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Research article

Variation in water utilization by mammal diversity in Khao Phaeng Ma Non-hunting area, Thailand

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A R T I C L E I N F O

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A B S T R A C T

Access to suitable water sources is important for mammals. This study aimed to compared mammal diversity and water use among water springs, standard artificial ponds, and water pans within the Khao Phaeng Ma Non-Hunting Area in 2020 and 2021. Two camera traps were installed at each water sources for 749 nights with a total of 12 camera traps of 6 water sources. A total of 19,467 photographs were recorded comprising 13,777 photographs of gaur (*Bos gaurus*, vulnerable and the most important species in the area), and 5690 photographs of other mammals. In the wet season, relative use was highest at standard artificial pond number 2, which is established in the forest plantation area (4 × 4 m spacing, 12–20 m height, and 60%–80 % crown cover) and has a high volume of water, and at water pan number 1, which mimics a natural water spring in the man-made grassland and can supply water to mammals throughout the year. In the dry seasons, relative use was highest at water pan numbers 1 and 2; at the same time, other water sources dried up. During the study period, the number of mammal species was highest at water pan number 1 (10 species, diversity index [H'] = 1.38), and water pan number 2 (11 species, H' = 1.75). Grazers and browsers, including gaur, sambar deer (*Rusa unicolor*), northern red muntjac (*Muntiacus vaginalis*), omnivores (e.g. wild boar, *Sus scrofa*), and Asian black bear (*Ursus thibetanus*), used the water pan in the artificial grassland and standard artificial pond in the forest plantation rather than the water spring in the dry evergreen forest. Beside forest types, the use of water springs was associated with water period (months), while the use of standard artificial pond and water pans was associated with water surface area, water depth, altitude, species diversity, and species richness, and number of mammals photographed. The results show that water pans were more suitable for utilization by mammals than are other water sources.

1. Introduction

Animal water requirements depend on environmental conditions [1]. For example, gaur (*Bos gaurus*), sambar (*Rusa unicolor*), northern red muntjac (*Muntiacus vaginalis*), and Asian elephants (*Elephas maximus*) are grazers and browsers found at the forest edge,

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whereas wild boar (*Sus scrofa*) and greater hog badgers (*Arctonyx collaris*) are omnivores and frugivores found in the forest interior. Carnivores such as dhole (*Cuon alpinus*) are specific to the forest edge, while clouded leopards (*Neofelis nebulosi*) are specific to the forest interior [2]. The negative effects of environmental factors include heat load and performance, especially in the summer season [3–5]. When the water is unavailable, it affects the thermal equilibrium and performance of animals. Climatic factors, diets, animal breed, animal weight, and animal physiological status, makes it difficult to determine daily water requirements. Ambient temperature, minimum temperature, and the temperature humidity index are the primary factors that influence daily water intake, while solar radiation has a smaller influence on daily water intake [1].

Natural surface water is important for the population dynamics of many wildlife species [6], especially in arid zones [7], with the distribution and use of many wildlife species are dependent on the availability of free-standing water [8]. The limitation of natural surface water may induce human–wildlife conflict in the area. Wildlife managers have generally assumed that the provision of water is beneficial to native species inhabiting environments where surface water is scarce, and that water is a main factor that drives wildlife to enter the communities around Protected Areas and increases human–wildlife conflicts [9]. However, this assumption has not been rigorously tested [10,11].

Artificial water sources for wildlife, which include man-made and modified natural water sources [12] that mitigate the loss of natural water sources, expand species distributions and improve the performance of wildlife populations [13]. Nevertheless, the practice of artificial water sources for wildlife is controversial [14–16] because the effects of artificial water sources to ecosystems are difficult to determine and the studies are limited [11,17–19].

The role of artificial water sources in wildlife is of interest [11,17], and information on this subject has increased substantially in recent years. There are reports of water sources becoming unsustainable when deforestation and conversion to agricultural areas occur [20,21]. Agricultural areas may need more ground water to support crop plants, and artificial ponds may be constructed in these areas. The creation of agricultural areas can also lead to wildlife feeding outside protected areas and increase human–wildlife conflicts [22–24]; for example, conflicts with wild Asian elephant [25,26] and gaur [27–29] in South and Southeast Asia.

