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兴安落叶松林碳平衡及管理活动影响研究

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摘 要 在利用大兴安岭地区根河落叶松（*Larix gmelini*）林生态系统定位研究站的实际观测资料验证CENTURY模型的基础上，探讨了林业经营管理方式对兴安落叶松林碳循环的影响，指出：1）目前兴安落叶松林是一个碳汇，每年净吸收碳2.65 $t\cdot hm^{-2}$。2）砍伐将使兴安落叶松林生物量和生产力下降，土壤碳含量则有所增加。干扰强度越大则其植物总生物量、生产力和土壤碳含量变化幅度越大，伐后恢复时间也越长。3）连年去除枯枝落叶处理使兴安落叶松林土壤碳含量下降，土壤越来越贫瘠。植物总生物量在前30年迅速增加，之后则趋于稳定。生产力在去除枯枝落叶的前10年增加，之后则逐渐下降，到100年时与不去除枯枝落叶的森林生产力相近。不同枯枝落叶去除强度影响之间没有显著差异。

关键词 兴安落叶松林 碳平衡 砍伐 去除枯枝落叶 CENTURY模型

CARBON BALANCE OF *LARIX GMELINI* FOREST AND IMPACTS OF MANAGEMENT PRACTICES

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Abstract We applied CENTURY model (version 4.0) to simulate the impacts of forestry management practices on the carbon (C) balance of *L. gmelini* (Dahurian larch) forest. The model was validated using the observed data of *L. gmelini* forest ecosystem. The results indicated that *L. gmelini* forest served as a net C sink of about 2.65 $t\cdot hm^{-2}\cdot a^{-1}$ at present. Forest felling decreased the gross plant biomass and NPP while increased soil C content. When the harvesting rate was increased, the magnitude of the change (increase or decrease) of the forest gross plant biomass, NPP and soil C content increased and more time was required for its restoration. Annually removal of litter decreased the soil C content and increased the gross plant biomass of *L. gmelini* forest. NPP increased in the first 10 years and then decreased gradually. After 100 years, it was close to the NPP of the forest without litter removal. There were no significant differences among the impacts of different removal intensities.

Key words *Larix gmelini* forest, Carbon balance, Forest felling, Litter removal, CENTURY model

Global change resulted from the elevated concentrations of greenhouse gases, especially CO_2, in the atmosphere has become a hot point of ecosystem research. As an important component of terrestrial ecosystems, forests play a key role in regulating the concentration of atmospheric CO_2 because of their large area, biomass, NPP and capacity for C storage (Zheng, 1989; Jiang, 1996). Forests sequester CO_2 through photosynthesis and release CO_2 through plant and soil respiration and litter decomposition. Thus, any changes of these processes in forests will result in change of atmospheric CO_2 concentration.

Larix gmelini forest distributed in the Daxing'an Mountains serves as an important research site for forest ecosystem studies because it represents regional vegetation in the cold-temperate coniferous forest domain in China and also a major component of boreal forests (Taiga) in the world. It covers about 1.56×10^7 hm^2 or 13.2% of the total forested area in China (1.18×10^8 hm^2) and provides about 4.7×10^9 US $ or 4% of the gross annual forest ecosystem services in China (Jiang *et al.*, 1999). Thus, a long-term ecosystem research station, Genhe Larch Forest Ecosystem Research Station, was established in 1991, sponsored by Inner Mongolia Forestry College.

In addition, this area is the most sensitive area to global change (Zhang *et al.*, 1993; Zhang, 1993). According to Zhang *et al.* (1993) and Zhang (1993), it would be likely to move northward out of China under the condition of 2 ℃ or 4 ℃ increase in temperature and 20% increase in precipitation. Besides the effects of global climate change, human activities, especially forest felling and litter removal resulting from fuel gathering, are also the main reasons threatening forest vegetation in Chi-

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na. Because of an upright trunk, high timber quality and high rate of timber production, coniferous trees became the first object of logging. Three largest coniferous forest districts in China, Daxing'an Mountains, Changbaishan Mountains and southwestern Hengduanshan Mountains, have had 70% of their natural forests cleared. Thus, the impacts of human activities on *Larix gmelini* forest are drawing more and more attention.

