Characteristics of General Soils, Natural Saltlicks and Artificial Saltlicks for Wild Asian Elephants (*Elephas Maximus*) Conservation in the Western Forests of Thailand

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Research Article

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Abstract

Saltlicks are a keystone resource of wildlife. This study aimed to compare the characteristics among general soil, natural saltlicks and artificial saltlicks in the natural forest of Salakphra Wildlife Sanctuary (SWS) and restoration habitat for elephant (*Elephas maximus*) in Kui Buri National Park (KNP), western Thailand. Twenty general soils, 33 natural and 35 artificial saltlicks were analyzed. The chemical compositions in natural saltlicks were not consistent. The K, Mg, Fe and Cu in natural saltlicks were higher than artificial saltlicks in both areas. The Ca and Zn in artificial saltlicks in SES were higher than natural saltlicks of KNP. The salinity in artificial saltlicks was highest and higher than in natural saltlicks in both areas and can provide supplemental Na, thereby increasing salinity in both areas. The artificial saltlicks cannot provide Ca, K, Mg, Fe and Cu when compared to natural saltlicks that can provide a primary target for elephants at these sites. The findings have consequences for conservation of elephants and other large herbivores by supplementing essential macro- and micro-nutrients in artificial saltlicks. The key resources can provide information to help maintain the wildlife health and fecundity of the region.

Introduction

The distribution range of the Asian elephants (*Elephas maximus*) is western India, Sri Lanka, northern India, and Himalayan countries such as Nepal, Bangladesh, Myanmar, Thailand, China, Lao PDR, Cambodia, Vietnam, Malaysia, Sumatra Island and Borneo Island[1]. The total population has been estimated to be 41,410–52,345 Asian elephants worldwide[2]. Perera[3] reported that the distribution of wild elephants has increased in Bhutan, India, Sumatra Island and Thailand. Elephants are the symbolic animal of Thailand. In Thailand, the overall population trend was considered constant between 2003 and 2009. The total wild elephant population in the protected areas of Thailand was estimated at 3,000–3,500 elephant in 56,270 km^2 [4]. In SWS, an estimated 180 elephants with increased activity near saltlicks were reported[5]. While in KNP, approximately 168 elephants were concentrated in The King's project area, which highlights the importance of habitat improvement to elephants. In the King's project area, 12 small reservoirs were created, and many ponds and hundreds of check dams were built to keep water all year round[6]. About 30 artificial saltlicks were also created. In addition, two ranger stations were established in 1998 and 2004 in both Kui canal valleys to provide safety for the elephants[7].

Elephants need food every 12 hours with a dry weight of 1.5% of their body weight during dry season and 1.9% in the wet season[8]. Elephants directly receive minerals such as phosphorus (P), calcium (Ca), sodium (Na), and potassium (K) from food especially in mineral rich soils[9], but some nutrients such as sodium (Na), sulfur (S) and magnesium (Mg) cannot be obtained from most plants[10]. Both Asian and African wild elephants (*Loxodonta africana*) must receive these minerals from others sources such as soil, drinking water[11–14] or termite mounds in the case of African elephants[15]. The macronutrients included Na, Ca, Mg, K, P, and S with an average value at 356.1, 1,540.2, 389.7, 158.4, 61.0, 62.9 and 16.0 ppm respectively. Various natural sources contain Na. Geophagia by herbivore mammals will assist in controlling Na and help in controlling hungriness[16]. Soil consumption is more obvious when the minerals in nature are decreased[17]. Mostly, wildlife was found to eat the saltlicks to supplement Ca and Na intake. In areas, which lack the required soil nutrients or natural saltlicks, artificial saltlicks are suitable to manage the habitat and maintain the elephants' health[18–21].

When the agricultural areas were expansion invading in forest areas; especially slash and burn agriculture at the beginning of 19th century reduced the wild elephant habitat in both African and Asian elephants[22]. These activities cause elephant-human conflict (HEC) for more than 100 years[23–25]. Causes of conflict can be summarized as land use changes such as forest land use, logging and secondary forest. This made the elephants moved closer to human habitats[22]. In addition, artificial water sources built adjacent to forests attracted wild elephants to come out of the forest, particularly in dry season[26]. Moreover, building barriers on the travel routes of the elephants affected the elephant's behavior to be more aggressive27. Wild elephant's behavior and ecological characteristics been changed such as some populations that have become familiar with people[28]. Socioeconomics and politics have changed; for example, expansion of pineapple crops by Dole Company from Hawaii, USA in Kui Buri District in Prachuap Khiri Khan province in 1967[29]. Later, there was agricultural expansion as the governmental policy aimed for the local people to settle in forest areas during that period. As a consequence, it has caused conflict between people and wild elephants.