While gaur (Family Bovidae) once ranged widely throughout mainland South and Southeast Asia, in 2016, the global population was estimated at only 15,000 to 35,000, with mature individuals numbering between 6000 and 21,000 [30]. During the past century, the wild gaur population has declined by > 80 % owing to the loss of suitable habitats to agriculture and poaching for horn and meat. Hybridization between wild gaur and domestic cattle has also resulted in the transmission and outbreak of various diseases, such as foot-and-mouth, rinderpest, and anthrax [30]. Currently, gaurs are listed as vulnerable (VU) in the IUCN Red List of threatened species [31]. Gaurs are the largest living wild cattle species [32], and are the main prey of large carnivores and play important roles in maintaining the ecosystem by preventing vegetation overgrowth [28,33–35].

In Thailand, the gaurs were reassigned as an endangered species from a vulnerable species in 2005, and are also a protected wild animal listed in the Wild Animal Reservation and Protection Act [36]. With the expansion of agricultural areas, settlements, and roads, many wildlife habitats have become fragmented, resulting in small gaur populations in many protected areas [37]. Consequently, gaur are rapidly disappearing from northern and southern areas of Thailand [29], and urgent conservation management is required to provide a concrete action plan.

Gaurs are now located in 46 protected areas in Thailand, with the highest abundance in the Eastern Forest Complex, followed by Dong Phayayen-Khao Yai, Khlong Sang-Khao Sok, and Western Forest complexes [29,38]. Gaur can also be found in the Dong Phayayen–Khao Yai Forest Complex where the land area supports viable populations, with a high and medium abundance of animal tracks and signs [39]. Several gaur populations inhabit the land between protected areas and surrounding agricultural areas, such as the Khao Phaeng Ma Non-Hunting Area (KPMNA) and Khao Yai National Park [40,41]. KPMNA was a deforestation area after forest concession. Following the logging ban in Thailand, forest plantations were restored in 1994. Following the success of the reforestation program, gaur were taken from Khao Yai National Park and re-established in KPMNA around 1990, with 35 gaurs being observed [42].

Since 1990, the gaur population of the protected area has gradually increased and begun to spread into adjacent agricultural areas [27]. The population had 96 individuals in 2006, 160 individuals in 2011, 271 individuals in 2016, and 250–300 individuals recorded in 2022 [41–43]. This situation has increased human–wildlife conflicts around the protected area, as found in the buffer zone of Khao Yai National Park [28]. These conflicts are associated with limited water availability, which affects the behavioral and physiological mechanisms of wildlife [44,45]. The loss of water is driven by low precipitation in the dry season [46]. Among herbivores, dependence on free-standing water and rates of forage consumption are associated with the moisture content of forage [8,12,47]. Thus, availability of free-standing water may be a limiting factor for populations of large herbivores (at least seasonally) if water requirements are not met by forage consumed [8,48]. Water limitations of water may affect the physiology and survival of cattle [49] and gaur.

To reduce water shortages, KPMNA constructed artificial ponds were constructed in the KPMNA, at great expensive; however, this did not reduce the human–wildlife conflicts. In 2018, water pans were constructed to simulate the ecological services of natural water springs for mammals (J. Chimplee, personal communication, 2021) [50], but an assessment of the efficiency of these surface water sources, mammal behavior, and environmental factors such as vegetation types, prevailing climate conditions, water surface area, water depth, and altitude was not performed. To address this issue, the objective of this study was to determine the dynamics that influence mammalian water source preferences in the KPMNA. We hypothesized that surface water limitations induce human–wildlife conflict in the area, and that suitable management of surface water is important in addressing this problem. The results of this study provide a reference for improving the utilization efficiency of water sources by mammals in KPMNA and other areas.

2. Methodology

2.1. Study area

KPMNA (14°21′55“N, 101°47′38“E, ~8 km^2; Fig. 1) is a reforestation area at the border of Khao Yai National Park and forms part of the Dong Phayayen-Khao Yai Forest Complex [27]. Prior to its establishment, the area was free from any vegetation. After reforestation, gaur, a large herbivore, was introduced to the area. Between 2020 and 2022, the Department of National Parks, Wildlife, and Plant Conservation (DNP) recorded 243–258 gaur at the KPMNA. These are separated into six subpopulation groups, with four groups mainly dwelling in KPMNA and moving between the KPMNA, Khao Yai National Park, and the surrounding agricultural areas; in addition, two small subpopulations inhabit fragmented forest patches outside the protected areas [43]. The landscape includes an agricultural matrix of farms (with crops including corn, cassava, and other crops), orchards and gardens, plantations, fallows, and various animal farms; it lacks noteworthy patches of natural vegetation. The climate in the area is tropical monsoon, with a dry season from November to March, followed by a hot inter-monsoonal period until May, and a wet season from May to October (Fig. 2) [46].

