

# Metal Accumulation in Lichens as a Tool for Assessing Atmospheric Contamination in a Natural Park

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## ABSTRACT

Motor vehicles passing through natural areas could contribute to the air pollution that most likely causes biodiversity losses and decreases air quality. This study assessed the impact of tourism on atmospheric metal pollution in Khao Yai National Park (KYNP), Thailand. Native thalli of the epiphytic lichen *Parmotrema tinctorum* were collected during the rainy period at a total of eleven sampling sites: three sites in forested (no traffic), four sites in accommodation (low-moderate traffic) and four sites in parking (moderate-high traffic) areas in KYNP. Nine traffic-related metals, including As, Cd, Cr, Cu, Fe, Pb, Sb, V and Zn, were detected using inductively coupled plasma mass spectrometry (ICP-MS). The concentrations of most metals did not show significant differences between the higher traffic intensity areas and the no traffic area, and the concentrations of the metals were in the range of their background concentrations. Only Cr and V, metals related to motor vehicles, were identified at the accommodation sites at significantly higher concentrations (Cr=3.4 µg/g, V=1.33 µg/g) than their baseline concentrations (Cr=1.4 µg/g, V=0.96 µg/g). These two metals have adverse effects on humans, plants, lichens and other organisms. Bioaccumulation ratios (B ratios) indicated that most metals at most sampling sites did not bioaccumulate. No metal demonstrated high or severe bioaccumulation. This result suggests that the impact of tourism on atmospheric metal pollution in the rainy period at the KYNP was modest. It also affirms the ability of lichen as an effective tool for assessing atmospheric contamination in natural areas.

## 1. INTRODUCTION

Natural parks are generally rich in biodiversity, provide increased air quality and serve as recreational sites for family vacations and tourists. Most national parks are modified to facilitate and support tourism, such as the construction of access roads, accommodations and camping sites. Motor vehicles passing through these areas could affect both biodiversity and the purity of the air (Liu et al., 2018; Nascimbene et al., 2014). Several pollutants are released from motor vehicles, such as heavy metals (Koz et al., 2010; Yemets et al., 2014; Zhao et al., 2019). They can pollute the air and are toxic to living

organisms, especially sensitive species such as lichens, bryophytes and aerial plants, leading to biodiversity losses (Spellerberg, 1998). In addition, park authorities and visitors are most likely affected by their toxicity (Kampa and Castanas, 2008). The need to understand the impact of tourism on environmental quality in natural areas is crucial for sustainable tourism, organisms and ecosystems.

Lichens are symbiotic organisms of fungi and algae and/or cyanobacteria. They have no root system or waxy cuticle and rely on atmospheric water and nutrients for growth and survival. These characteristic enable them to serve as great bioaccumulators of

atmospheric deposition (Bargagli and Mikhailova, 2002; Garty and Garty-Spitz, 2015). Unlike gaseous pollutants i.e., NO<sub>x</sub> and SO<sub>x</sub>, lichens are tolerant to metals. They can accumulate amounts of metals above their need. The tolerance mechanism is very complex and still not fully understood. Lichen substances or secondary metabolites (e.g., usnic acid, norstictic acid and psoromic acid) play an important role in the tolerance mechanism (Bačkor and Loppi, 2009). Pawlik-Skowrońska and Bačkor (2011) found a strongly positive correlation between the amounts of secondary metabolites and Zn/Pb accumulation in the studied lichens. Oxalates also showed a potential mechanism for extracellular metal detoxification (Pawlik-Skowrońska et al., 2006).

Biomonitoring with lichens is a cost-effective technique that is easy to implement and requires no electricity for installation and operation, allowing the technique to be used in natural/remote areas (Conti et al., 2009; Loppi, 2014) as opposed to conventional air monitoring instruments. The lichen *Parmotrema tinctorum* (Despr. ex Nyl.) Hale is a cosmopolitan species (Louwhoff and Elix, 2000). In Thailand, it is found in cool, humid, moderate-high light intensity and relatively unpolluted areas (e.g., mountain areas). Its potential to be used as a bioindicator/biomonitoring species of air quality has been tested and confirmed by several scientists (Boonpeng et al., 2018; Koch et al., 2016; Port et al., 2018). In Thailand, it was used as a biomonitor of atmospheric deposition for assessing air quality in the Map Ta Phut petrochemical complex (Boonpeng et al., 2017a; Boonpeng et al., 2017b; Boonpeng et al., 2018). In Brazil, it was used as a bioaccumulator of atmospheric pollutants in urban and forested areas in the Rio Grande do Sul (Koch et al., 2016; Port et al., 2018), and in the urban area of the Porto Alegre (Käffer et al., 2012). It was also used to monitor radionuclides around the Fukushima Dai-ichi Nuclear Power Plant in Tsukuba city, Japan (Ohmura et al., 2015).