In Thailand, critical issues from wild elephants include damaging agricultural and crop products, accidents and killing people. The trends have continually increased. It found in at least 14 preserved areas such as Phu Luang Wildlife Sanctuary, Phu Kradueng National Park, or KNP, due to expansion of the pineapple crop industry, wild elephants damaged crops by eating the pineapples both in dry and rainy season. This has been a long-term issue until projects were initiated by His Majesty the King and the guidelines set to solve the problems between people and wild elephants[6]. Nelson et al.[23] and Perera[3] suggested methods to solve conflicts between people and wild elephants which included traditional methods, killing elephants, translocation, repellant methods, physical barriers, compensation schemes, wildlife utilization schemes and land use planning. Artificial saltlicks are one of several methods to solve the problems between elephant and human conflict[30]. Consequently, distribution of natural saltlicks for elephants is not suitable. Even if elephants are able to take up nutrients from plants, some minerals are insufficient for wild elephants' needs, resulting in lack of minerals in their bodies. This is evident in male wild elephants that require high Ca to form teeth, tusks and bones18-21. The female wild elephants also need Ca during pregnancy or nursing a baby, because primary minerals of elephants are highly vital for breast milk. The World Wide Fund for Nature[29] reported that the S intake of wild elephants was not adequate, and it is necessary for wild elephants and other mammals to supplement minerals by consuming saltlicks[31, 32]. However, there is no previous study exhibiting that minerals in saltlicks are sufficient for wild elephants. SWS and KNP located in the western forest of Thailand are well known for habitat of wild elephants. Wild elephants in these two areas are known to utilize in agricultural areas and consume agricultural products. These events chronically lead to conflict between humans and wild elephants despite both SWS and KNP being divergent as conservation areas.

The SWS is a natural forest, while KNP is a restored forest. Although both areas have saltlicks, there has been no clear approach and standard analysis of mineral content in either artificial or naturally occurring saltlicks. We aim to determine whether or not minerals in both the artificial and natural saltlicks of SWS and KNP are sufficient for wild elephants. These finding are important in terms of providing standardized approach to ensure that the mineral requirements of elephants are met with the provision of artificial saltlicks, thereby potentially decreasing human-elephant conflict.

Materials And Methods

Sample collection. This work was conducted under an appropriate animal ethics approval (COA. No. MU-IACUC 2019/008), permission of the Department of National Parks, Wildlife and Plant Conservation, the Ministry of Natural Resources and Environment (MNRE 0907.4/4772).

Study sites. Salakphra Wildlife Sanctuary is located in Kanchanaburi province and is 858.55 km2 in size. It is located from latitude 14° 9' to 14° 40' N and longitude 99° 9' to 99° 30' E. Most areas form a mountainous complex with 50 – 1,178 m height differences from mean sea level. The highest mountain peak is Kao Hua Loan Mountain, 1,178 m from mean sea level. Average highest temperature is 34°C and lowest temperature is 23.1°C. Important water sources are Kao Huai Sadong and Huai Salakphra which are located in the central part of the area. Its length is approximately 26 km. Plant communities include dry dipterocarp forest, dry evergreen forest, mixed deciduous forest, bamboo forest and tropical grassland. The geology is Karst topography, metamorphic rock and sedimentary rock. There is also a small amount of igneous (granite) rock in this area[33] (Fig. 1). Kui Buri National Park is located in Prachuap Khiri Khan province and is 969 km2 in size (14° 9' to 14° 41' N and 99° 10' to 99° 25' E). The geography is mostly part of the mountain range complex of Tenasserim ridge with an average elevation of 750 m above sea level. The forest community consists of mixed deciduous forest, dry evergreen forest and tropical rainforest[34] (Fig. 1).

Field surveys. The locations of natural and artificial saltlicks were recorded by rangers under the SMART Patrol System in both SWS and KNP. From the distribution of natural and artificial saltlicks in the Geographic Information System maps of SWS and KNP, 50 locations of soil samples (12 general soils, 23 natural saltlicks and 15 artificial saltlicks) in SWS, and in 38 locations of soil samples (eight general soils, 10 natural saltlicks and 20 artificial saltlicks) in KNP were randomly selected (Fig. 2). Soils alongside neighboring at 10 m from saltlicks were collected with a shovel. At a consistent depth of 2 cm at least one kg of soil was collected in a clean container at each sample site[35]. Soil sample locations were recorded. All samples were sent to laboratory of the Faculty of Environment and Resource Studies, Mahidol University were standard analysis methodologies of the United States Department of Agriculture was performed[36].

Soil chemical analysis. Cation exchange capacity (CEC) and saturation of exchangeable bases (Ca, Mg, K and Na) were determined using ammonium acetate (one natural and neutral). Electrical conductivity (EC) was determined in a saturation extract, and particle size (texture) identification was performed using the hydrometer method[37]. Phosphorus (P) was determined using the Bray II method. Trace elements (Fe, Cu, Mn, and Zn) were extracted with DTPA[38]. Organic carbon concentration was determined by the Walkley–Black method[39]. The pH was also determined for each sample[40]. The results of these analyses were compared to the control samples (n = 7) that were obtained from 30 cm below the soil surface in places where there was no evidence of geophagy.