In this paper, we used the CENTURY model (version 4.0) to simulate the C budget of *L. gmelini* forest of Genhe *L. gmelini* Forest Ecosystem Research Station and the potential impacts of forestry management practices in order to improve the understanding how *L. gmelini* forest will respond to human activities.

1 Study area

L. gmelini forest is mainly located in Daxing'an Mountains and Xiaoxing'an Mountains (43°0'-53°7' N, 118°0'-132°5' E). A temperate monsoon climate zone characterizes the climate. Its winter can be as long as nine months and the summer less than one month long. There is almost no summer in most parts of this area. The annual mean temperature ranges from −4.7 ℃ to 5.4 ℃ and the frost-free period lasts from 90 to 180 days. The annual mean precipitation is about 300-600 mm. The soil type is podsolic with a very thin solum (20-40 cm). The main vegetation types include *Rhododendron dauricum* (Dahurian rhododendron) and *L. gmelini* (Dahurian larch) forest (Xu, 1998).

Genhe Larch Forest Ecosystem Research Station was established in 1991, sponsored by Inner Mongolia Forestry College. It is located in Genhe Forest Bureau, E'ergunazuoqi county, Hulunbei'ermeng, Inner Mongolia, about 50°49'-50°51' N, 121°30'-121°31' E. The station is located in the northwest slope of Daxing'an Mountains, and the altitude ranges from 784-1142 m. The annual mean temperature is −5.4 ℃ and the annual mean precipitation being 450-550 mm. The vegetation type still keeps primary situation, and the dominant tree species is *L. gmelini* (Dahurian larch) forest (Li & Li, 1996).

2 Study methods

2.1 Model description

At present, a lot of forest growth dynamic models have been developed, such as NEWCOPE (Yan, 1997; Yan *et al.*, 2000), ZELIG (Yu, 1996; Yu *et al.*, 1997), KOPIDE (Shao, 1989), BIOME-BGC (Running & Hunt, 1993), TEM (Melillo *et al.*, 1993), and CENTURY model (Parton *et al.*, 1994). Among them, CENTURY model is the only one that can simulate impacts of natural/man-made disturbances (e.g., fire and felling) on forest ecosystems.

CENTURY model simulates long-term dynamics of carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) for different plant-soil systems. It can simulate the dynamics of grassland systems, agricultural crop systems, forest systems, and savanna systems. The model runs using a monthly time step and the major input variables for the model include: 1) monthly average maximum and minimum air temperatures, 2) monthly precipitation, 3) lignin content of plant material, 4) plant N, P, and S contents, 5) soil texture, 6) atmospheric and soil N inputs, and 7) initial soil C, N, P, and S levels (Parton *et al.*, 1988; 1993; 1994). Thus, CENTURY model would be used to simulate the potential impacts of forestry management practices on the forest carbon budget.

2.2 Forestry management practices

Two kinds of forestry management practices: forest felling and litter removal were considered in this paper. Forest felling was divided into three intensities: light (felling 20% of the large wood biomass), medium (felling 60% of the large wood biomass) and strong (felling 90% of the large wood biomass). Litter removal was also divided into three levels: low (removing 20% of litter), medium (removing 60% of litter) and strong (removing 90% of litter). The impacts of forestry management practices on *L. gmelini* forest's soil C concentration, gross plant biomass, net primary productivity (NPP) and function as a C sink/source were simulated by CENTURY model. The forest restoration occurs as 95% of gross plant biomass of the forest recovered from the initial level after forest felling. Fig. 1 indicates the flow chart for simulating the carbon balance of *L. gmelini* forest and the impacts of management practices.