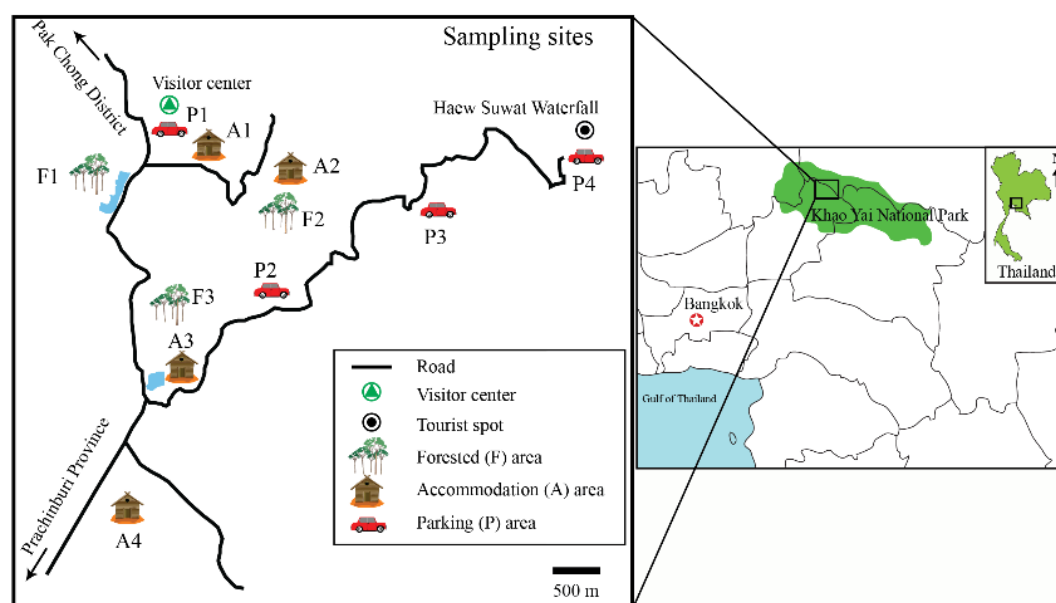
Khao Yai National Park (KYNP) was announced as a World Heritage Site in 2005 by the United Nations Educational, Scientific and Cultural Organization (UNESCO). Due to its high biodiversity of both flora and fauna, beautiful scenic views and

waterfalls, cool weather, and proximity to Bangkok, KYNP is one of the most popular tourist places in Thailand. The impacts of tourism on soil, vegetation, wildlife and water in the area were previously documented (Phumsathan, 2010), but the impact of the area on air quality has never been determined. The number of visitors in the park has sharply increased from ca. 750,000 in 2010 to 1,500,000 visitors in 2018 (2 fold increase); similarly, the number of motor vehicles (cars and motorcycles) has steadily increased from ca. 280,000 to 380,000 vehicles (1.4 fold increase) over the last 6 years (Figure 3). The result of this study can reveal the situation of air quality in KYNP. The objectives of this study were to (i) use the lichen *P. tinctorum* to monitor the concentrations of traffic-related metals in the air in KYNP; and (ii) assess the impact of tourism on atmospheric metal pollution during the rainy season in KYNP. We hypothesized that motor vehicle traffic can contribute to the level of metal pollutants in the study area.