2.2. Water sources

Natural water sources in KPMNA are scattered and mostly available during the wet season. The artificial water sources were established in the forest plantation area (4 × 4 m, spacing, 12–20 m height, and 60%–80 % crown cover). These artificial water sources are located in the same area as the natural water sources. In this study, the utilization of three types of water sources by mammals was investigated. Natural water springs are natural underground water that are held in the soil; there are eight natural water springs in the study area, among which two of different sizes were selected for analysis: water springs number 1 is 1.2 × 3 × 0.4 m (width [w] × length [l] × depth [d]), and water spring number 2 is 6 × 10 × 1 m (w × l × d) [Fig. 3(a)]. Standard artificial ponds are man-made, dug by back-hole; there are 30 standard artificial ponds in the study area, among which two were selected for analysis. The two standard artificial ponds, under the recommendation of the DNP, are 10 × 20 × 3 m (w × l × d) [Fig. 3(b)]. Water pans are man-made, dug by human, less expensive, and there are only two in the study area, both located in the man-made grassland and established in 2016 to mimic natural water springs in KPMNA and supply water to mammals throughout the year. The water pans are 2 × 0.5 m (diameter [di] × d) and 5 × 1.2 m (di × d). The water pans used gravity to supply water and the water level is controlled using a float valve [Fig. 3 (c)].

2.3. Camera trapping

We installed 12 cameras traps (Bushnell 12 MP Trophy Cam HD Essential Trail Camera; Suresnes, France) in 2020 and 2021. Memory cards and batteries were changed monthly at each location throughout the 2 year study period. Each camera was installed ~3 m from the water source, 1 m above of the ground, and operated continuously, 24 h per day [51] with two cameras opposite to each other, positioned to photograph both asymmetrical flanks of the mammals for positive identification [52] The images had a resolution of 1648 × 1236 pixels. The camera ID and date were also recorded for each exposure and were stamped onto the photographs [51].

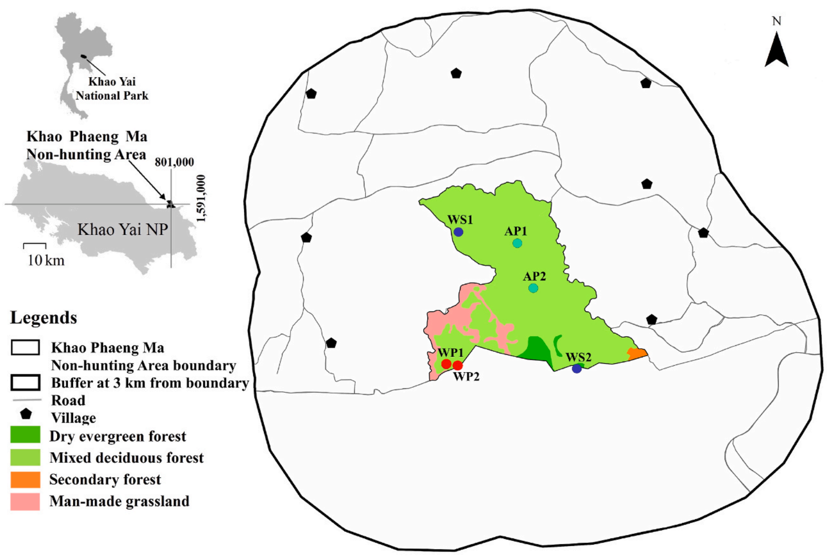

Fig. 1. Location of the water sources that were researched in Khao Phaeng Ma Non-Hunting Area and surrounding farmland.