2.3 Model parameter and validation

The parameters used in this study were collected from Editorial Committee of Inner Mongolia Forest (1989), Feng *et al.* (1985; 1994a; 1994b), Feng (1999), Gu (1987), Institute of Forest Soil, CAS (1980), Jiang (1996), Wu *et al.* (1995), Xu (1998), Zhou (1991) (Table 1). CENTURY model has been validated based on the observed data of *L. gmelini* forest from Genhe Larch Forest Ecosystem Research Station (Jiang *et al.*, 2001). The results indicated that CENTURY model was an appropriate model to simulate C cycle of *L. gmelini* forest. Moreover, *L. gmelini* forest is assumed to remain as dominant species in the simulated site when we simulated the effects of forest felling and litter removal practices on *L. gmelini* forest by CENTURY model.

3 Results

3.1 C source/sink

The C budget of *L. gmelini* forest at present was simulated by CENTURY model. The simulation results indicate that *L. gmelini* forest sequestered 4.03 $tC\cdot hm^{-2}\cdot a^{-1}$ through plant photosynthesis (after subtracting C released from plant respiration) and released 1.38 $tC\cdot hm^{-2}\cdot a^{-1}$ through soil respiration and litter decomposition. Thus, the net ecosystem productivity (NEP) of *L. gmelini* forest was about 2.65 $tC\cdot hm^{-2}\cdot a^{-1}$. It indicates that *L. gmelini* forest was a carbon sink.

3.2 Impact of forest felling on *Larix gmelini* forest

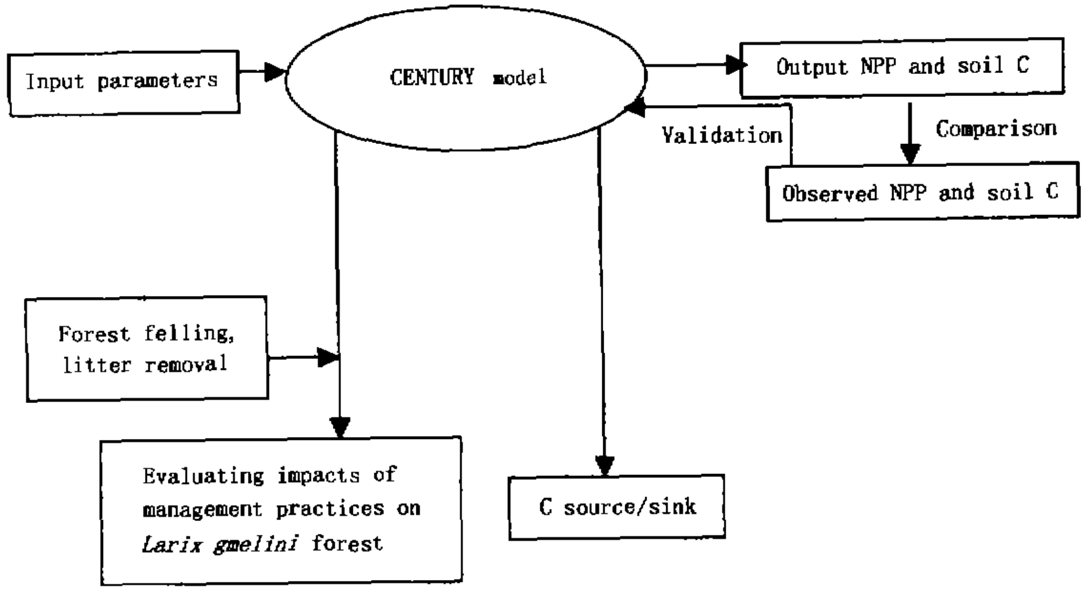

Fig.1 Flow chart for simulating the carbon balance of *Larix gmelini* forest and the impacts of management practices

Table 1 *Larix gmelini* forest site-specific parameters and weather data of Genhe Larch Forest Ecosystem Research Station