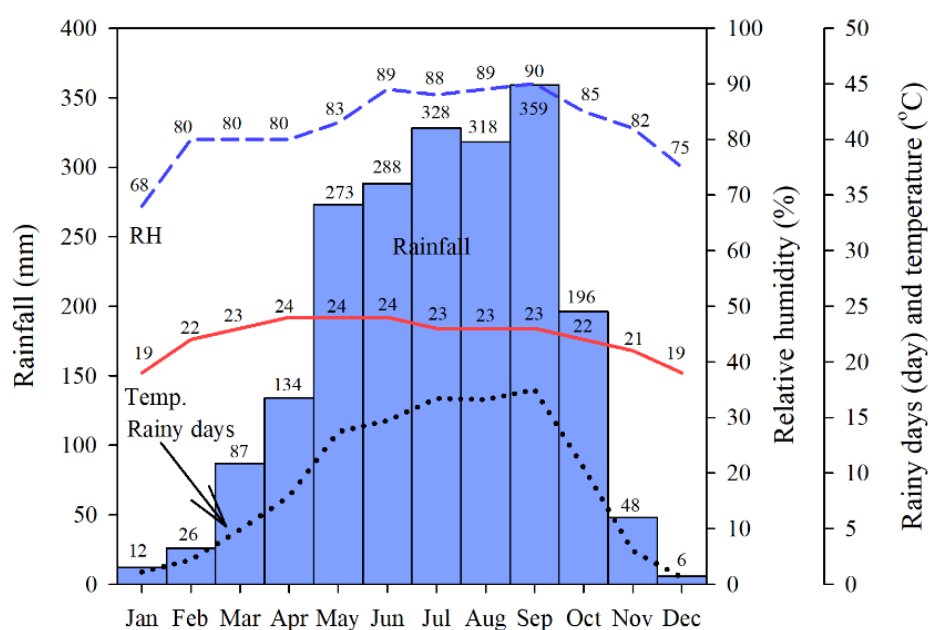
## 2. METHODOLOGY

### 2.1 Study area

Khao Yai National Park (KYNP) is located in the areas of Nakhon Nayok, Prachinburi, Saraburi and Nakhon Ratchasima Provinces in Thailand, covering an area of 2,169 km<sup>2</sup> with a complex terrain and elevations ranging from ca. 50 to 1,351 meters above sea level (m.a.s.l.), the park is approximately 170 km northeast of Bangkok (Figure 1). Climatic conditions in the area are shown in Figure 2. The annual cumulative rainfall is 2,073 mm, the rainy period occurs from April to October (7 months), and the dry period occurs from November to March (5 months) (Brockelman et al., 2017). The monthly relative humidity (RH) ranges from 68 to 90%, which is consistent with the amount of rainfall and rain events. The monthly average temperature ranges from 19 to 24 °C; April, May and June are the hottest months (>23.7 °C); and November, December and January are cool months (<21 °C). A high number of visitors and motor vehicles appear in the tourist season from October to January and especially in December and January when there are >180,000 visitors per month and >40,000 vehicles per month (Figure 3).



**Figure 1.** Location of eleven sampling sites in the forested (F), accommodation (A), and parking (P) areas in Khao Yai National Park in Thailand.



**Figure 2.** Monthly average climatic conditions in Khao Yai National Park include temperature (temp., solid red line), cumulative rainfall (blue bars) and rainy days (dotted black line), which were averaged from 1994 to 2014 (modified from Brockelman et al., 2017), and monthly average relative humidity (RH, dashed blue line), which was measured at the canopy of the tropical rain forest near the Khao Yai Meteorological Station from 2013 to 2014 (Mongkol Phaengphech, unpublished data).

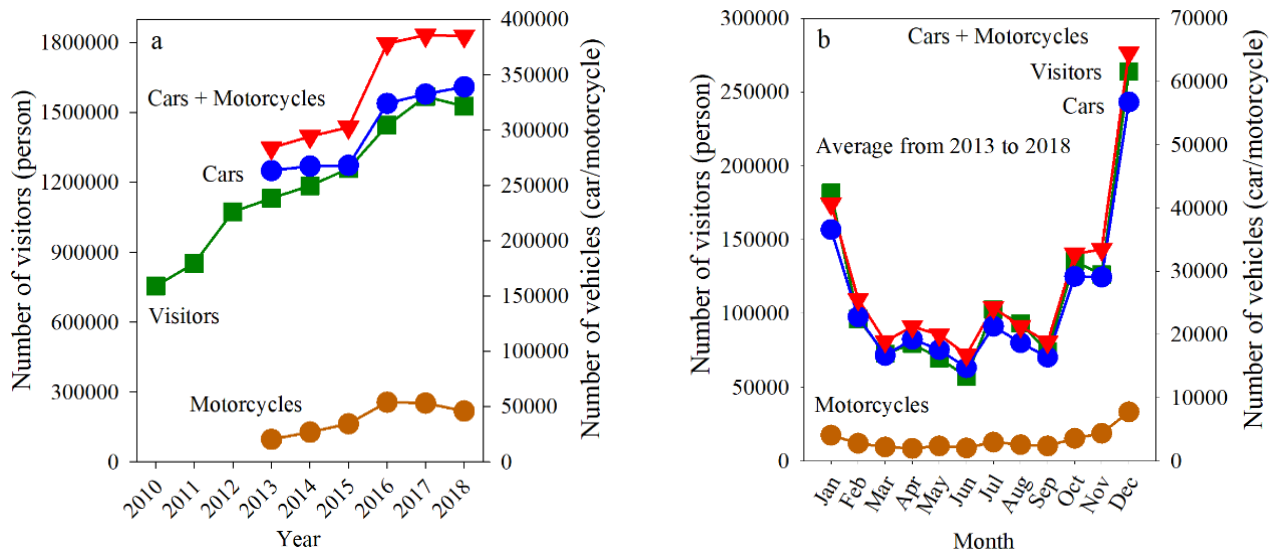
## 2.2 Lichen collection and sampling sites