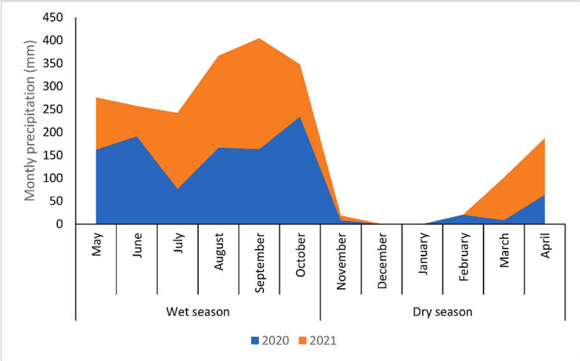

Fig. 2. The monthly precipitation in Khao Phaeng Ma Non-Hunting Area between 2020 and 2021.
Source: The Meteorological Department of Thailand.[41]

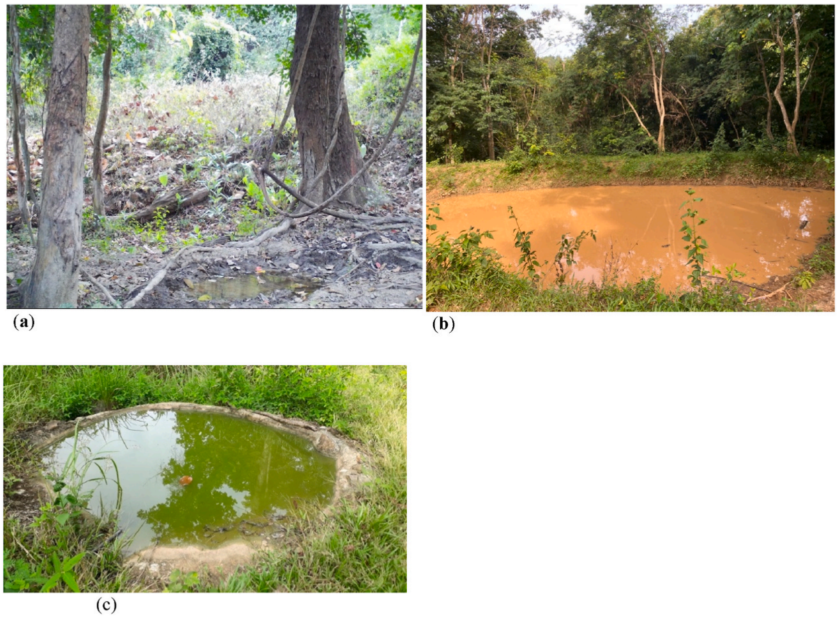

Fig. 3. Water sources: natural water springs (a); standard artificial ponds of the Department of National Parks, Wildlife and Plant Conservation (DNP) (b); and water pans (c) in Khao Phaeng Ma Non-Hunting Area.

2.4. Data analysis

The relative use index (RUI) was used to analyze the water is used by mammals. RUI was calculated as the number of independent photographs of mammals (photographs) taken at a certain water source divided by the total number of photographs taken at all water sources. To exclude the influence of replicated photographs triggered by one individual, an interval time of 30 min was set to segregate independent detections of the same species [53–55]. The relative abundance index (AI) was used to explain the distribution of mammals in the water sources, and was calculated as the number of water sources used by mammals divided by the total number of water sources in the study area.

The Vegan Package 2.6–4 in R-Studio [56] was used to analyze the species diversity index, Shannon–Wiener index (*H*') [57], and evenness (*E*) in each water source type by using the number of photographs of species *i*/the total number of photographs. We used the Jaccard index to measure similarity (*SI*), and *SI* was used to group the relationships among mammalian species and water sources using Bray–Curtis distance analysis. The relationships between the water sources and their environmental factors were analyzed using ordination analysis.

Two binary matrices for repeated measurements were prepared with water sources in rows (6 rows) and mammal species in columns (14 columns). Observations of water source were made per season and per year. The first matrix was used for the mammalian species composition. The second matrix included data on the environmental factors, such as water level in the wet season (m), water level throughout the year (m), distance from the nearest village (km), distance from the nearest road (km), elevation (asl; m), slope

Table 1
The number of photographs (N) and relative use index (RUI) of mammals in the wet and dry seasons in Khao Phaeng Ma Non-Hunting Area.