Statistical analysis. Box plots were used to illustrate the distribution of data among different treatments. ANOVA were performed to identify whether the soil reaction, salinity and chemical composition (macro- and micro-nutrient) of the soil types between the two study areas were different from one another with significant differences set at the p-value = 0.05 level. The correlative coherence analysis (CCA) was used to test the relationships between 10 minerals and environmental parameters (pH and salinity) among general soil, natural saltlicks and artificial saltlicks samples in Salakphra Wildlife Sanctuary and Kui Buri National Park (NSOSWS = general soils in Salakphra Wildlife Sanctuary, ASASWS = artificial saltlicks in Salakphra Wildlife Sanctuary, NSASWS = natural saltlicks in Salakphra Wildlife Sanctuary, NSOKNP = general soils in Kui Buri National Park, ASAKNP = artificial saltlicks in Kui Buri National Park and NSAKNP = natural saltlicks in Kui Buri National Park). The CCA was done using PC-ORD 5.1[41].

Results

Soil reaction and salinity. Soil reaction (pH) was significantly different among general soils, natural saltlicks and artificial saltlicks ($F = 14.737$, $df_{1,2} = 5, 82$, $p < 0.0001$). In SWS samples were significantly different ($p < 0.05$), while KNP samples were not significantly different ($p > 0.05$). General soils in SWS (6.8 ± 0.5 ppm) were lowest, while natural saltlicks in SWS (8.7 ± 0.5 ppm) were highest in pH. After salts and minerals were supplemented, the pH of artificial saltlicks in SWS was higher than KNP (Table 1 and Fig. 2).

Table 1

Chemical composition among general soil, natural saltlicks and artificial saltlicks in Salakphra Wildlife Sanctuary and Kui Buri National Park

Parameter	Salakphra Wildlife Sanctuary (ppm)			Kui Buri National Park (ppm)			F	df1, 2	p-value
	General soil (n = 12)	Artificial saltlick (n = 15)	Natural saltlick (n = 23)	General soil (n = 8)	Artificial saltlick (n = 20)	Natural saltlick (n = 10)			
pH	6.8 ± 0.5a	7.7 ± 0.6b	8.7 ± 0.5c	7.3±1.4ab	7.2±1.1ab	7.3±0.8ab	14.737	5, 82	< 0.000.1
Salinity	372.6 ± 185.7a	8,507.8 ± 8,197.3b	1,967.4 ± 881.1a	979.5±895.6a	16,774.7 ± 9,148.6c	9,583.8 ± 6,551.3b	7.116	5, 82	< 0.000.1
P	559.8 ± 196.6b	614.8 ± 236.2b	676.2 ± 342.8b	324.1±91.3a	347.8±86.9a	378.2±107.2a	5.875	5, 82	< 0.000.1
K	1,262.9 ± 580.6cd	963.6 ± 270.5bc	1,378.6 ± 423.7d	954.0±458.9ab	566.8±498.9a	954.3±461.5bc	2.167	5, 82	0.066
Ca	191.7 ± 115.6a	850.3 ± 1135.1a	932.2 ± 977.0a	89.7±104.9a	1,054.7±1,298.5a	3,021.7±2,793.5b	15.729	5, 82	< 0.000.1
Mg	2,046.0 ± 758.1a	4,693.5 ± 1,035.0b	6,643.3 ± 2,315.0c	3,212.4±1,337.1a	2,879.5±1,728.0a	7,377.5±4,084.2c	3.284	5, 82	0.009
Na	649.1 ± 390.5a	1,282.3 ± 963.3ab	1,745.6 ± 1,189.0b	583.6± 444.6a	1,500.5±996.4b	1,577.0±1,424.1b	3.197	5, 82	0.011
Mn	749.8 ± 378.8b	1,148.8 ± 564.7c	1,086.3 ± 494.6c	271.9±144.9a	271.9±144.9a	237.9±116.8a	3.472	5, 82	0.007
Zn	25.6 ± 9.5a	47.7 ± 20.5b	43.9 ± 11.7b	17.6±6.7a	17.8±9.0a	27.1±11.1a	2.140	5, 82	0.069
Fe	8,006.1 ± 4,511.5a	14,138.2 ± 5,357.5b	18,890.1 ± 6,279.9c	10,462.5±2,316.3ab	6,796.9±4,629.0a	14,761.6±7,899.9bc	2.444	5, 82	0.041
Cu	18.0 ± 9.3bc	24.7 ± 16.4cd	30.6 ± 14.3d	8.6±2.6a	9.4±5.0ab	11.3±3.1ab	3.046	5, 82	0.014
Se	1.7±0.2b	1.7±0.2b	1.8±0.2b	1.6±0.18ab	1.8±0.16b	1.7±0.10b	1.348	5, 82	0.252

Different letter = significantly different at 95% ($p < 0.05$).

Salinity among general soils, natural and artificial saltlicks was significantly different ($F = 7.116$, $df1, 2 = 5, 82$, $p < 0.0001$). Natural saltlicks in SWS were lower than in KNP (P < 0.05). Supplementation by added salts increased the salinity in artificial saltlicks in SWS and KNP (Table 1 and Fig. 2).