Parameters	Parameter values	References
Monthly average precipitation (cm)	Year from 1957 to 1995	Climate data of Genhe Larch Forest Research Station
Monthly average maximum air temperature (℃)	Year from 1957 to 1995	Climate data of Genhe Larch Forest Research Station
Monthly average minimum air temperature (℃)	Year from 1957 to 1995	Climate data of Genhe Larch Forest Research Station
Site latitude	50.68°	Zhou (1991)
Site longitude	121.95°	Zhou (1991)
Fraction of sand in soil	0.47	Xiong & Li (1987)
Fraction of silt in soil	0.35	Xiong & Li (1987)
Fraction of clay in soil	0.18	Xiong & Li (1987)
Soil bulk density ($kg \cdot L^{-1}$)	1.16	Institute of Forest Soil, CAS (1980)
Soil pH	5.3	Institute of Forest Soil, CAS (1980)
Predominant species	Larch	Li & Li (1996)
Evergreen or deciduous	Deciduous	Li & Li (1996)

The impacts of forest felling practices on soil C content, gross plant biomass, net primary productivity (NPP) and function as a C sink/source of *L. gmelini* forest were simulated by CENTURY model in terms of the parameters from Genhe Larch Forest Research Station. The forest restoration time was also discussed.

Soil C content The soil C content of *L. gmelini* forest initially increased after forest felling and then decreased along with the forest's growth. The higher the rate of forest felling, the more the soil C content decreased. Over 50 years, the soil C content gradually increased as the forest matured. It reached the level before forest felling at the same time as gross plant biomass (Fig.2a).

Gross plant biomass The more the forest was felled, the more its gross plant biomass decreased, and the longer the time recovering forest was. Light, medium and strong felling intensities decreased the gross plant biomass by 15.0%, 45.6% and 74.9% respectively and required 96 years, 173 years and 173 years respectively, for restoration (Fig.2b).

NPP In the first year after felling, the NPP of *L. gmelini* forest decreased sharply. The more the forest was felled, the more its NPP decreased. NPP of *L. gmelini* forest decreased by 5.9%, 19.0% and 40.9% in the first year for light, medium and strong felling intensities, respectively. After the first year NPP of *L. gmelini* forest increased gradually along with the forest's renewal. When the forest was restored, its NPP was 0.2% lower for light felling, but 1.8% and 6.5% higher for medium and strong felling intensities respectively, compared to its NPP without forest felling situation (Fig.2c).

C source/sink The *L. gmelini* forest serves as C sink for three intensities of forest felling, and the capacity of C sequestration decreased in the first year. However, the stronger the *L. gmelini* forest was felled, the more its capacity as a C sink decreased (Fig. 2d).