Year	Scientific name	Common name/ Abbreviation	W1		W2		W3		W4		W5		W6	
			N	RUI	N	RUI	N	RUI	N	RUI	N	RUI	N	RUI
2020	*Bos gaurus*	Gaur/GA	1049	32.4	375	11.6	0	0	118	3.6	1468	45.3	229	7.1
2020	*Ursus thibetanus*	Asiatic black bear/ABB	4	22.2	8	44.4	0	0	0	0	0	0	6	33.3
2020	*Muntiacus vaginalis*	Northern red muntjac/ BD	18	1.9	0	0	0	0	900	95.2	27	2.9	0	0
2020	*Herpestes urva*	Crab-eating mongoose/ CREM	0	0	0	0	0	0	0	0	0	0	0	0
2020	*Paradoxurus hermaphroditus*	Common palm civet/CPC	0	0	0	0	0	0	8	100	0	0	0	0
2020	*Cuon alpinus*	Dhole/DH	15	15.5	0	0	0	0	0	0	82	84.5	0	0
2020	*Canis aureus*	Golden jackal/JK	11	100	0	0	0	0	0	0	0	0	0	0
2020	*Viverra megaspila*	Large-spotted civet/LSC	2	20	8	80	0	0	0	0	0	0	0	0
2020	*Hystrix brachyura*	Malayan porcupine/MP	12	60	0	0	0	0	8	40	0	0	0	0
2020	*Macaca leonina*	Northern pig-tailed macaque/NPTM	0	0	0	0	0	0	4	100	0	0	0	0
2020	*Rusa unicolor*	Sambar/SA	14	2.6	42	7.7	0	0	332	61.1	155	28.6	0	0
2020	*Sus scrofa*	Wild boar/WB	31	77.5	3	7.5	0	0	0	0	0	0	6	15
2020	*Martes flavigula*	Yellow throated marten/ YTM	0	0	0	0	0	0	0	0	0	0	0	0
2021	*Bos gaurus*	Gaur/GA	937	53	271	15.3	187	10.6	328	18.5	0	0	46	2.6
2021	*Ursus thibetanus*	Asiatic black bear/ABB	159	19.2	671	80.8	0	0	0	0	0	0	0	0
2021	*Muntiacus vaginalis*	Northern red muntjac/ BD	1	10	0	0	0	0	1	10	0	0	8	80
2021	*Herpestes urva*	Crab-eating mongoose/ CREM	0	0	0	0	0	0	0	0	0	0	0	0
2021	*Paradoxurus hermaphroditus*	common palm civet/CPC	0	0	0	0	0	0	0	0	0	0	0	0
2021	*Cuon alpinus*	Dhole/DH	4	100	0	0	0	0	0	0	0	0	0	0
2021	*Canis aureus*	Golden jackal/JK	0	0	122	100	0	0	0	0	0	0	0	0
2021	*Viverra megaspila*	Large-spotted civet/LSC	8	11	27	37	0	0	0	0	0	0	38	52.1
2021	*Hystrix brachyura*	Malayan porcupine/MP	1	100	0	0	0	0	0	0	0	0	0	0
2021	*Macaca leonina*	northern pig-tailed macaque/NPTM	0	0	0	0	0	0	0	0	0	0	0	0
2021	*Rusa unicolor*	Sambar/SA	60	23.4	15	5.8	67	26.1	115	44.8	0	0	0	0
2021	*Sus scrofa*	Wild boar/WB	115	68.1	54	32	0	0	0	0	0	0	0	0
2021	*Martes flavigula*	Yellow throated marten/ YTM	0	0	0	0	0	0	0	0	0	0	0	0
			D1		D2		D3		D4		D5		D6	
2020	*Bos gaurus*	Gaur/GA	1074	26.4	2380	58.4	0	0	86	2.1	514	12.6	19	0.5
2020	*Ursus thibetanus*	Asiatic black bear/ABB	124	77	23	14.3	0	0	0	0	0	0	14	8.7
2020	*Muntiacus vaginalis*	Northern red muntjac/ BD	24	17.3	0	0	0	0	21	15.1	43	30.9	51	36.7
2020	*Herpestes urva*	Crab-eating mongoose/ CREM	0	0	0	0	0	0	0	0	0	0	0	0
2020	*Paradoxurus hermaphroditus*	Common palm civet/CPC	0	0	0	0	0	0	0	0	0	0	2	100
2020	*Cuon alpinus*	Dhole/DH	197	92.1	17	7.9	0	0	0	0	0	0	0	0
2020	*Canis aureus*	Golden jackal/JK	91	92.9	7	7.1	0	0	0	0	0	0	0	0
2020	*Viverra megaspila*	Large-spotted civet/LSC	28	28.3	57	57.6	0	0	0	0	14	14.1	0	0
2020	*Hystrix brachyura*	Malayan porcupine/MP	24	82.8	5	17.2	0	0	0	0	0	0	0	0
2020	*Macaca leonina*	Northern pig-tailed macaque/NPTM	32	8.9	317	87.8	0	0	0	0	0	0	12	3.3
2020	*Rusa unicolor*	Sambar/SA	969	66.8	102	7	18	1.2	300	20.7	21	1.5	40	2.8
2020	*Sus scrofa*	Wild boar/WB	62	31.5	0	0	0	0	0	0	0	0	135	68.5
2020	*Martes flavigula*	Yellow throated marten/ YTM	0	0	0	0	0	0	0	0	0	0	5	100
2021	*Bos gaurus*	Gaur/GA	3160	36.5	4747	54.8	23	0.3	727	8.4	0	0	0	0
2021	*Ursus thibetanus*	Asiatic black bear/ABB	1	1.3	77	96.3	0	0	2	2.5	0	0	0	0
2021	*Muntiacus vaginalis*	Northern red muntjac/ BD	0	0	34	40	2	2.4	13	15.3	0	0	36	42.4
2021	*Herpestes urva*	Crab-eating mongoose/ CREM	0	0	4	100	0	0	0	0	0	0	0	0
2021	*Paradoxurus hermaphroditus*	common palm civet/CPC	0	0	0	0	0	0	0	0	0	0	0	0
2021	*Cuon alpinus*	Dhole/DH	0	0	45	100	0	0	0	0	0	0	0	0
2021	*Canis aureus*	Golden jackal/JK	1	20	4	80	0	0	0	0	0	0	0	0
2021	*Viverra megaspila*	Large-spotted civet/LSC	19	8.8	194	89.4	0	0	0	0	0	0	4	1.8
2021	*Hystrix brachyura*	Malayan porcupine/MP	1	4.8	20	95.2	0	0	0	0	0	0	0	0