Macronutreints. Concentrations of P was significantly different ($F = 7.116$, $df1, 2 = 5, 82$, $p < 0.0001$) among the experiments, but inside the SWS and KNP were not significantly different ($p > 0.05$). Phosphorus was highest in natural saltlicks in SWS. In general soils and natural saltlicks in SWS were higher than general soils and natural saltlicks in KNP ($p < 0.05$). After supplement of minerals P in artificial saltlicks of SWS was higher than KNP ($p < 0.05$) (Table 1 and Fig. 2).

Concentrations of K among general soils, natural saltlicks and artificial saltlick were not significantly different ($F = 2.167$, $df_{1,2} = 5, 82$, $p = 0.066$). The K in natural saltlicks was significant different from artificial saltlicks in SWS ($p < 0.05$). Comparisons between artificial saltlicks in SWS and natural saltlicks in KNP were not significantly different ($p > 0.05$) (Table 1 and Fig. 2).

Calcium among general soils, artificial saltlicks and natural saltlick soils were significantly different ($F = 15.729$, $df_{1,2} = 5, 82$, $p < 0.0001$). Calcium among general soils, artificial saltlicks and natural saltlick soils in SWS were not significantly different ($p > 0.05$). The Ca was significantly different only with natural saltlicks in KNP ($p < 0.05$) (Table 1 and Fig. 2).

Concentration of Mg was significantly differently among experiments ($F = 3.284$, $df_{1,2} = 5, 82$, $p = 0.009$). The Mg was not significantly different among general soils in SWS, general soils and artificial saltlicks in KNP ($p > 0.05$). The Mg was highest in natural saltlicks in KNP (p < 0.05) (Table 1 and Fig. 2)

The Na was significantly different among general soils, natural saltlicks and artificial saltlicks ($F = 3.197$, $df_{1,2} = 5, 82$, $p = 0.011$). Concentrations of Na were not significantly different between natural and artificial saltlicks in both areas ($p > 0.05$). These saltlicks were significantly higher than in general soils in both areas ($p < 0.05$) (Table 1 and Fig. 2).

Concentrations of Mn were significantly different among general soils and natural saltlicks and artificial saltlicks ($F = 3.472$, $df_{1,2} = 5, 82$, $p = 0.007$). In KNP, they were not significantly different among the experiments ($p > 0.05$), but the artificial saltlicks were significantly higher than general soils ($p < 0.05$), but were not significantly different with natural saltlicks ($p > 0.05$) (Table 1 and Fig. 2).

Micronutrients. Concentrations of Zn among general soils, natural saltlicks and artificial saltlicks were not significantly different ($F = 2.140$, $df_{1,2} = 5, 82$, $p = 0.069$). The Zn in artificial saltlicks and natural saltlicks in SWS were significant different among other general soils and natural and artificial saltlicks ($p < 0.05$) (Table 1 and Fig. 2).

Concentrations of Fe in SWS were significantly different among general soils, natural and artificial saltlicks ($F = 2.444$, $df_{1,2} = 5, 82$, $p = 0.041$). In SWS, Fe among general soils, artificial saltlicks and natural saltlicks were significant different ($p < 0.05$), while in KNP, Fe in artificial saltlicks were lower than general soils and artificial saltlicks ($p < 0.05$) (Table 1 and Fig. 2).

Concentrations of Cu significantly different among general soils, artificial saltlicks and natural saltlicks ($F = 3.046$, $df_{1,2} = 5, 82$, $p = 0.014$). The Cu in artificial saltlicks and natural saltlicks were significantly different from general soils in both areas ($p < 0.05$), but artificial saltlicks in KNP when compare to other saltlicks in both areas ($P < 0.05$) (Table 1 and Fig. 2).

Concentrations of Se among general soils, artificial saltlicks and natural saltlicks were not significantly different ($F = 1.348$, $df_{1,2} = 5, 82$, $p = 0.252$) (Table 1 and Fig. 2)

Relationships among artificial, natural saltlicks and general soils. The relationships among artificial, natural saltlicks and general soils in SWS and KNP, environmental factors and minerals was analyzed by using CCA (Table 2 and Fig. 3). The natural saltlicks in SWS (NSASWS) had a high pH and contained high levels of P, K, Zn, Fe, Cu and Mn, while naturals saltlick in KNP (NSAKNP) and artificial saltlick in both area (ASASWS and ASAKNP) had a high level of salinity and contained high levels of Ca, Na, Mg and Se.

