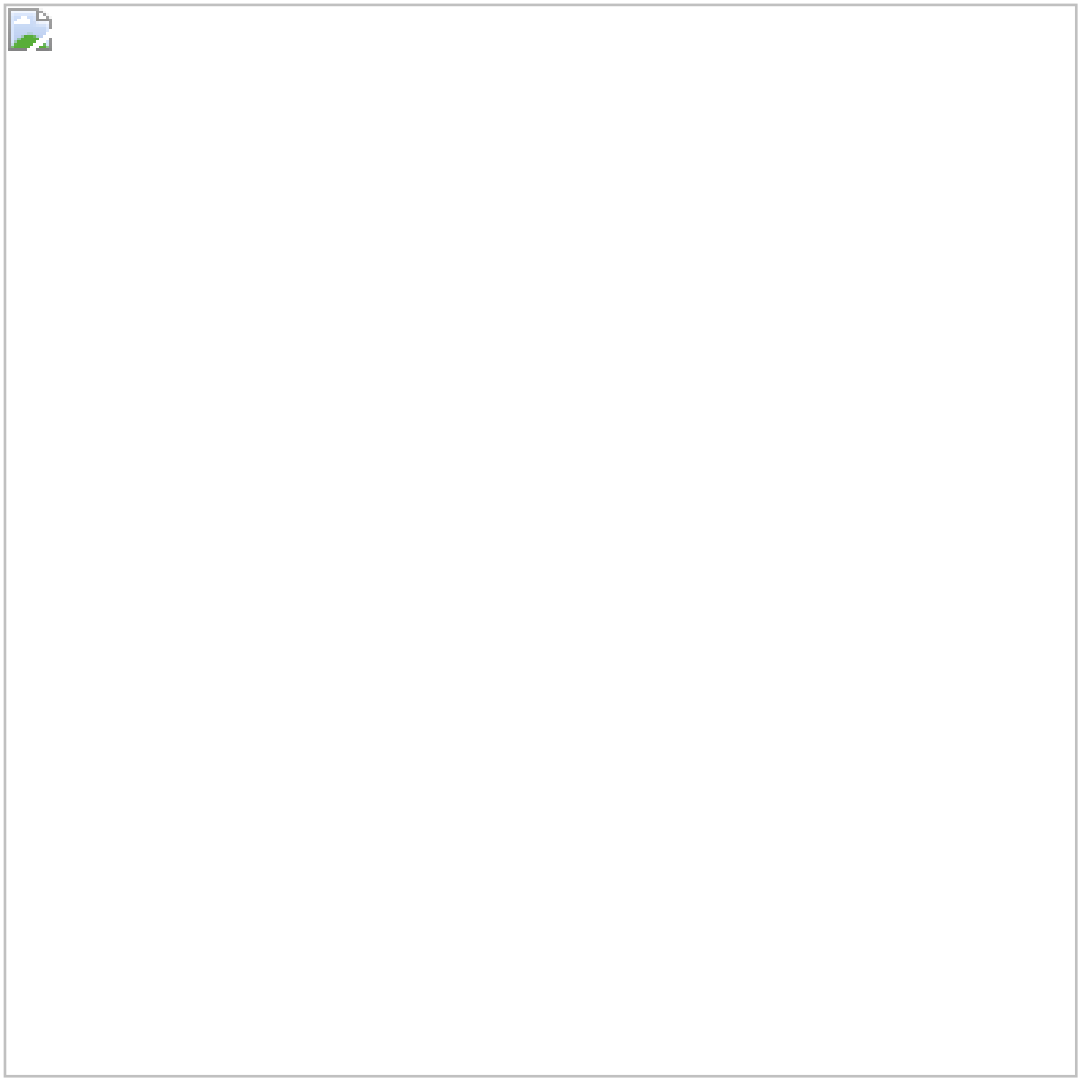


Recent Carbon Accumulation in Changbai Mountain Peatlands, Northeast China

Authors: Bao, Kunshan, Yu, Xiaofei, Jia, Lin, and Wang, Guoping

Source: Mountain Research and Development, 30(1) : 33-41

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-09-00054.1

The BioOne Digital Library (https://bioone.org/) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses

Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainResearch
Systems knowledge

Recent Carbon Accumulation in Changbai Mountain Peatlands, Northeast China

*Kunshan Bao[1], Xiaofei Yu[1], Lin Jia[2], and Guoping Wang[1]**

** Corresponding author: wangguoping@neigae.ac.cn*

[1] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 3195 Weishan Road, Gaoxin District, Changchun 130012, Jilin, China

[2] Department of Geographical Environment and Human Health, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A Datun Road, Anwai District, Beijing 100101, China

Open access article: please credit the authors and the full source.

The Changbai Mountain range is a well-known and important mountain chain in northeast China, bordering the Korean Peninsula in the south. It is also one of the areas most sensitive to global change. Massive peatlands that play a key role in the global carbon (C) cycle are found in this region. Estimating and assessing C dynamics in Changbai Mountain peatlands is of great importance to local sustainable development. Dry bulk density and C content analyses based on 8 selected peat cores dated by ^{210}Pb were used to estimate recent rates of carbon accumulation (RERCA, g C m^{-2} yr^{-1}) in Changbai Mountain peatlands. RERCA ranged from 124.2 to 292.8 g C m^{-2} yr^{-1} (average 199.6 ± 60.9 g C m^{-2} yr^{-1}). Obvious increasing trends in RERCA were observed in all peat cores. The C pool for 200 years was 38.5–52.1 kg C m^{-2}, which can supplement the database of C pools for Changbai Mountain ecosystems. The ^{210}Pb radiometric technique was tested and found to be a useful study method for recent terrestrial carbon sequestration. This study could contribute to a better understanding of rarely studied mountain peatlands in China and may be useful to global mountain and climate change research.