(*continued on next page*)

Table 1 (*continued*)

Year	Scientific name	Common name/ Abbreviation	W1		W2		W3		W4		W5		W6	
			N	RUI	N	RUI	N	RUI	N	RUI	N	RUI	N	RUI
2021	*Macaca leonina*	northern pig-tailed macaque/NPTM	4	1.4	286	96.3	0	0	0	0	0	0	7	2.4
2021	*Rusa unicolor*	Sambar/SA	71	3.8	730	38.8	14	0.7	830	44.1	0	0	236	12.6
2021	*Sus scrofa*	Wild boar/WB	44	22.5	150	76.5	2	1	0	0	0	0	0	0
2021	*Martes flavigula*	Yellow throated marten/ YTM	0	0	0	0	0	0	0	0	0	0	0	0

W = the wet season; D = the dry season; 1 = standard artificial pond number 1 (AP#1); 2 = standard artificial pond number 2 (AP#2); 3 = water pan number 1 (WP#1); 4 = water pan number 2 (WP#2); 5 = natural water spring number 1 (WS#1); 6 = natural water spring number 2 (WS#2).

(%), distance from the grassland (km), distance from the mixed deciduous forest (km^2), water time (months), number of species (species), and number of mammalian photograph events (events). All statistical analyses were performed in the R programming environment version 3.5.2 [56].

Each matrix was prepared to perform a similarity analysis of species diversity in the six water sources using Ward's method [57], which is a criterion applied in cluster analysis. Based on the calculation of Euclidean distances, a hierarchical dendrogram which illustrating clusters of sites with similar mammalian species was generated. To implement Ward's clustering criterion, the function 'hclust' (R Stats Package) with the defined method "ward.D2" was applied [58].

Canonical correspondence analysis (CCA) was used to investigate the relationship between species composition, photographic rates, and environmental covariates [59], with the aim of assessing the possible influence of covariates that could represent a key habitats for the mammalian species. The normality and homogeneity of variance of the data were verified before analysis, and all data were in accordance with these assumptions. CCA, a direct gradient analysis, was chosen because of its ability to examine several environmental gradients simultaneously and provide reliable results even with interrelationships among habitat characteristics and skewed distributions of species [60]. CCA analyses were performed in R version 2.15.0 using a CCA function in the Vegan package version 2.0–4 for community analysis [61].