Table 2
Factor loading eigenvalue, saltlicks, minerals and coordinates of sites of correlative coherence analysis (CCA) in Salakphra Wildlife Sanctuary and Kui Buri National Park

Protected area	**Factor**	**Abbreviation**	**PC1**	**PC2**	**PC3**
eigenvalue			0.027	0.003	0.023
Salakpra Wildlife Sanctuary	General soils	NSOSWS	1.674	2.822	-1.999
	Artificial saltlicks	ASASWS	0.468	-1.089	-0.687
	Natural saltlicks	NSASWS	0.464	-1.127	-0.448
Kui Buri National Park	General soils	NSOKNP	1.313	-0.502	-0.714
	Artificial saltlicks	ASAKNP	-1.436	0.804	0.666
	Natural saltlicks	NSAKNP	-1.761	0.718	2.112
	pH	pH	-0.150	-1.047	0.000
	Salinity	Salinity	-1.039	-0.201	0.000
	Phosphorus	P	0.109	0.110	-0.27
	Potassium	K	0.239	0.191	-0.149
	Calcium	Ca	-0.554	0.089	0.460
	Magnesium	Mg	-0.075	-0.028	0.121
	Sodium	Na	-0.269	-0.019	-0.092
	Manganese	Mn	0.198	-0.056	-0.443
	Zing	Zn	0.036	-0.005	-0.233
	Ferrous	Fe	0.067	-0.013	-0.027
	Copper	Cu	0.149	-0.063	-0.293
	Selenium	Se	-0.024	0.229	-0.189

Discussion

Macronutrients (P, K, Ca and Mg) and micronutrients (Zn, Mn, Fe and Cu) in natural saltlicks in SWS was higher than in KNP, but they were higher than those in the natural saltlicks in Huai Kha Khaeng Wildlife Sanctuary[42], Phu Khieo Wildlife Sanctuary[43] and natural saltlicks utilized by elephants in Mt. Elgon National Park[44] (Table 3).

Table 3
Mineral composition of general soils, artificial saltlicks, natural saltlicks and Asian elephants (*Elephas maximus*)’ forages and bloods

Locality	**pH**	**Salanity**	**Macronutrient (ppm)**					**Micronutrient (ppm)**					**Reference: Modified from**
		(ppm)	**P**	**K**	**Ca**	**Mg**	**Na**	**Mn**	**Zn**	**Fe**	**Cu**	**Se**	
SWS													
General soil	6.8	372.6	559.8	1,262.9	191.7	2,046	649.1	749.8	25.6	8,006.1	18.0	1.7	This study
Artificial saltlicks	7.7	8,507.8	614.8	963.6	850.3	4,693.5	1,282.3	1148.8	47.7	14,138.2	24.7	1.7	This study
Natural saltlicks	8.7	1,967.4	676.2	1,378.6	932.2	6,643.3	1,745.6	1086.3	43.9	18,890.1	30.6	1.8	This study
KNP													
General soil	7.3	979.5	324.1	954.0	89.7	3,212.4	538.6	271.9	17.6	10,462.5	8.6	1.6	This study
Artificial saltlicks	7.2	16,774	347.8	566.8	1,054.7	2,879.5	1,500.5	271.9	17.8	6,796.9	9.4	1.8	This study
Natural saltlicks	7.3	9,583.8	378.2	954.3	3,021.7	7,377.5	1,577	237.9	27.1	14,761.6	11.3	1.7	This study
San Miguel Reservation Caqueta Department, Colombia	6.5	-	278.5	42,500	1,005,000	397,500	240,000	17.8	2.2	115.5	0.7	-	Molina et al. (2014)
Tambopata Research Centre, Peru	8.7	-	-	36,000	213,000	213,000	592,000	16.9	2.3	119	0.7	-	Brightsmith et al. (2008)[53]
Tambopata Natural Reserve Buffer Zone, Peru	-	-	-	27,000	124,000	459,000	110,000	-	-	-	-	-	Brightsmith and Aramburu (2004)[54]
Wild forage, Beijing, China	-	-	2,494	15,915.5	29,989.5	3,650	145	–	60.9	553.4	-	-	Lihong et al. (2007)[46]
Beijing Zoo forage, China	-	-	3,226.5	7,118	11,563.5	2,603.5	2,181.3	-	27.3	367.9	-	-	Lihong et al. (2007)[46]
Asian Elephant Blood	-	-	-	-	-	-	-	N/A	6.1	-	0.8	0.4	Wiedner et al. (2011)[47]

SWS = Salakphra Wildlife Sanctuary, KNP = Kui Buri National Park, N/A = > 70% of the sample were either non detectable or below the limit of quantification and therefore at very low concentration, - = not analyze.

The most common chemical component in soils in SWS and KNP were Fe and Mg (natural saltlicks > artificial saltlicks > general soils). At our study area, the amount of Se was consistently the lowest of all nutrient types in both areas with natural saltlicks, followed by artificial saltlicks and then general soils having the lowest concentrations respectively. Therefore, it can be seen that in both areas Fe and Mg were highest and Se was lowest. This finding was similar with Huai Kha Khaeng Wildlife Sanctuary[45]. Minerals were found in natural saltlicks at higher levels than general soil as was found in natural saltlicks of Huai Kha Khaeng Wildlife Sanctuary. These minerals were higher than baseline levels of trace metals in the food (Mg, Na, Zn and Fe) in zoo[46] and blood (Fe, Zn, Na, Mg and Ca) of captive Asian elephants[47] (Table 3).