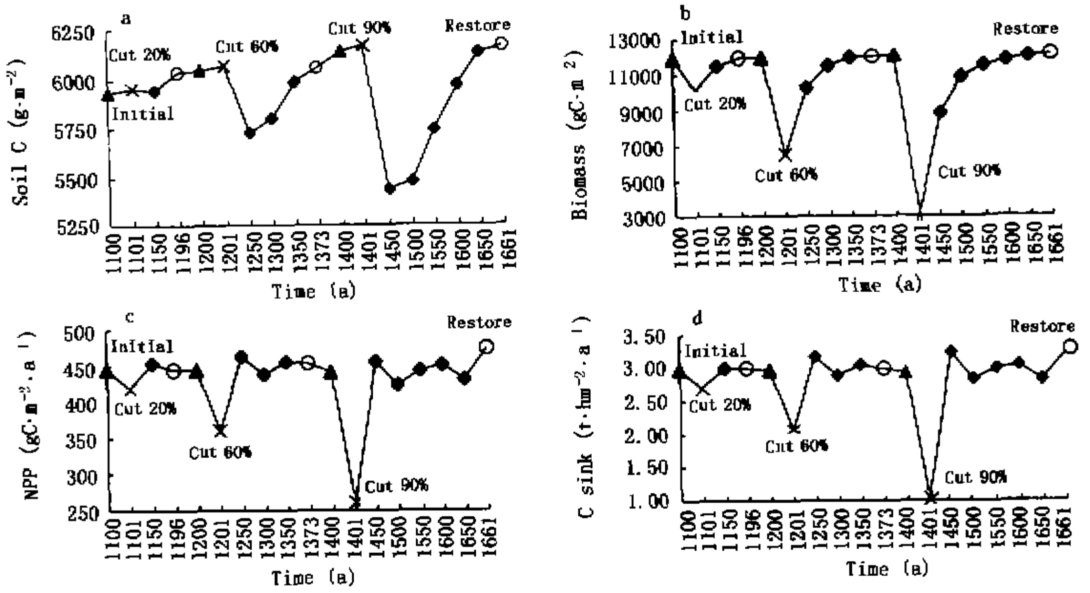

Fig.2 Impact of forest felling on the *Larix gmelini* forest: soil carbon (a), biomass (b), NPP(net primary productivity, c), and carbon sink (d)
▲: initial, value before forest felling ○: restore, the value when the forest restore from forest felling ×: cut, being cut at this year

3.3 Impact of litter removal on *Larix gmelini* forest

The impacts of litter removal practices on net ecosystem productivity of *L. gmelini* forest were simulated by CENTURY model in terms of the parameters from Genhe Larch Forest Research Station. The forest restoration time was also discussed.

Soil C content Different intensities of removing litter would result in the decrease of soil C content of *L. gmelini* forest (Fig.3a). Moreover, the impacts of three different intensities of litter removal on soil C content indicated no obvious differences. After 100 years of continuous removal of litter, the soil C content decreased by about 30% compared with those without removal.

Gross plant biomass Different intensities of removing litter would cause the increase of gross plant biomass of *L. gmelini* forest, especially in the first 30 years. Moreover, the gross plant biomass has the same situation with soil C content, that is to say, the impacts on gross plant biomass resulting from different intensities of removing litter did not show the obvious differences. After 30 years of litter removal, gross plant biomass of *L. gmelini* forest would increase by 3% compared with those without litter removal practices (Fig. 3b).

NPP The NPP changes of *L. gmelini* forest resulting from different litter removal intensities did not show obvious differences. In the first 10 years with annual litter removal, the NPP of *L. gmelini* forest increased sharply and was obviously higher than NPP of *L. gmelini* forest without litter removal practice. After 10 years, NPP of *L. gmelini* forest decreased gradually, but was still higher than NPP of *L. gmelini* forest without litter removal practice before 60 years. There were no obvious differences between the NPP of *L. gmelini* forest with and without litter removal practices after 60 years (Fig. 3c).

C source/sink The impacts of three intensities of litter removal practices of *L. gmelini* forest on C budget did not show obvious differences (Fig.3d). In the first 10 years with litter-removal practices, the capacity of C sink of *L. gmelini* forest increased sharply and was obviously higher than those without litter removal practices. Then, this capacity decreased gradually, but it was still higher than those without removal practice. After 100 years of litter removal practices, the C sink reached about 3.41 $t\cdot hm^{-2}$ and increased by 22% compared with those without litter removal practice (2.79 $t\cdot hm^{-2}$).

4 Discussion

Forest ecosystems play a key role in regulating the balance of atmospheric CO_2 because of their large area, biomass, NPP and capacity for C storage. However, with the development of industrialization and the increase in population in the world, great demand and excessive utilization of human beings on natural resources have resulted in decrease, degradation and exhaustion of forest resources. Although forest cover in China has an increasing trend during recent decades due to an increase in artificial forests, the natural forest is still decreasing. Furthermore, most of natural forests are deteriorating. China's forest and natural forest areas during the inventory period of 1973-1976 were 1.2186×10^8 hm^2 and 9.817×10^7 hm^2, respectively. The corresponding figures for 1977-1981 were 1.1527×10^8 hm^2 and 9.308×10^7 hm^2. Three largest coniferous forest districts in China: Daxing'an Mountains, Changbaishan Mountains and southwestern Hengduanshan Mountains, have had 70% of their natural forests cleared. Although the loss rate of forest resources indicated a decreasing trend during the period of 1990-1993, forest over-logging still continued. In 1993, the national forest resource loss exceeded a reasonable limit by 3.4×10^7 m^3. As a consequence of over-logging and