Keywords: *Peatlands; carbon pool; recent rate of carbon accumulation (RERCA); ^{210}Pb dating; climate change research; Changbai Mountains; northeast China.*

Peer-reviewed: *October 2009* ***Accepted:*** *November 2009*

Introduction

Peatland ecosystems are an important type of wetland ecosystem; they account for 3–6% of the Earth's land surface and 50–70% of the global wetland area (Clymo 1984; Gorham 1991; Joosten and Clarke 2002). They play a key role in the global carbon (C) cycle and are influenced by global climate change (Lal 2004; IPCC 2007; Zhang et al 2008). Peat deposits are characterized by a high C content, equivalent to about 50% of the dry organic matter, and the C storage in peatlands represents nearly one third of the world's terrestrial C, corresponding to 75% of C storage in the atmosphere (Gorham 1991; Shurpali et al 1995; Vitt et al 2000; Asada and Warner 2005). The rate of C sequestration in peatlands is a crucial element in understanding the global C cycle and has been estimated on different timescales to ascertain the role of peatlands in global warming in the context of rising atmospheric CO_2 (Vitt et al 2000; Joosten and Clarke 2002; Büchler et al 2004; Brown et al 2007; Beilman et al 2009).

Much research on C dynamics in peatlands has been carried out in Europe and the United States; research has focused mainly on assessing the long-term rate of C accumulation (Gorham 1991; Botch et al 1995; Tolonen and Turunen 1996; Turunen et al 2001; Borren et al 2004). The need for better quantitative information about recent C balance in modern peatlands has been acknowledged because exposure to climatic variables is greatest at or near peat surface. Recently, short-lived radioisotopes (^{210}Pb, etc) highlighting recent palaeoecological succession and sedimentation rates have been used for studies conducted in peatlands (Turetsky et al 2000, 2004; Charman and Garnett 2005; Ukonmaanaho et al 2006; Ali et al 2008).

The Changbai mountain region in northeast China is an important location for scientific assessment of vulnerability to climate change, as the ecosystems in this region are highly sensitive to anticipated warming (Büchler et al 2004; IPCC 2007). Peatlands are an important ecosystem in the Changbai Mountains, but they have received less attention than other ecosystems (Figure 1). Data on C accumulation in these mountain peatlands are scarce. For a complete picture of the global C cycle, it is thus necessary to take Changbai Mountain peatlands into account. It is especially urgent to ascertain the short-term rate of C accumulation in Changbai Mountain peatlands. We examine the ^{210}Pb dating carried out on 8 subsurface peat sequences to estimate recent rate of C accumulation (RERCA) and

 © 2010 by the authors

Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

FIGURE 1 Yuanchi peatland, a quaking mire of 404 ha, is located in the coniferous forest zone at 1281–1288 masl on the eastern slope of Changbai Mountain, northeast China. It originated from an infilling shallow volcanic lake, with no significant inflow or outflow of surface water or groundwater. (Photo by Guoping Wang)

improve understanding of the role of mountain peatlands in climate change. The data on RERCA and C storage over the last 200 years are critical to sustainable development in the Changbai Mountains in light of global change.

Study area

The Changbai Mountains stretch along the boundary between China and North Korea (Figure 2). The area is characterized by a dormant volcano and a subtropical continental monsoon climate with long, cold winters and short, cool summers. The annual mean temperature ranges from −7 to 3°C, and the annual precipitation increasing with elevation ranges from 700–1400 mm (Zhao et al 2002; Deng et al 2009).

The topography of the mountain range includes hilltops, valleys, basins, and hillsides with steep slopes (varying between 0° and 73°). Elevation ranges from about 410–2740 m above sea level and decreases gradually from southeast to northwest (Zhang et al 2009). There are 4 distinct vertical vegetation zones: the alpine tundra zone (above 2000 m), the subalpine *Betula ermanii* forest (1800–2000 m), the coniferous forest zone (1100–1800 m), and the mixed forest of broadleaved and Korean pine forest (500–1100 m) (Zhang et al 2007). There are also corresponding vertical soil zones.

Abundant peat resources are available in the Changbai Mountains as a result of the cold and wet weather conditions and the topographical and geological features. The peat is characterized by concentrated distribution, successive deposit, and high accumulation rate (Zhao et al 2002). However, most valley mires have degraded to paddy and upland fields because of human disturbances.

Methods

Core samplings

Three peatland types (Carex moss, woody moss, and herbaceous) were identified along the elevation gradient in the study area, and the dominant vegetation was investigated (Table 1). Eight peat cores ($10 \times 10 \times D$ cm^3, where D is the depth of each core measured by standard meter ruler) were collected using a titanium (Ti) Wardenaar peat profile sampler (Eijkelkamp, Netherlands) in September 2005 in the Changbai Mountains (Figure 2). At Yuanchi peatland (Yc; Figure 1), 4 peat cores (Yc-1, Yc-2, Yc-3, and Yc-4) were taken from west, south, east, and north of the study area. The latitude and longitude at sampling sites were determined with a portable global positioning system (Table 1). Peat cores were sectioned on-site at 1-cm or 2-cm intervals with a stainless steel band saw and then stored in polyethylene plastic bags until laboratory analysis was conducted.