The first two dimensions were considered because they resulted in a good fit according to the stress values. Ordination graphs were overlaid with the explanatory variables to quantify their influence. Significant variables ($p < 0.05$) were automatically projected onto the CCA biplots, including the effects of the predictors.

3. Results and discussion

3.1. Relative use and abundance index of mammals

Owing to the limited supply of natural water sources in the KPMNA, especially during the dry season, artificial water sources were established to support the mammalian community in the area. Camera traps were used to compare the mammalian dynamics between different water sources and environmental factors. In 2020, 3881 photographs of gaur and 2229 photographs of other mammals were captured over 370 nights per water source for a total of six water sources (12 camera traps). In the wet season, the highest three relative use index values for water pan number 1, located in the artificial grassland, were for Asiatic jackal (*Canis aureus*; AJ, the major carnivore), wild boar (WB), and Malayan porcupine (*Hystrix brachyura*; MP); while in the dry season, the results were Asiatic jackal, dhole (DH), and Malayan porcupine. Asiatic jackal and dhole are the predators that are specific to the forest edge [5] and their main prey are gaur, sambar deer, and northern red muntjac [62], which are not commonly found at this water source. Mammals seen frequently at water pan number 2 during the wet season were large-spotted civet (*Viverra megaspila*; LSC) and Asiatic black bear (ABB), while in the dry season, northern pig-tailed macaque (*Macaca leonine*; NPM), gaur, and large-spotted civet were prevalent. This water source was also located in the artificial grassland, but it had a low abundance of dholes. Gaur, which are the main prey of dhole [62] are commonly found in the dry season when the water supply is limited to other areas. At standard artificial pond number 2, the Asian palm civet (*Paradoxurus hermaphroditus*; APC), northern pig-tailed macaque, and northern red muntjac (NRM) were prevalent. Furthermore, gaur was mostly found at water spring number 1, which is located in the dry evergreen forest, a habitat that offers resources to support resting and chewing the cud under the tree [63]. In the dry season, water spring number 2 was dominated by Asian palm civet, yellow-throated marten (*Martes flavigula*; YTM), and wild boar (Table 1).

In 2021, 9896 photographs of gaur and 3461 photographs of other mammals were captured over 379 nights per water source for a total of six water sources (12 camera traps). During the wet season, the three highest relative use indices values were calculated for water pan number 1, including Asiatic jackal, and Asiatic black bear. This water source plays an important role in the hunting of the Asiatic jackal. Pan number 2 supported the large-spotted civet and Asiatic black bear, whereas in the dry season, it supported dhole, crab-eating mongoose (*Herpestes urva*; CEM), and northern pig-tailed macaque. Dhole were more abundant compared with in 2020 because of the commonly used water source in the previous year. At standard artificial pond number 2, which was established in forest plantations, sambar deer was the most abundant species in both seasons; this species preferentially graze and brow on grass and others dicotyledons on the forest floors at the forest edge [2]. Northern red muntjac was mostly found at water spring number 1, which is located in a dry evergreen forest that has higher cover than other forest types in the area. Furthermore, northern red muntjac is a solitary medium-size herbivore that is the main prey of dhole [64] and Asiatic jackal; living in a dense forest offers a greater chance of survival (Table 1).

In both the wet and dry seasons of 2020, the three highest relative abundance index values were calculated for gaur, sambar deer, and dholes. In 2021, the highest three relative absolute index values were for gaur, sambar deer, and large-spotted civets (Table 2). Furthermore, in both years, gaur was found at most water sources in both the wet and dry seasons (Table 2). The relative use results support the theory that water pans can mimic a water spring, providing year-round water supplies for mammals, as suggested by Epaphras et al. [64], controlling mammal behavior in the areas, and can reducing water shortages in the dry season [17,62].

