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Trace metals of needles and litter in timberline forests in the Eastern of Tibetan Plateau, China

Ronggui Tang[a,b], Ji Luo[a,*], Peijun Yang[c], Jia She[a,b], Youchao Chen[a,b], Yiwen Gong[a], Jun Zhou[a]

[a] Key Laboratory of Mountain Surface Processes and Ecological Regulation, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences & Ministry of Water Conservancy, Chengdu, China
[b] University of the Chinese Academy of Sciences, Beijing, China
[c] School of Biological Sciences and Engineering, Shaanxi University of Technology, Hanzhong, Shaanxi 723000, China

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ABSTRACT

Concentrations of six trace elements (Cr, Pb, Cd, Co, V and Ni) in needles and litter of the fir (*Picea spinulosa*) and spruce (*Abies georgei* var. *smithii*) collected respectively at 42 sites and 18 sites in timberline forests in Heng Duan mountains, China, are reported in the present study. Mean concentrations of trace metals (Cr, Co, Ni, V, Cd and Pb) were 3.07 mg kg^{-1}, 2.48 mg kg^{-1}, 39.81 mg kg^{-1}, 8.12 mg kg^{-1}, 0.13 mg kg^{-1}, 4.26 mg kg^{-1} respectively in litter and 0.89 mg kg^{-1}, 0.38 mg kg^{-1}, 7.33 mg kg^{-1}, 0.38 mg kg^{-1}, 0.92 mg kg^{-1} and 0.92 mg kg^{-1} in needles. In contrast to needles, all of elements in both parts were significantly enriched in the litter. Translocation of trace metals in the needles senescence before falling off may be confirmed, but additional investigations should be performed. Geostatistical analysis of Arcgis 10.0 was carried out in order to present the spacial distribution of trace metals in needles. The mine areas had relatively high levels of trace metals according to our original data. Trace metal concentrations of three belt transects, which could be the results of responding to the effects of the monsoon, were different. We deduced that mineral resources and climatic factor (southeasterly and southwesterly monsoon) could be possible contributions regarding the distribution of trace metals in needles. Depending on the results, we proposed a simple and novel way of the bio-monitor of trace metal. This method maybe used as a preliminary judgment to the possible source of trace metals. This study also is the first report on the spatial distribution of needle trace metals in the timberline forests by geostatistical analysis. Such biological monitoring is needed to provide databases which will facilitate the next step of this kind of studies which would be to evaluate levels of trace metal accumulation. In order to better understand trace metals of our study area, more sampling sites, climate data, soil data of trace metal, back trajectory studies of air mass and the continuous monitor should be good choices.

1. Introduction

Trace metals may create adverse effects on the environment and human health depending upon their bioavailability and toxicity in various environmental compartments (Pacyna and Pacyna, 2001). Many trace metals are ubiquitous in various raw materials, such as fossil fuels and metal ores, as well as in industrial products (Pacyna and Pacyna, 2001). Some elements, such as Co, Ni and Zn are essential for various metabolic processes with trace amounts in organisms but can also be toxic to these organisms at high concentrations (Clemens, 2006; Gandois and Probst, 2012). Some other elements, especially toxic metallic elements (Pb, Cd, Cr) have been reported to reduce plant growth and development at high concentrations, causing death of plants in extreme cases (Kuang et al., 2007).

Previous studies of trace metal in needles mainly are limited to the region which is located in the nearby zone of smelters, urban and industrial areas (Gratton et al., 2000). *Pinus pinea* L. is suitable to assess the pollution of trace metal in industrial areas

* Corresponding author at: Institute of Mountain Hazards and Environment, Chinese Academy of Sciences & Ministry of Water Conservancy, #9, Block 4, Renminnan Road, Chengdu 610041, China. Tel.: +86 13548109631; fax: +86 028 85222258.
E-mail address: tangrongguiztx@163.com (J. Luo).

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and pine needles could be considered as a suitable bio-monitor for atmospheric pollution (Aksoy and Öztürk, 1997; Mingorance et al., 2007; Mingorance et al., 2005; Oliva and Mingorance, 2004; Rossini Oliva and Mingorance, 2006; Sawidis et al., 1995). High concentrations of trace metals (Pb, Cr, and Cd) in needles of Masson Pine growing near industrial sources are reported, which indicate that industrial activities heavily influence the contents of trace metals in needles (Sun et al., 2010). Moreover, needles could be used as a bio-monitor of airborne trace element pollution (Aboal et al., 2004; Al-Alawi and Mandiwana, 2007; Čeburnis and Steinnes, 2000; Holoubek et al., 2000; Trimbacher and Weiss, 2004). Although a few studies focus on the trace metal in the soil under natural plants (Sheng et al., 2012; Wang et al., 2009; Wu et al., 2011), little attention has been paid to trace metals of fragile ecology timberline areas. There are not any perceptible anthropogenic activities and human intrusion is very rare. However, human population, urbanization and industrialization continue to expand. The emission of trace metals into the atmosphere and the resultant hazards to human life are growing up to be a matter of great concern (Sun et al., 2010, 2011). Trace metal pollutants are brought to remote mountain areas by long-range atmospheric transport and accumulate in the soil and plants by wet or dry deposition (Gandois and Probst, 2012; Migon et al., 1997; Wu et al., 2011). The majority of trace metals from the atmosphere, which are intercepted by plant canopies, are the main source of natural forest areas. On step further, trace metals could be trapped in the epicuticular waxes on the needles surface following atmospheric particulate deposition because of large surface area (Gandois and Probst, 2012). Furthermore, trace metal concentration levels in needles rarely are assessed in low contamination environment (Gandois and Probst, 2012). Kuang et al. report that trace metals (Pb, Cd, etc.) may threaten the health of Masson pine (Kuang et al., 2007). Apparently, the determination of trace metals in needle samples is extremely important for monitoring environmental pollution.