Higher concentrations of Mg, Ca, Mn, Fe, Zn and Cu in natural saltlicks than in general soil can thus represent an important nutrient supplement to wild elephant enabling their forage to sustain their body and health[45], especially Ca required to support their bones and ivory[48]. Seidensticker and McNeely[45] also describe Na and an important driver of geophagy.

In general soils, SWS and KNP differed in their amounts of minerals with soil in SWS having higher mineral contents than in KNP due to SWS having been designated as a protected area by the Royal Forest Department pursuant to Wildlife Reservation and Protection Act 2019 and not having been subjected to resource degradation over time such as in KNP[49]. The degradation of KNP was mostly caused by other land use demands as humans were unrestricted in converting forest to cropland and hunted wild animals for food. The Conservation and Restoration of Kui Buri National Forest Project under His Majesty the King's Royal Initiation began in 1997[34]. However, levels of K, Na and Se were similar in both study sites. While KNP had salinity in general soils at higher levels than in SWS. This result agreed with the study on the development scheme of lands with agricultural difficulties in the western area of Thailand, which reported that the soil series under soil salinity problems were the Tha Chin Series, which were founded in Prachuap Khiri Khun and the Nong Kae Series[50].

In natural saltlicks, P, K, Ca, Mg, Ze and Cu are rich at both study areas, while Ca and Mg were lower in SWS than KNP. Na, Fe and Se were not significantly different in both areas. Hence, SWS is not faced with minerals deficiency in natural saltlicks, but KNP may need to supplement some minerals to enrich the minerals in the artificial saltlicks depending on the spatial condition and composition of soil in each area. This difference in mineral concentration may lead to differing mineral concentration in the forage of elephants[51].

Artificial saltlicks were found to be important to enrich the minerals in general soils and elephants, but, P, K, Mg, Mn, Ze, Fe and Cu in SWS and KNP were different, because of differences in historical land-use practices over time, and differences in the provision of artificial saltlicks in each area[51]. Currently, providing artificial saltlicks is not specifically formulated and hence, each area should add minerals associated with the specific soil condition of the local area rather than merely providing artificial saltlicks with salt that attracted few wild animals for utilization[52].

Mineral compositions in general soils and natural saltlicks in both areas were different. For preparation of future artificial saltlicks, the mineral composition of the local area needs to be understood as a guideline for making cost-effective and suitable artificial saltlicks for elephants and other geophagies.

This study suggests that the concentration of macronutrients in descending order for natural saltlicks in SWS was Ca > Mg > Na > K > P, while macronutrients in artificial saltlicks were arranged in the following descending order as Mg > Na > K > Ca > P. For KNP, the natural saltlicks had a descending concentration order of Mg > Ca > Na > K > P, while for artificial saltlicks it was found to be Mg > Na > Ca > K > P. The salinity was found significantly higher in the artificial when compared to the natural saltlicks, while P, Ca, Na, Mn and Zn were not different. Overall SWS contained higher levels of nutrients when compared to KNP. According to the high number of artificial saltlicks in KNP, salinity in KNP was much higher than in SWS as these artificial saltlicks add salt to the system. Other minerals such as P, K, Mg, Mn, Ze, Fe and Cu in both areas are not significantly different. Ca, Na and Se were higher in SWS than in KNP. Finally, managers should provide artificial saltlicks that are specifically formulated by adding minerals based on the local spatial distribution of nutrients found in the general soil types of a specific area to make them suitable for wild elephant and other geophagies. We recommend further studies on the relationships between wild elephant distribution and spatial distribution and the occurrences of natural saltlicks in the area. Forage samples should be investigated for their composition of minerals to ensure the quantities are suitably available for elephants. Artificial saltlicks are important where low concentrations of mineral elements are found in forage or natural saltlicks.

Declarations

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Contributions

R. Chaiyarat and S. Kanthachompoo conceived the research and designed the experiments. R. Chaiyarat, N. Thongthip and M. Yuttitham performed the experiments. R. Chaiyarat and S. Kanthachompoo analyzed the data, wrote the article and edited the manuscript. All authors read and approved the final manuscript and agree to authorship and submission of the manuscript for peer review.

Ethics declarations

Competing interests

The authors declare no competing interests.