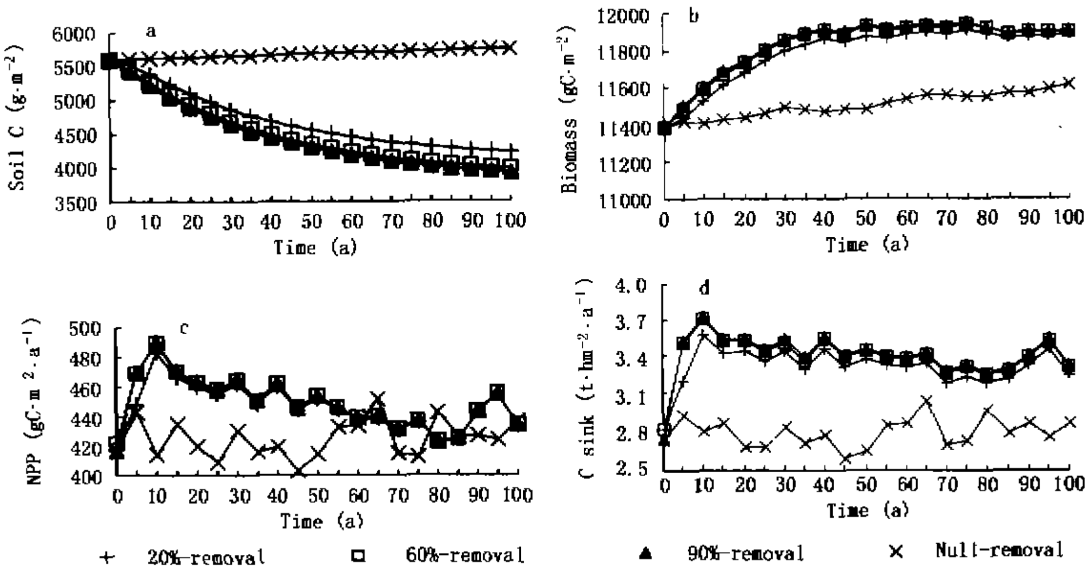

Fig. 3 Impact of litter removal on *Larix gmelini* forest: soil carbon (a), biomass (b), NPP(net primary productivity, c), and carbon sink (d)

slower reafforestation, more and more open forests, over-cutting sites and bare mountain areas increased. Thus, it is urgent to understand how forest ecosystems will respond to human activities. As a case study, this paper simulated the impacts of forestry management practices on the carbon (C) balance of *L. gmelini* (Dahurian Larch) forest based on CENTURY model and the data from Genhe Larch Forest Ecosystem Research Station. This study provides understanding how forest ecosystems will respond to human activities with the research method and technology.

The research results indicate that *L. gmelini* forest at present served as a net C sink. It may result from low soil CO_2 emission due to low temperature in this area, although the NPP is not very high compared with that of tropical areas. However, the further field study related to carbon cycling of *L. gmelini* forest ecosystems should be done in the future in order to understand how it will respond to environment and human activities.

The gross plant biomass and NPP of *L. gmelini* forest would decrease under forest felling while soil C content increase. Moreover, their magnitudes also increased with the increase of forest felling intensities, and the forest's restoration time increased. However, the gross plant biomass of *L. gmelini* forest would increase under litter removal practices while soil C content decrease. The NPP of *L. gmelini* forest increased in the first 10 years and then decreased gradually. The increase of the gross plant biomass and NPP may result from the environmental improvement, such as more sunlight, higher temperature, and the decrease of soil C content may cause by the loss of litter. The decrease of NPP after 10 years of litter removal practices may be due to the limitation of the soil nutrient on forest growth. Moreover, the impacts of three different intensities of litter removal on soil C content, gross plant biomass and NPP of *L. gmelini* forest indicated no obvious differences. In addition, the effects of forest felling practices on *L. gmelini* forest are more serious than those of litter removal practices. Thus, a lot of forest felling may seriously affect the carbon cycle of forest ecosystems.

It should be pointed out that the mechanisms of carbon cycling of *L. gmelini* forest ecosystems under forestry management are not clear yet, the field experiments should be emphasized in the future in order to understand how *L. gmelini* forest will respond to environment and human activities.

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