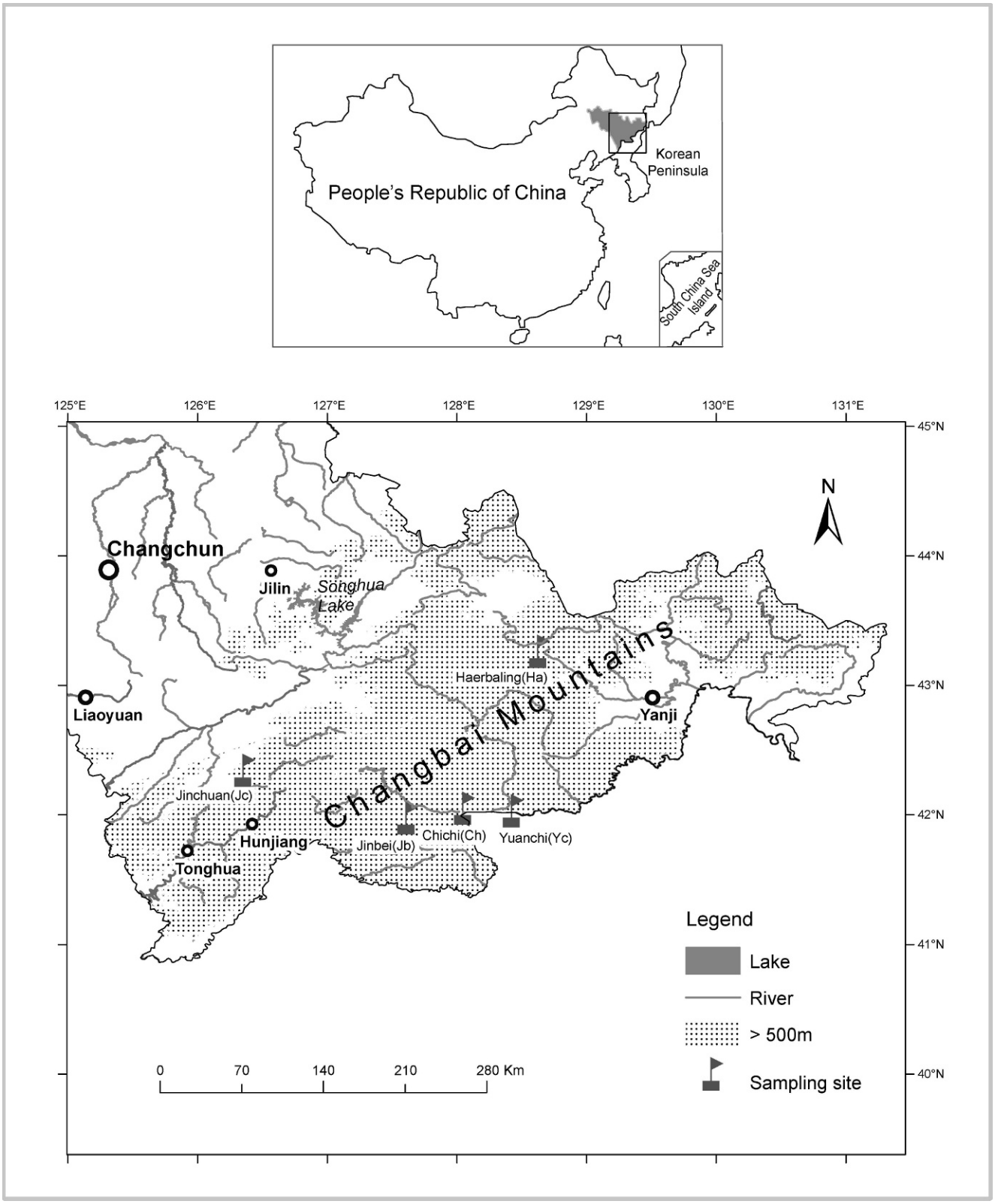
Physicochemical analysis

Water content, dry bulk density, and loss-on-ignition (LOI) analyses were performed at the Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences (CAS).

Water content (%) and dry bulk density (g cm^{-3}) were determined by weighing a volumetric subsample of each slice before and after drying at 105°C overnight. The former was calculated from the mass difference, and the latter was calculated from stable weight and known volume (Wang et al 2004). Peat organic matter content was determined by LOI analysis in a muffle furnace at 550°C overnight (Beaudoin 2003; Asada and Warner 2005; Ali et al 2008). Thus the organic C content was calculated by multiplying the organic matter content by 0.50 (Craft

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

FIGURE 2 Regional location of sampling sites in Changbai Mountains. (Map by Guoping Wang)



http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

TABLE 1 Peat samples collected in the Changbai mountain region in northeast China.