Additional information

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Figures

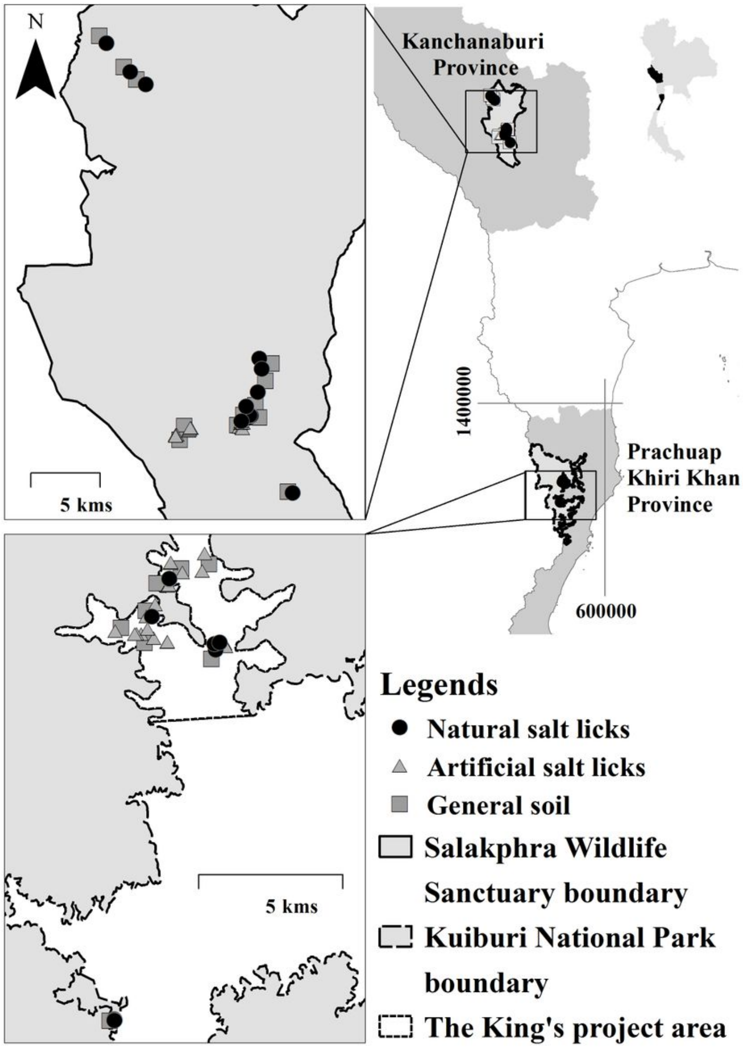

Figure 1

Salakphra Wildlife Sanctuary in Kanchanaburi province and Kui Buri National Park in Prachuap Khiri Khan Province Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

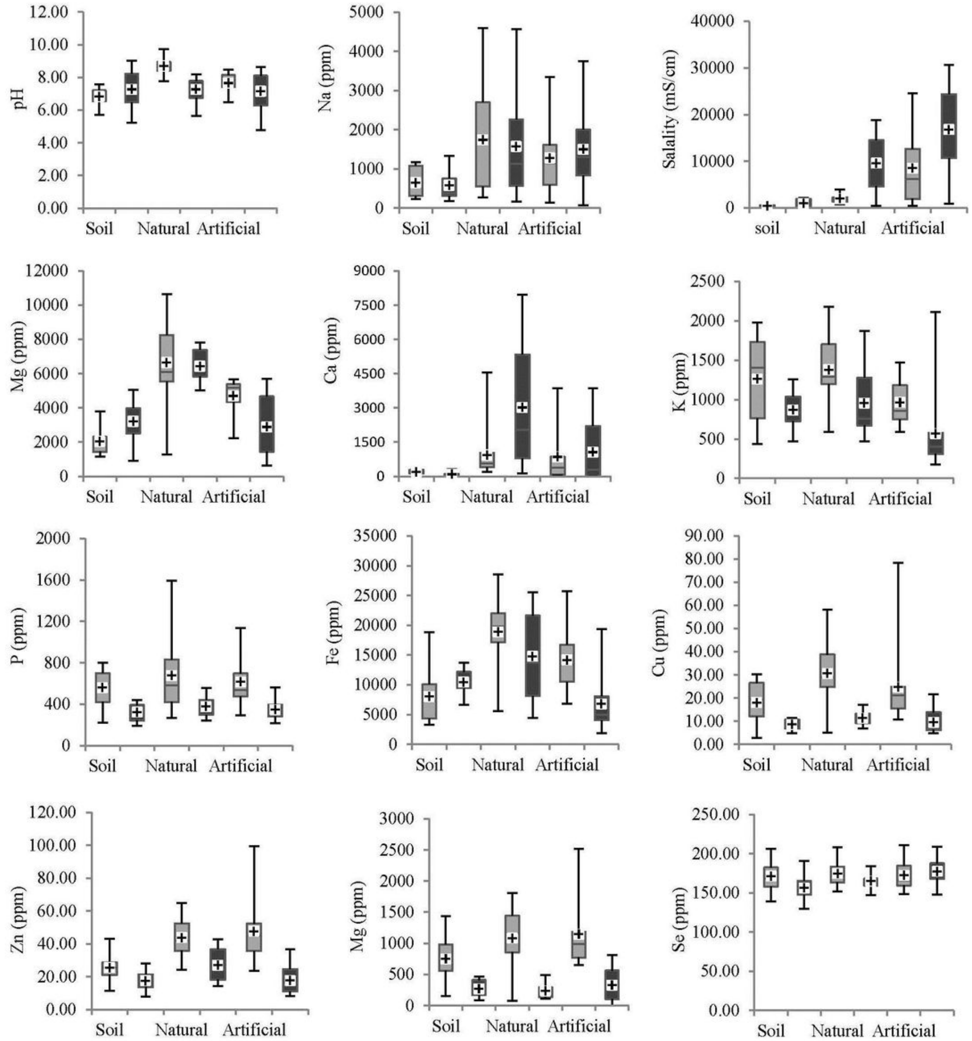

Figure 2

Soil reaction, salinity and chemical composition of general soils (Soil), natural saltlicks (Natural) and artificial saltlicks (Artificial) from Salakphra Wildlife Sanctuary (gray) and Kui Buri National Park (black)