The native (*in situ*) thalli of the epiphytic foliose (lobe-like) lichen *P. tinctorum* (Figure 4) were collected early in the rainy season on June 2, 2018. This lichen species was selected because it was found at all sampling sites and was easy to identify and collect. The zonation of a lichen thallus probably shows different element concentrations due to different ages (Bargagli and Mikhailova, 2002);

therefore, only the peripheral parts of the thalli, approximately 2-4 cm from the lobe tips, were collected. This zone corresponds to 2-3 years (Wannalux, 2014); thus, it should represent element accumulations during the last 2-3 years. Because the same tree species cannot be observed at all sampling sites, the lichen samples were then picked up from various tree species, on 3-5 trees, approximately 2-4 meters above the ground, at each of the eleven

sampling sites in the forested (F1 to F3), accommodation (A1 to A4) and parking (P1 to P4) areas (Table 1, Figure 1), with 10-15 thallus fragments each (ca. 2-3 g air-dry weight, and 1-2 fragments from each thallus). Samples from each site were then divided into 5 portions for chemical analysis. These areas were chosen based on their traffic levels, which were estimated based on the

intensity of motor vehicles passing through: 0 (no traffic, forested), 1 (low-moderate traffic, accommodation) and 2 (moderate-high traffic, parking). At the forested sites, the samples were collected within the forests at least 1 km from nearby roads. At the accommodation sites, the samples were taken at the roadside within the areas, and at the parking sites, the samples were picked up at the center of the areas.



**Figure 3.** Annual (a) and monthly (b) number of visitors and motor vehicles in Khao Yai National Park. The brown circles represent motorcycles, the blue circles represent cars, the red triangles represent both types of vehicles, and the green squares represent visitors (Department of National Parks, Wildlife and Plant Conservation, 2019).



**Figure 4.** The lichen sample and sampling site. (a) the epiphytic lichen *Parmotrema tinctorum* (Despr. ex Nyl.) Hale, and (b) collecting lichen samples on a tree at a sampling site in the parking area in KYNP.

**Table 1.** Description of the sampling sites in Khao Yai National Park in Thailand.

Sampling mode	Sampling site	Latitude Longitude	Local name	Elevation (m.a.s.l.)	Traffic level
Forested (F)	F1	14°25'58"N 101°21'59"E	Mo Singto	803	0 (no traffic)
	F2	14°25'50"N 101°23'04"E	Golf Course	738	0
	F3	14°25'11"N 101°22'25"E	Nong Khing	758	0



**Table 1.** Description of the sampling sites in Khao Yai National Park in Thailand (cont.).

Sampling mode	Sampling site	Latitude Longitude	Local name	Elevation (m.a.s.l.)	Traffic level
Accommodation (A)	A1	14°26'01''N 101°22'47''E	Suratsawadee Young Camp	722	1 (low-moderate)
	A2	14°26'07''N 101°23'04''E	Tiewthus Zone	771	1
	A3	14°24'52''N 101°22'29''E	Khao Yai Training Center 2	754	1
	A4	14°24'02''N 101°22'09''E	Thanarat Zone	766	1
Parking (P)	P1	14°26'17''N 101°22'20''E	Khao Yai National Park Office	741	2 (moderate-high)
	P2	14°25'23''N 101°23'11''E	Lam Ta Khong Camping Ground	725	2
	P3	14°25'52''N 101°24'01''E	Pha Kluai Mai Camping Ground	701	2
	P4	14°26'05''N 101°24'52''E	Haew Suwat Waterfall	651	2

### 2.3 Metal analysis

Lichen samples were processed in the Analytical Chemical Laboratory at Ramkhamhaeng University and carefully cleaned to remove extraneous materials such as mosses and barks. Analytical method for metals in the lichens was based on the procedure done by Sangiamdee (2014). Unwashed lichen material was immersed in liquid nitrogen and subsequently pulverized and homogenized with a ceramic mortar and pestle. It was then separated through a 500-µm sieve plate. Approximately 200 mg of lichen powder was mineralized with 2 mL of conc. HNO<sub>3</sub> in a block digestion system (AIM 600, Aim Lab, Australia) at 150 °C for 150 min. The concentrations of nine traffic-related metals, including As, Cd, Cr, Cu, Fe, Pb, Sb, V and Zn, were determined using inductively coupled plasma mass spectrometry (ICP-MS, NexION 300Q, PerkinElmer, USA). The analytical quality was assessed with the certified reference material BCR-482 (lichen, *Pseudevernia furfuracea*) and spike samples. The recoveries (n=7) ranged between 92.3% (Sb) and 99.5% (Cr). The analytical precision, expressed as percent relative standard deviation (%RSD), was less than 6% (n=7) for all analyzed metals.