Peatland type	Sampling site	Predominant vegetation	Coordinates	Altitude (m)	Depth (cm)	Area (ha)
Carex moss	Chichi (Ch)	*Carex* species, *Sphagnum*	42°03′17″N, 128°03′27″E	1832	24	50
	Yuanchi(1) (Yc-1)	*Carex lasiocarp*	42°01′54″N, 128°26′02″E	1281	29	404
	Yuanchi(2) (Yc-2)	*Carex lasiocarp*, *Sphagnum*	42°01′52″N, 128°26′06″E	1282	31	
	Yuanchi(3) (Yc-3)	*Vaccinium uliginosum* L.	42°01′58″N, 128°26′10″E	1288	37	
Woody moss	Yuanchi(4) (Yc-4)	*Sphagnum*, *Vaccinium uliginosum* L.	42°02′06″N, 128°26′03″E	1281	30	
	Jinbei (Jb)	Larch, *Sphagnum*	41°58′43″N, 127°37′17″E	909	44	494
Herbaceous	Jinchuan (Jc)	*Carex lasiocarp*	42°20′33″N, 126°21′46″E	614	34	110
	Haerbaling (Ha)	*Carex* species	43°15′49″N, 128°38′12″E	550	38	917

and Richardson 1993; Tolonen and Turunen 1996; Clymo et al 1998; Inisheva and Golovatskaya 2002). Peat inorganic C content is very low and often negligible (Beilman et al 2009), so the organic C content derived from LOI was used to estimate RERCA in this study. Residues of ignition are assumed to be ash and mineral particles such as silt, clay, and sand, so the ash content (%) was correspondingly calculated.

Dating and estimating RERCA

The process of ^{210}Pb dating was performed at the State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, CAS. Activities of total ^{210}Pb and supported ^{210}Pb were measured by the gamma ray emission of the samples on the high pure germanium semiconductor and low-background gamma spectrometer (OTEC Instruments Ltd., USA). Count times for ^{210}Pb were typically in the range of 50,000–86,000 s, giving a measurement precision of between ca. ± 5% and ± 10% at the 95% level of confidence. The constant rate of supply model (CRS; Appleby and Oldfield 1978) was used to determine the age of the peat profiles and RERCA as follows (Reddy et al 1993; Mauquoy et al 2002; Ali et al 2008):

$$T_{yr} = -(1/\lambda)\ln(I_z/I_{tot}) \quad (1)$$

$$\mathrm{RERCA}\left(\mathrm{g\ C\ m^{-2}\ yr^{-1}}\right) = Z(\mathrm{cm})/\mathrm{T}_{yr} \times d_{bulk}\left(\mathrm{g\ cm^{-3}}\right) \times \mathrm{C}_c(\%) \times 100, \quad (2)$$

where T is the age; I_z refers to the inventory of unsupported ^{210}Pb at depth Z (cm); I_{tot} is the total inventory of unsupported ^{210}Pb in the core section; λ is the constant of decay of the ^{210}Pb, that is, 0.0307; d_{bulk} is the dry bulk density, and C_c is the organic C content.

Results

Water content, dry bulk density, and ash content

Water content of the peat cores ranged from 47%–95%. The distributions were characterized by the highest value occurring in the topmost sections, with a rapid decrease on moving to deeper layers for Ch, Yc-2, Yc-3, Yc-4, Ha, and Jb, cores (Figure 3A). However, the values of Yc-1 and Jc cores increased toward the bottom layer. The ranges of dry bulk density were 0.036–0.684 g cm^{-3} (Figure 3A). It was obvious that the dry bulk densities of most peat profiles increased with depth, except for the Yc-1 and Jc cores, which showed the opposite trend. The average ash contents of these profiles was between 18% and 59%, and they increased toward the bottom, except for the Yc-1 and Jc cores (Figure 3B).

Organic C profiles

The calculated organic C values ranged from 10%–50% for the sampling profiles. Yc-1 had the highest C value (mean 40.5%), with Ch (mean 26.0%), Yc-2 (mean 31.9%), Yc-3 (mean 28.9%), Yc-4 (mean 28.9%), Ha (mean 20.3%), Jc (mean 32.5%), and Jb (mean 38.0%) having less C. For the Ch, Ha, and Jb profiles, organic C content declined from the top to the substrate, while the values of Yc-1 and Jc cores

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

increased with depth. The remaining cores showed an increase from the surface to the middle layers (12–17 cm) but a decrease with depth below the middle layers (Figure 3B).

Radioisotope chronology

Radioisotope results for ^{210}Pb were plotted and are shown in Figure 4A. In all sampled peatlands, the unsupported ^{210}Pb activities presented relatively well-defined exponential decrease with depth and reached the detecting depths (20–31 cm). The continuous dating records were reconstructed, and the age/depth models for 8 cores were plotted (Figure 4B). These peat cores were dated back about 200 years from the time of core collection, except for the Ch profile, which was dated back about 130 years.

Recent rate of C accumulation

The application of ^{210}Pb dating allowed RERCA (g C m^{-2} yr^{-1}) to be determined. The ranges and mean of RERCA, with standard deviation for each profile, are summarized in Table 2. The greatest average was 292.8 ± 176.8 g C m^{-2} yr^{-1} for Ha, and the smallest average was 124.2 ± 102.5 g C m^{-2} yr^{-1} for Yc-4. Based on these data, the RERCA of Changbai Mountain peatlands was estimated to be 124.2–292.8 g C m^{-2} yr^{-1} with a mean of 199.6 ± 60.9 g C m^{-2} yr^{-1}.

Discussion

Variation of RERCA in Changbai Mountain peatlands

As indicated in Figure 4B, the temporal variation of RERCA in Changbai Mountain peatlands exhibited an increasing tendency. It was consistent with distributions of organic C and water content and contrary to that of mineral matter in most peat profiles (Figure 3A, B). Moreover, the temporal increase in RERCA changed to a much greater extent in recent decades than in the earlier period of peat formation. The Changbai Mountain peatlands, as a young and growing peatland ecosystem, have a great potential C sequestration capacity, which is definitely worth the effort to protect from degradation.