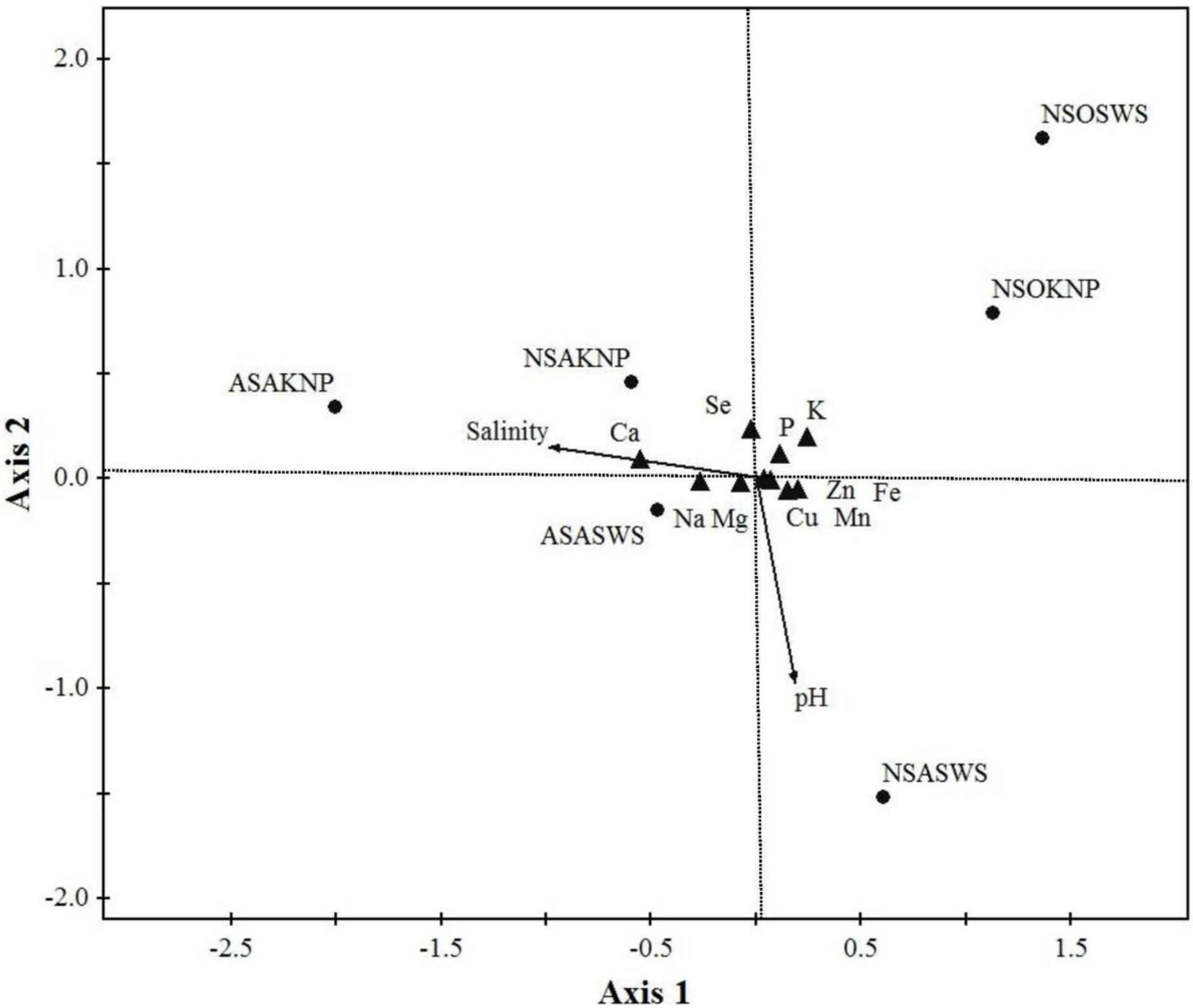

Figure 3

Relationships of 10 minerals and environmental parameters (pH and salinity) among general soil, natural saltlicks and artificial saltlicks in Salakphra Wildlife Sanctuary and Kui Buri National Park (NSOSWS = general soil in Salakphra Wildlife Sanctuary, ASASWS = artificial saltlicks in Salakphra Wildlife Sanctuary, NSASWS = natural saltlicks in Salakphra Wildlife Sanctuary, NSOKNP = general soil in Kui Buri National Park, ASAKNP = artificial saltlicks in Kui Buri National Park and NSAKNP = natural saltlicks in Kui Buri National Park).