### 2.4 Data interpretation

The concentration of each metal from each sampling site was compared with its background concentration to determine the variation from its baseline concentration. The background concentrations were obtained from the same lichen species

(*P. tinctorum*), which were collected on various tree species in all seasons at KYNP (Boonpeng, 2016; Boonpeng et al., 2017b). The results were subsequently interpreted using bioaccumulation ratios (B ratio) (B ratio=mean concentration of an analyzed metal in a sampling site divided by mean background concentration of that metal): ≤1.0=absence of bioaccumulation, >1.0-2.1=low bioaccumulation, >2.1-3.4=moderate bioaccumulation, >3.4-4.9=high bioaccumulation, and >4.9=severe bioaccumulation (Cecconi et al., 2019).

### 2.5 Statistical analysis

The amount of each metal from all the sampling sites was tested for normality using Shapiro-Wilk's test (p<0.05). The metals with normal distributions (Cr and Cu) were examined using one-way ANOVA with Tukey's test for post hoc comparison, whereas those with non-normal distributions (As, Cd, Fe, Pb, Sb, V, Zn) were tested using the Kruskal-Wallis test for analyzing statistically significant differences (p<0.05). Spearman correlation was used to test the relationship between traffic levels and metal contents in the lichen samples. All statistical analyses were performed using SPSS V. 22 (IBM Corp, NY, USA), and graphs were constructed using SigmaPlot 11.0 (Systat Software, CA, USA).

## 3. RESULTS AND DISCUSSION

### 3.1 Metal concentrations in lichens

The concentrations of the nine traffic-related metals analyzed from the native lichen *P. tinctorum*

at the eleven sampling sites in KYNP are shown in Table 2 and Figure 5. The data revealed that tourism had a minor impact on the atmospheric metal pollution in the park. Concentrations of most metals were not significantly different in the higher traffic intense areas (accommodation or parking) than in the no traffic intensity area (forested). However, Cr and V had significantly higher concentrations in the accommodation and parking areas than in the forested area (Figure 5,  $p < 0.05$ ). No metal showed a significantly positive correlation with the estimated traffic intensity. In addition, 88 (89%) out of 99 mean concentrations of all metals at all sampling sites were below or in the range of the background concentrations of the metals. All means of As, Cd, Fe, Pb and Zn could be acceptable as the baseline concentrations, while 5, 2, 2 and 2 mean values of Cr, Cu, Sb and V, respectively, exceeded the range of their baseline concentrations (Table 2). The highest concentrations

of Cu and Sb were observed at the forested sites, and geogenic and biomass decomposition could be sources of these metals. Chromium and vanadium, which are metals related to motor vehicles, showed peak concentrations at the accommodation sites.

### 3.2 Bioaccumulation ratios

The bioaccumulation ratios (B ratios) reveal variation in each metal at each sampling site compared to its background concentration (Table 3). Based on the B ratios, most metals, 77.8%, demonstrated an absence of bioaccumulation, 17.2% of the metals demonstrated low bioaccumulation, only 5% of the metals demonstrated moderate bioaccumulation (Cr, Sb), and no metal demonstrated high or severe bioaccumulation (Table 3). According to their concentrations, Cr was moderately bioaccumulated at three accommodation sites (A1, A2, A4), while Sb occurred at 2 forested sites (F1, F2).

**Table 2.** Means and Standard Deviations (SD) (n=5) of 9 traffic-related metals in the native lichen *Parmotrema tinctorum* collected at eleven sampling sites in the Forested (F), Accommodation (A) and Parking (P) areas in Khao Yai National Park, and the background element concentrations (BECs) obtained from previous studies (Boonpeng, 2016; Boonpeng et al., 2017b).

Sampling site	Mean±SD (µg/g dry weight)								
	As	Cd	Cr	Cu	Fe	Pb	Sb	V	Zn
F1	0.15±0.04	0.07±0.06	1.6±0.8	5.2±1.0	222±80	0.6±0.7	0.11±0.16	0.74±0.20	13±5
F2	0.12±0.02	0.05±0.03	1.8±1.6	6.6±1.1	268±159	BDL	0.15±0.17	0.76±0.13	14±6
F3	0.15±0.02	0.07±0.04	2.7±0.8	2.8±1.3	201±43	2.1±1.8	0.04±0.03	0.92±0.31	14±5
A1	0.19±0.09	0.02±0.02	3.6±0.8	2.0±1.5	271±121	1.2±1.5	0.03±0.01	1.00±0.58	9±3
A2	0.13±0.02	0.05±0.03	3.8±0.7	3.0±2.0	265±48	2.3±0.7	0.02±0.02	0.97±0.28	10±3
A3	0.24±0.07	0.09±0.06	2.9±0.3	4.4±2.4	200±26	3.6±3.6	0.04±0.01	1.35±0.37	17±14
A4	0.33±0.16	0.09±0.06	3.4±1.0	4.4±3.3	411±258	2.1±1.8	0.06±0.04	2.02±2.06	7±9
P1	0.16±0.02	BDL	0.6±0.2	1.8±1.1	234±87	1.8±1.7	0.04±0.01	0.99±0.27	20±9
P2	0.17±0.03	0.08±0.07	1.8±0.7	6.2±0.6	353±87	1.8±1.0	0.02±0.02	1.09±0.19	17±5
P3	0.15±0.02	0.02±0.02	1.2±1.0	1.9±1.1	202±56	1.6±1.6	0.03±0.01	0.99±0.25	21±8
P4	0.11±0.04	BDL	BDL	1.1±0.1	246±106	1.7±1.7	0.02±0.01	1.22±0.56	9±4
Mean BEC	0.27	0.11	1.4	3.4	340	4.1	0.04	0.96	20
Range of BEC	0.16-0.35	0.04-0.15	0.4-2.1	1.4-5.6	211-450	1.1-6.8	0.02-0.08	0.44-1.25	11-26