Under global climate warming and metabolic changing (Dillon et al., 2010), in addition to the fact that timberline forests are very sensitive to input of pollutants, also the enhanced photosynthesis or respiration is likely to boost the absorption, transfer, and accumulation of many trace metals. 30–40 years ago, forest's health received a major concern from scientists and the general public in Europe, and two levels of the forest monitoring system have been established successfully (Shparyk and Parpan, 2004). However, health study of timberline forests in the Eastern of the Tibetan Plateau is rare. The eastern Tibetan Plateau is just an isolated region and remote from anthropogenic activities. Due to global change and regional economic development, a large amount of fossil fuel combustion and smelting produce different kinds of pollution. Because these mountain areas are the head water of many large rivers such as the Salween River, Lancang River, Jinsha River, long-term and extensive pollution can be a severe threat to its ecosystem stability (especially to the fragile timberline forest) and downstream (Luo et al., 2013a). As a result, bio-monitor of trace metals in timberline forests becomes increasingly significant. In this present study, the fir (*Picea spinulosa*) and spruce (*Abies georgei* var. *smithii*) are selected as a bio-monitor of trace metals for several reasons; (1) the similarity of nutrient uptake between spruce and fir, data from the two species are comparable (Yanai et al., 2009); (2) they grow abundantly in timberline; have a widely geographical range in the mountains of southwest, China; and (3) sampling, identification is easy (Çelik et al., 2005). The aim of the present study is (1) to investigate the current regional levels and distributional characterization of Cr, Co, Ni, V, Cd and Pb using needles of fir and spruce in timberline forests in Hengduan mountains, Eastern Tibetan Plateau, China; (2) to explore possible sources and influence factors of trace metal in needle.

2. Materials and method

2.1. Study sites

Needles samples were separately collected from July to August, 2012, in timberline forests of the middle of the Hengduan Mountains, eastern Tibetan Plateau, China. The Hengduan mountains are situated in western Sichuan and Yunnan provinces in China and eastern Tibetan Autonomous Region, China. It is a series of mountain ranges that stretch in the north-south direction, with nearly 900 km long, 4000–5000 m above sea level, and commonly 1000 m or more elevation difference between mountain valleys. The climate of Hengduan mountain is affected by westerly circulation (south branch), Indian Ocean monsoon and Pacific Ocean monsoon. It is also the only region containing both the Pacific and Indian Ocean water system (Yao et al., 2013). Pacific and Indian Ocean water system produced southeasterly and southwesterly monsoon respectively in the summer. The southwesterly monsoon was landed and developed northward from India and Myanmar in May each year. The air mass southeasterly monsoon from Pacific Ocean passed though Sichuan province and was northwestard taken to our study area (Wang et al., 1983). There are for two seasons: the dry season and the wet season, with a deposition ranging 903–2595 mm. Most of (~85%) precipitation is concentrated in June, July and August. In the dry season, the region is mainly dominated by westerly circulation, with scarce rainfall and dry air (Cong et al., 2010). The annual mean temperature ranges from 14–16 °C and the mean temperature in the coldest month was 6–9 °C.

Needle materials were collected at 42 sites and litter samples were collected at 18 sites (Fig. 1) in Heng Duan mountains, where mentioned vegetation species were abundant. In order to understand the influence of further large scale of air mass, differences of trace metal concentrations were analyzed among three belt transects, which were divided into TA, TB and TC due to the climatic factor (Figs. 1 and 5). TA included S29, S30, S31, S42, S25, S40, S41, S19, S20, S21, S22, S23, S18, S24, S39, S28 and S26; TB included S35, S36, S27 and S37; and TC included S2, S32, S33, S3, S4, S38, S1, S6, S7, S8, S5, S12, S13, S16, S17, S9, S10, S11, S14, S15 and S34. "S" stood for the sample site. TA was more influenced by the southwesterly monsoon, while TB was mainly influenced by southeasterly monsoon. As for TC, there was scarcely any influence of southeasterly and southwesterly monsoon compared with TA and TB.

2.2. Sampling

At each sample point, three 20 m × 30 m sample plots were established as replicates (Fig. 2). Each sample plot was composed of twenty-four 5 m × 5 m quadrants (Pouyat and McDonnell, 1991). Twelve quadrants in each sample plot were randomly selected for sampling like the cell A (Luo et al., 2013b). Needles were collected from 1 to 2 trees in each quadrant. From those trees, the age of needles, which were gathered from three years or older branches 2 m above the ground in all directions (Čeburnis and Steinnes, 2000), should be one or two years. Needle samples from different trees and litter samples from the latest deciduous needles (just including needles with rare decomposing) under the corresponding conifer tree were homogeneously mixed respectively. The latest litter was judged by an experienced specialist who worked on the study of decomposition of litter many years. All samples were kept in plastic bags in a cold room. After transferred to laboratory, the samples were rinsed with distilled water for about 1 min to remove materials deposited on needle and litter surfaces so that the results of chemical analysis of samples collected in various locations could be compared (Dmuchowski and Bytnerowicz, 1995; Karweta and Poborski, 1988). After the attachments of litter surface were eliminated, we would easily prove the transfer of trace metals between