Differences in RERCA and RERCA variation exist among peat profiles (Table 2). These sampling peatlands are located at different elevations, under different geological conditions, and grow in different vegetation landscapes. The fundamental physicochemical indexes of peat deposits showed different variations in behavior (Figure 3A, B). Therefore, the spatial variability of peat properties and the effects of human activities on modern processes of environmental evolution are expected to result in the divergences of RERCA in these cores. Further studies on the influences of the spatial and temporal heterogeneities of peat on C sequestration rates are needed.

Comparisons of RERCA with other studies

Current concern about greenhouse gas and global C balance has stimulated a growing interest in documenting environmental and climatic changes over recent time periods, especially the last few hundred years. Relevant studies on short-term C accumulation worldwide are available to ensure comparisons of RERCA estimated by various dating methods (Table 3). Our results are comparable to the values of 94–161 g C m^{-2} yr^{-1} found by Craft and Richardson (1993) for the Everglades in the USA with the ^{137}Cs dating method, that of 11.8–290.3 g C m^{-2} yr^{-1} found by Tolonen and Turunen (1996) for Finnish peatlands with the pine method, and that of 40–117 g C m^{-2} yr^{-1} found by Turunen et al (2004) for the ombrotrophic peatlands of eastern Canada, calculated with the ^{210}Pb dating method. As a result, ^{210}Pb dating has proven to be a suitable technique to characterize RERCA in peatlands. The values of RERCA are of great importance to research on climate change and mountains in the absence of baseline data in the Changbai Mountain peatlands.

Carbon pool inferred from RERCA

According to the RERCA values given above, the soil C pool for 200 years in the Changbai Mountain peatlands was estimated by multiplying RERCA by the accumulation time. That is, the mean organic C storage per unit area was found to be 38.5–52.1 kg C m^{-2}. This result is within the range of the organic C pool, that is, 30–108 kg C m^{-2}, calculated as average from the total global peatland area, about 5×10^6 km^2 (Gorham 1991), and the total C pools, 150–540 gigatons (Turunen et al 2002; Otieno et al 2009). It is also comparable to a mean C pool of 14.4–105.1 kg C m^{-2} estimated by Zhang et al (2008) in the Sanjiang Plain temperate wetlands adjacent to the Changbai Mountains. Hence it provides factual knowledge as a basis for obtaining a better understanding of C flux in mountain peatlands.

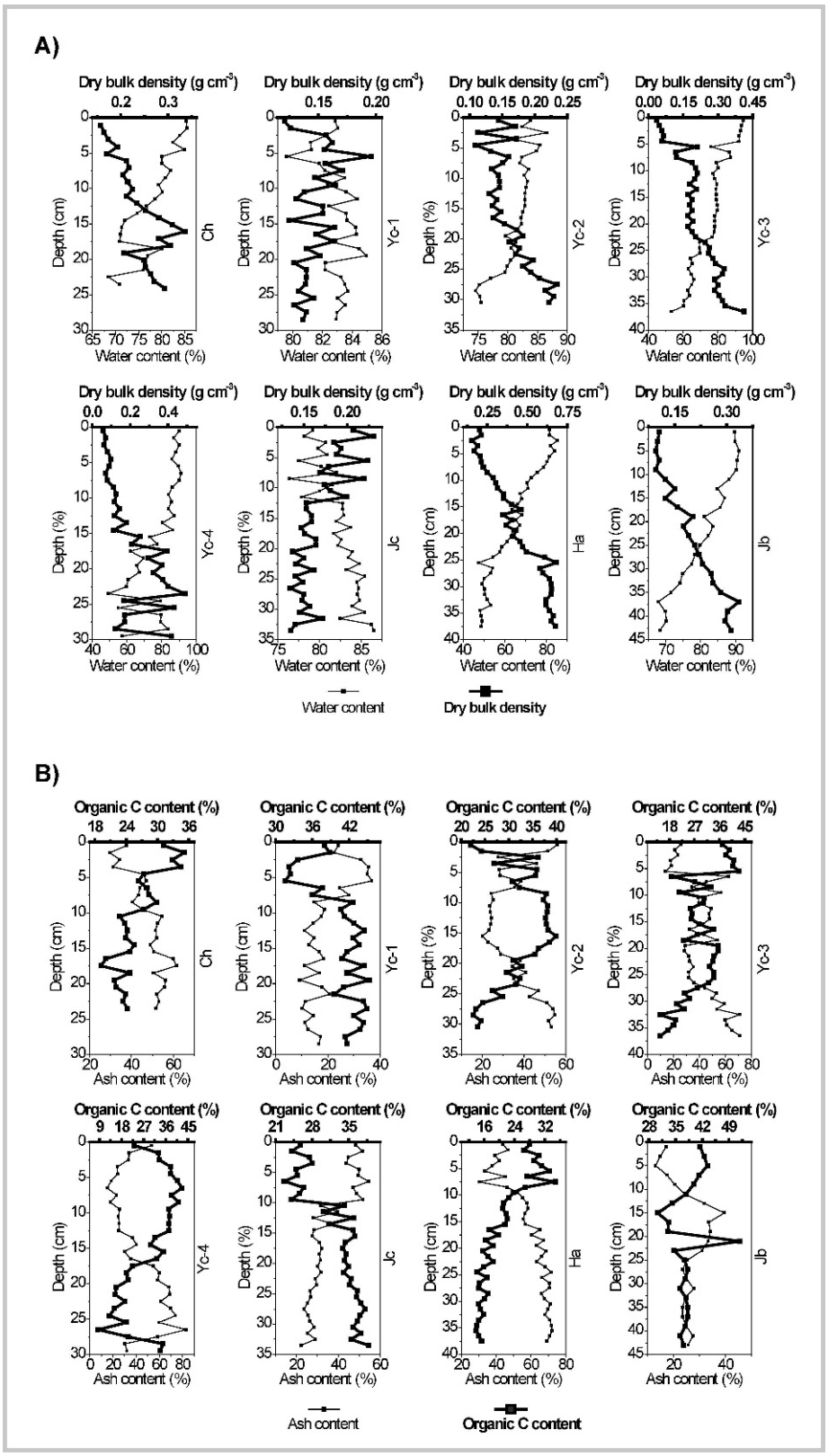
The estimate of short-term C pool, 38.5–52.1 kg C m^{-2}, was smaller than others, for instance 140 kg C m^{-2} for tropical mountain peatlands in the Andes of Ecuador (Chimner and Karberg 2008), but it is larger than that of 14.2–21.1 kg C m^{-2} for temperate wetlands and of 6.8–15.3 kg C m^{-2} for tropical wetlands in Ohio, USA, and in Costa Rica (Bernal and Mitsch 2008). This suggests that C storages vary in different types of peatlands.