BDL = Below Detection Limit, Cd = 0.013 µg/g, Cr = 0.100 µg/g, Pb = 0.07 µg/g.

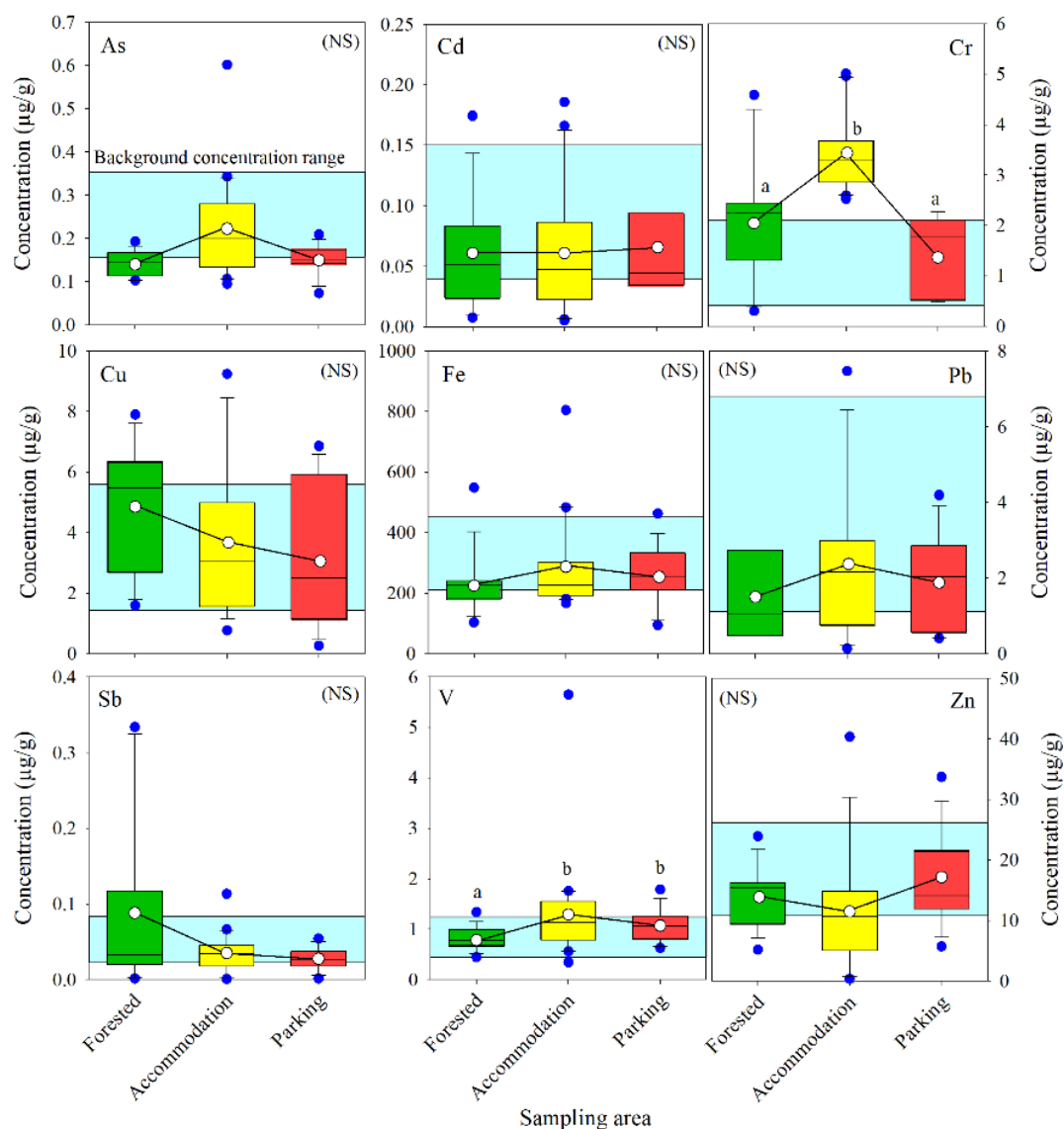
**Table 3.** Bioaccumulation ratios (B ratios) of metals in the native lichen *Parmotrema tinctorum* at eleven sampling sites in the Forested (F), Accommodation (A) and Parking (P) areas in Khao Yai National Park.

