosystem would be enormous.

(viii) Climate change characterized by temperature rise is likely to have serious impacts on ecosystems of China. But in some areas, especially in cold areas, earlier warming is helpful for satisfying eco-requirement. Therefore, for the near-term damage degrees are likely to be reduced for the forest ecosystems in Northeast China. However, as temperature rises, other factors of ecosystems are likely to vary such as evaportranspiration increase and living conditions degradation, which resulting in ecosystem degradation throughout China. This study is based on climate scenario (RCM) and biogeochemical simulation (AVIM2). There is uncertainty in the study to a certain degree, which is relevant mainly to two aspects. As all know, climate (change) process is a complex non-linear process. Uncertainty exists in all the climate scenarios. Such an uncertainty leads to uncertainty to ecosystem status simulation. Another uncertainty comes from recognition on response of physiological process of ecosystem to climate change. Both uncertainties cause uncertainty to the assessment of ecosystem vulnerability. Reducing uncertainty depends on: a) progress of science and technology, especially further recognition and interpretation on physical phenomena; and b) further understanding of the plants and vegetation response processes to climate change by experiments/examination. Ultimately, the certainty in ecosystem vulnerability assessment would be improved.

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