Conclusions

This research provides baseline data on RERCA and C pool for 200 years in the Changbai Mountain peatlands, in one of the most important mountain chains in northeast China. The values obtained in this study are comparable to those reported in other regions in the world. An increasing variation of RERCA over time was observed. These results contribute to a better

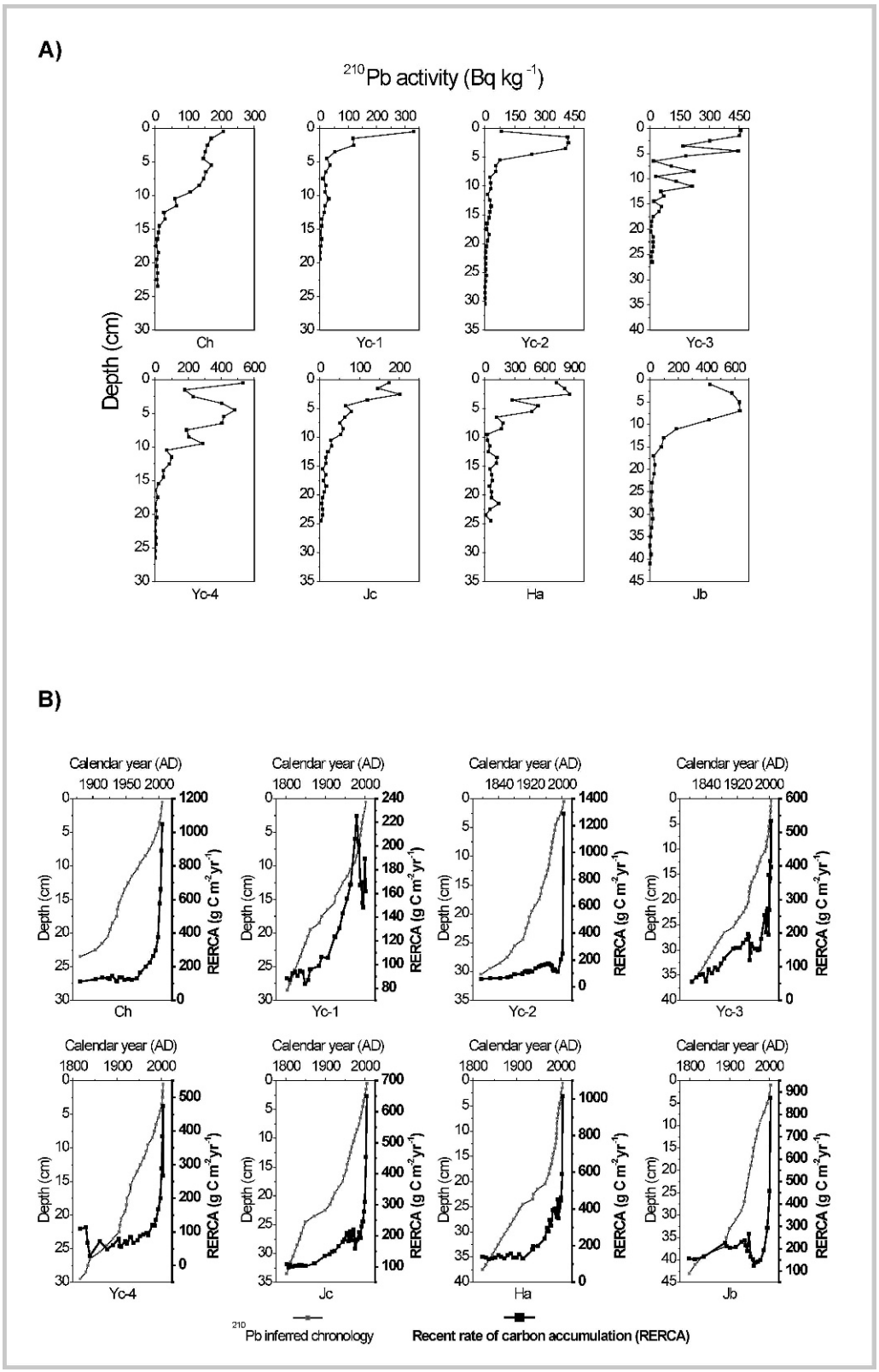
http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