Sampling site	B ratio								
	As	Cd	Cr	Cu	Fe	Pb	Sb	V	Zn
F1	0.5	0.6	1.2	1.5	0.7	0.1	2.4	0.8	0.7
F2	0.4	0.4	1.3	1.9	0.8	<0.07*	3.4	0.8	0.7
F3	0.6	0.7	2.0	0.8	0.6	0.5	0.9	1.0	0.7
A1	0.7	0.2	2.6	0.6	0.8	0.3	0.6	1.0	0.4
A2	0.5	0.4	2.8	0.9	0.8	0.6	0.4	1.0	0.5
A3	0.9	0.8	2.1	1.3	0.6	0.9	0.8	1.4	0.8

**Table 3.** Bioaccumulation ratios (B ratios) of metals in the native lichen *Parmotrema tinctorum* at eleven sampling sites in the Forested (F), Accommodation (A) and Parking (P) areas in Khao Yai National Park. (cont.).

Sampling site	B ratio								
	As	Cd	Cr	Cu	Fe	Pb	Sb	V	Zn
A4	1.2	0.8	<b>2.4</b>	1.3	1.2	0.5	1.3	2.1	0.3
P1	0.6	<0.013*	0.4	0.5	0.7	0.5	0.9	1.0	1.0
P2	0.6	0.8	1.3	1.8	1.0	0.4	0.3	1.1	0.9
P3	0.6	0.2	0.9	0.5	0.6	0.4	0.6	1.0	1.0
P4	0.4	<0.013*	<0.100*	0.3	0.7	0.4	0.4	1.3	0.5

Bioaccumulation ratio (B ratio):  $\leq 1.0$ =absence of bioaccumulation (regular),  $>1.0$ - $2.1$ =low bioaccumulation (italic),  $>2.1$ - $3.4$ =moderate bioaccumulation (bold),  $>3.4$ - $4.9$ =high bioaccumulation, and  $>4.9$ =severe bioaccumulation (Cecconi et al., 2019). Asterisk (\*)=the value is not B ratio; it is the method detection limit of each element in  $\mu\text{g/g}$ .



**Figure 5.** Box plots of metal concentrations in the lichen *Parmotrema tinctorum* in the forested (F), accommodation (A) and parking (P) areas. The horizontal bar within each box represents the median, while the empty circle with a connecting line represents the mean. The sky-blue area behind the boxes shows the range of the background concentration of each metal. Different letters on the boxes of Cr and V indicates statistically significant differences, and NS denotes nonsignificant differences among the study areas ( $p < 0.05$ ).

#### 4. DISCUSSION

This study assessed the impact of tourism on atmospheric metal pollution in a natural park in

Thailand. We found that the impact was modest because the concentrations of most traffic-related metals were comparable to their background

concentrations. Only Cr and V seemed to be problems (pollute the air) in the park. Chromium is associated with the wearing of brakes (Liu et al., 2018; Sorbo et al., 2008). It had a significantly higher concentration in the accommodation area than in the forested area ( $p < 0.05$ ). However, the Cr content in the highest traffic intensity area (parking) was comparable to that in the lowest traffic intensity area (forested), indicating that there were additional sources of Cr in the accommodation area apart from vehicle traffic. There were reports that bark substrates can contribute to some element contents in lichen thalli growing in a forested area and the element concentrations in the barks were correlated with those in the lichens (Prussia and Killingbeck, 1991). However, amounts of the elements in the lichens were found in the range of their background concentrations. Thus, the higher Cr content in the lichen of this study than its background concentration observed at the accommodation sites was probably caused by the atmospheric composition rather than the bark differences. Regardless of the additional source of Cr, Cr has serious effects on living organisms, including humans. According to the ATSDR 2017 Substance Priority List (ATSDR, 2017), its toxicity, frequency, and potential for human exposure in the United States was ranked at no. 17. Health effects of Cr on the respiratory tract include irritation of the lining of the nose, runny nose, and breathing problems (asthma, cough, shortness of breath, and wheezing). The International Agency for Research on Cancer (IARC) has determined that Cr(VI) compounds are carcinogenic to humans. Adverse effects observed in animals following ingestion of Cr(VI) compounds occur in the stomach, small intestine (irritation and ulcer) and blood (anemia) (ATSDR, 2012a). Chromium is a highly toxic nonessential metal for microorganisms and plants. It causes deleterious effects on plant physiological processes such as photosynthesis, water relations and mineral nutrition (Shanker et al., 2005). In addition, exposure to Cr(VI) has caused a significant decline in physiological processes in the lichen *Pyxine coccinea* (Bajpai et al., 2015). Vanadium is related to fossil fuel combustion (Yemets et al., 2014) and continental dust (ATSDR, 2012b). It had a significantly higher concentration in the accommodation and parking areas than in the forested area. This metal was placed at no. 200 by ATSDR (ATSDR, 2017). Breathing air with vanadium pentoxide can result in coughing, and the IARC has determined that V is possibly carcinogenic

to humans. Damage to the lungs, throat and nose, as well as a decrease in the number of red blood cells, have been observed in animals exposed to V compounds. Vanadium is a nonessential element for plants as well. It was found to retard the growth of Chinese green mustard and tomato plants (Vachirapatama et al., 2011) and induce a significant reduction in the phosphatase activity of lichens (LeSueur and Puckett, 1980). To reduce and remove these hazardous pollutants from the air, we recommend increasing tree density in the area (McDonald et al., 2016).

Several studies have reported that high quantities of metals in lichens in urban and/or industrial areas were associated to the local traffic density (Boonpeng et al., 2017b; Guidotti et al., 2009; Koz et al., 2010; Olowoyo et al., 2011; Sorbo et al., 2008). A number of studies have been carried out along highways in rural and natural areas to clarify and assess the impact of road traffic on atmospheric metal pollution (Liu et al., 2018; Yemets et al., 2014; Zhao et al., 2019). The previously mentioned study clearly suggests that motor vehicles can increase the amount of metals in areas with high traffic due to fossil fuel combustion, tire wear, brake abrasion, lubricating oils and vehicle component wear (Sorbo et al., 2008). Similar results should occur in KYNP where >300,000 cars and >45,000 motorcycles passed through yearly during the last three years. Nevertheless, only the results for Cr and V were in line with this assumption, while the results for the seven remaining metals (As, Cd, Cu, Fe, Pb, Sb, and Zn) were not. Notably, the methodology used in this study was appropriate for assessing the amounts of pollutants (metals) that were suspended in the air, and it may not be directly suitable for assessing pollutants that are on the ground or in the water. The metals As, Cd, Cu, Fe, Pb, Sb and Zn may have been released from vehicles but may have been suspended in the air for a short period of time. Tree leaves along the roads or in the sampling sites could have trapped the metals that were then leached out by rainwater, fog or dew. High and frequent rainfall in the area could help clean the air. High relative humidity does not allow metals that fall on the ground to resuspend in the air. In addition, ground level flora such as grasses and herbaceous plants act as biocovers on the ground, which could interrupt and reduce the resuspension of dust in the air.

Air pollutants clearly can be washed out of the air by rainfall; nevertheless, rainwater can both add



and remove pollutants in lichen thalli (Adamo et al., 2003; Gallo et al., 2017). Because the lichens of this study were sampled in the early part of the rainy period (June), the results of this study could confirm that the impact of tourism on airborne metal concentrations in the park in the rainy period was low. However, the situation may be different in the dry period.

Based on the recently developed scales proposed by Cecconi et al. (2019), the B ratios of most metals from most of the sampling sites indicated the absence of bioaccumulation (77.8%), no B ratio of any metal indicated high or severe bioaccumulation. Although the interpretative scales were properly developed for research in Italy, they could be used in studies with lichens in other countries as well because they were based on a robust conceptual framework (Cecconi et al., 2019).

This study stated the atmospheric metal contamination in the natural park in Thailand. However, several other pollutants can be emitted from motor vehicles, such as nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>) and polycyclic aromatic hydrocarbons (PAHs) (Gombert et al., 2003; Mateos and González, 2016; Nascimbene et al., 2014). Air pollution in the dry period may be different, and the impact of tourism on other environmental matrixes, i.e., pedosphere, hydrosphere and biosphere, should be assessed. Thus, periodic monitoring and an overall assessment of environmental quality for this UNESCO World Heritage Site is paramount because an increasing amount of motor vehicles have been passing through the park.

## 5. CONCLUSION

The impact of tourism on atmospheric metal pollution during the rainy period in KYNP was modest. Only Cr and V seemed to be problematic at some accommodation sites. The B ratios indicated that most metals at most sampling sites did not bioaccumulate. This study provides a model to assess the impact of tourism on environmental quality in natural parks. The model can be applied to other natural areas as they are also affected by tourism promotion policies.

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