FIGURE 3 (A) Variation of water content (%) and dry bulk density (g cm^{-3}) according to depth (cm); (B) variation of ash content (%) and organic C concentration (%) according to depth (cm).



http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

FIGURE 4 (A) Radioisotope results for ^{210}Pb plotted as activity (Bq kg^{-1}) and depth (cm); (B) ^{210}Pb-inferred chronologies (AD) and recent rate of C accumulation (RERCA, g C m^{-2} yr^{-1}) curves from the 8 peat core section. The small gray squares represent the calculated ages of samples at different depths, with a constructed age-depth model for each profile. The bold squares and lines correspond to RERCA, calculated with the unsupported ^{210}Pb fraction using the CRS model.



http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

TABLE 2 Maximum, minimum, and mean recent rate of C accumulation (RERCA, g C m^{-2} yr^{-1}), with standard deviation (SD) based on number of samples for each profile. For location of profiles, see Figure 2.

Profile	Number	Maximum	Minimum	Mean	SD
Ch	24	1049.2	111.4	269.7	260.3
Yc-1	29	225.7	83.9	134.1	43.5
Yc-2	31	1286.6	57.4	168.2	211.9
Yc-3	37	534.4	56.7	186.3	110.8
Yc-4	30	474.8	27.2	124.2	102.5
Jb	22	872.9	123.7	233.5	159.7
Jc	34	649.9	98.9	187.7	110.3
Ha	38	1016.1	126.9	292.8	176.8

TABLE 3 Comparison between recent rate of C accumulation (RERCA, g C m^{-2} yr^{-1}) and peatland dating method in China and other countries.

Region	RERCA	Dating method	Source
Changbai Mountain peatlands, China ($n = 8$)	124.2 – 292.8	^{210}Pb	This study
	199.6 ± 60.9		
Everglades, USA	94.0 – 161.0	^{137}Cs	Craft and Richardson (1993)
Finnish peatlands	11.8 – 290.3	The pine method	Tolonen and Turunen (1996)
Peatlands of eastern Canada	40.0 – 117.0	^{210}Pb	Turunen et al (2004)

understanding of rarely studied mountain peatlands in China; they may also be helpful for decision-making in the process of pursuing sustainable development in the face of global warming. Considering the complexity of C dynamics in peatland ecosystems and the effects of anthropogenic disturbance on modern peat evolution, more detailed studies are needed to investigate the influences of the spatial and temporal heterogeneities of peat on the rate of C sequestration.

ACKNOWLEDGMENTS

This study received financial support from the National Natural Science Foundation of China (No. 40871089, No. 40830535) and the Knowledge Innovation Program of the Chinese Academy of Sciences (No. KZCX2-YW-309).

REFERENCES

Ali AA*, *Ghaleb B*, *Garneau M*, *Asnong H*, *Loisel J. 2008. Recent peat accumulation rates in minerotrophic peatlands of the Bay James region, eastern Canada, inferred by ^{210}Pb and ^{137}Cs radiometric techniques. *Applied Radiation and Isotopes* 66:1350–1358.

Appleby PG*, *Oldfield F. 1978. The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. *Catena* 5:1–8.

Asada T*, *Warner BG. 2005. Surface peat mass and carbon balance in a hypermaritime peatland. *Soil Science Society of America Journal* 69:549–562.

Beaudoin A. 2003. A comparison of two methods for estimating the organic content of sediments. *Journal of Paleolimnology* 29:387–390.

Beilman DW*, *MacDonald GM*, *Smith LC*, *Reimer PJ. 2009. Carbon accumulation in peatlands of West Siberia over the last 2000 years. *Global Biogeochemical Cycles* 23(GB1012):1–12. http://dx.doi.org/10.1029/2007GB003112.

Bernal B*, *Mitsch WJ. 2008. A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio. *Ecological Engineering* 34:311–323.

Borren W*, *Bleuten W*, *Lapshina ED. 2004. Holocene peat and carbon accumulation rates in the southern taiga of western Siberia. *Quaternary Research* 61:42–51.

Botch MS*, *Kobak KI*, *Vinson TS*, *Kolchugina TP. 1995. Carbon pools and accumulation in peatlands of the former Soviet Union. *Global Biogeochemical Cycles* 9:37–46.

Brown S*, *Roa C*, *Roa CM*, *Yepes LD. 2007. Protocol for the characterization of carbon and water cycles in high-elevation ecosystems of the Andes. *Mountain Research and Development* 27(4):372–375.

Büchler B*, *Bradley R*, *Messerli B*, *Reasoner M. 2004. Understanding climate change in mountains. *Mountain Research and Development* 24(2):176–177.

Charman DJ*, *Garnett MH. 2005. Chronologies for recent peat deposits using wiggle-matched radiocarbon ages: Problems with old carbon contamination. *Radiocarbon* 47(1):135–145.

Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use

Chimner RA, ***Karberg JM***. 2008. Long-term carbon accumulation in two tropical mountain peatlands, Andes Mountain, Ecuador. *Mires and Peat* 3:1–10.
Clymo RS. 1984. The limits to peat bog growth. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 303(1117):605–654.
Clymo RS, ***Turunen J***, ***Tolonen K***. 1998. Carbon accumulation in peatland. *Oikos* 81(2):368–388.
Craft CB, ***Richardson CJ***. 1993. Peat accretion and N, P, and organic C accumulation in nutrient-enriched and unenriched everglades peatlands. *Ecological Applications* 3(3):446–458.
Deng XW, ***Han SJ***, ***Hu YL***, ***Zhou YM***. 2009. Carbon and nitrogen transformations in surface soils under Ermans birch and dark coniferous forests. *Pedosphere* 19(2):230–237.
Gorham E. 1991. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* 1:182–195.
Inisheva LI, ***Golovatskaya EA***. 2002. Elements of carbon balance in oligotrophic bogs. *Russian Journal of Ecology* 33(4):242–248.
IPCC [Intergovernmental Panel on Climate Change]. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. New York, NY: Cambridge University Press.
Joosten H, ***Clarke D***. 2002. *Wise Use of Mires and Peatlands—Background and Principles Including a Framework for Decision-Making*. Jyväskylä, Finland: International Mire Conservation Group and International Peat Society. www.imcg.net/docum/WUMP_Wise_Use_of_Mires_and_Peatlands_book.pdf; accessed on 6 December 2009.
Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623–1627.
Mauquoy D, ***Engelkes T***, ***Groot MHM***, ***Markesteijn F***, ***Oudejans MG***, ***van der Plicht J***, ***van Geel B***. 2002. High-resolution records of late-Holocene climate change and carbon accumulation in two north-west European ombrotrophic peat bogs. *Palaeogeography, Palaeoclimatology, Palaeoecology* 186:275–310.
Otieno DO, ***Wartinger M***, ***Nishiwaki A***, ***Hussain MZ***, ***Muhr J***, ***Borken W***, ***Lischeid G***. 2009. Responses of CO_2 exchange and primary production of the ecosystem components to environmental changes in a mountain peatland. *Ecosystems* 12:590–603.
Reddy KR, ***Delaune RD***, ***Debusk WF***, ***Koch MS***. 1993. Long-term nutrient accumulation rates in the Everglades. *Soil Science Society of America Journal* 57:1147–1155.
Shurpali NJ, ***Verma SB***, ***Kim J***, ***Arkebauer TJ***. 1995. Carbon dioxide exchange in a peatland ecosystem. *Journal of Geophysical Research* 100(D7):14319–14326.
Tolonen K, ***Turunen J***. 1996. Accumulation rates of carbon in mires in Finland and implications for climate change. *Holocene* 6(2):171–178.
Turetsky MR, ***Manning SW***, ***Wieder RK***. 2004. Dating recent peat deposits. *Wetlands* 24(2):324–356.
Turetsky MR, ***Wieder RK***, ***Willams CJ***, ***Vitt DH***. 2000. Organic matter accumulation, peat chemistry, and permafrost melting in peatlands of boreal Alberta. *Ecoscience* 7:379–392.
Turunen J, ***Tahvanainen T***, ***Tolonen K***. 2001. Carbon accumulation in West Siberian mires, Russia. *Global Biogeochemical Cycles* 15:285–296.
Turunen J, ***Roulet NT***, ***Moore TR***. 2004. Nitrogen deposition and increased carbon accumulation in ombrotrophic peatlands in eastern Canada. *Global Bioecological Cycles* 18(GB3002):1–12. http://dx.doi.org/10.1029/2003GB002154.
Turunen J, ***Tomppo E***, ***Tolonen K***, ***Reinkainen A***. 2002. Estimation carbon accumulation rates of undrained mires in Finland—Application to boreal and subarctic regions. *Holocene* 12:69–80.
Ukonmaanaho L, ***Nieminen TM***, ***Rausch N***, ***Cheburkin A***, ***LeRoux G***, ***Shotyk W***. 2006. Recent organic matter accumulation in relation to some climatic factors in ombrotrophic peat bogs near heavy metal emission sources in Finland. *Global and Planetary Change* 53:259–268.
Vitt DH, ***Halsey LA***, ***Bauer IE***, ***Campbell C***. 2000. Spatial and temporal trends in carbon storage of peatlands of continental western Canada through the Holocene. *Canadian Journal of Earth Sciences* 37:683–693.
Wang GP, ***Liu JS***, ***Tang J***. 2004. The long-term nutrient accumulation with respect to anthropogenic impacts in the sediments from two freshwater marshes (Xianghai wetlands, northeast China). *Water Research* 38:4462–4474.
Zhang N, ***Yu ZL***, ***Yu GR***, ***Wu JG***. 2007. Scaling up ecosystem productivity from patch to landscape: A case study of Changbai Mountain Nature Reserve, China. *Landscape Ecology* 22:303–315.
Zhang WJ, ***Xiao HA***, ***Tong CL***, ***Su YR***, ***Xiang WS***, ***Huang DY***, ***Syers JK***, ***Wu JS***. 2008. Estimating organic carbon storage in temperate wetland profiles in northeast China. *Geoderma* 146:311–316.
Zhang YJ, ***Xu M***, ***Adams J***, ***Wang XC***. 2009. Can Landsat imagery detect tree line dynamics? *International Journal of Remote Sensing* 30(5):1327–1340.
Zhao HY, ***Leng XT***, ***Wang SZ***. 2002. Distribution, accumulation rate of peat in the Changbaishan Mountains and climate change in Holocene [in Chinese with English abstract]. *Journal of Mountain Science* 20(5):513–518.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00054.1
Downloaded From: https://staging.bioone.org/journals/Mountain-Research-and-Development on 20 Apr 2025
Terms of Use: https://staging.bioone.org/terms-of-use