3.2. Species richness, species diversity, and evenness index of mammals in KPMNA

In 2020, the species richness was highest at water pan number 1 (10 species) and lowest at standard artificial pond number 1 (one species). Species richness at water pan numbers 2, water spring number 2, standard artificial pond number 2 and water spring number 1 were 9, 8, 7, and 5 species, respectively (Table 3). The mammalian species diversity index was highest at water spring number 2, followed closely by pan number 1. Standard artificial pond number 2, water pan number 2, and water spring number 1 had *H'* values of 0.85, 0.69, and 0.58, respectively (Table 3). Evenness was greatest in water spring number 2, followed by pan number 1 (Table 3).

A standard artificial pond can allow resident species, including gaur, to extend their distribution into otherwise suitable habitats that would otherwise lack of free-standing water [65–70]. In this study, the water pan in the artificial grasslands could support herbivore species that are the prey of carnivores. Mammalian species were less abundant at the springs and standard artificial ponds because mammal species richness increased with grass cover, decreased with shrub cover, and showed no clear pattern with increasing tree cover. Soto-Shoender et al. [71] found that reducing and increasing shrub and grass cover by 50 % increased species richness and local abundances of the mammal community in a bush encroached savanna in Africa. Increased the open space also increased the abundance and distribution of gaur in KPMNA [72]. Smaller sized mammals did not use the standard artificial pond in the forest plantations, which has high steeper slope and more open water surface compared with other water sources. Water storage in standard artificial ponds was found only in the wet season because owing to the high elevation; the soil could not hold water inside the ponds. In the KPMNA, the standard artificial ponds did not provide support to mammalian species in the dry season, as found in other studies [73]. Suitable water sources such as water pans can increase the diversity and distribution of mammalian species, especially large herbivores [11,17].

In 2021, the species richness was highest in water pan number 2 (11 species) and lowest in water spring 1 (no species). Standard artificial ponds 1 and 2 had 4 species, water pan 1 had 10 species, and water spring 2 had 6 species (Table 3). The mammal species diversity index was also greatest at water pan number 2, while at water pan number 1, water spring number 2, and standard artificial ponds numbers 1 and 2, *H'* was 1.47, 0.88, 0.22, and 0.1, respectively (Table 3). Evenness was greatest at spring number 2, and lowest at pan number 2 (Table 3).

The similarity indices of mammals among the water sources in 2020 and 2021 range between 0.04 and 0.08, and 0.04 and 0.14, respectively (Table 4). The similarity indices of the mammalian species showed that the water pan and spring were similar, whereas the standard artificial pond was different. Standard artificial ponds are large and deep compared with water pans and springs. Furthermore, the retention time in standard artificial ponds is shorter than those in water pans and springs. Mammal species showed a preference for the water springs during both the wet and dry seasons. This is consistent with past work, which showed that water sources that can maintain water in the dry season and have characteristics similar to water springs, such as water pans, are highly used by mammalian species [62] as rainfall and temperature drive the use of free water [66].

A cluster dendrogram at 50 % (height >5) showed the similarity of the water sources based on mammal usage. In 2020, the order was: water pan number 1 > standard artificial pond number 1 > standard artificial pond number 2 > water pan number 2 > water spring number 2 > water spring number 1 [Fig. 4(a)]. In 2021, the order was water pan number 2 > standard artificial pond number 1 > standard artificial pond number 2 > water pan number 1 > water spring number 2 > water spring number 1 [Fig. 4(b)].

In 2020, CCA showed that water pan number 2 (WP#2) had the greatest correlation with water duration (Waterperiod), greater

Table 2
The relative abundance index of mammals in the wet and dry seasons in Khao Phaeng Ma Non-Hunting Area.

Scientific name	Common name/Abbreviation	2020		2021		Two Year	
		Wet	Dry	Wet	Dry	Wet	Dry
Bos gaurus	Gaur/GA	20.7	15.8	13.6	12.5	15.8	12
Rusa unicolor	Sambar/SA	13.8	13.2	13.6	12.5	13.2	8
Muntiacus vaginalis	Northern red muntjac/BD	13.8	10.5	9.1	12.5	10.5	12
Cuon alpinus	Dhole/DH	10.4	10.5	9.1	6.3	10.5	10
Ursus thibetanus	Asiatic black bear/ABB	6.9	10.5	13.4	12.5	7.9	12
Sus scrofa	Wild boar/WB	6.9	7.9	9.1	9.4	10.5	10
Canis aureus	Golden jackal/JK	6.9	7.9	9.1	6.3	7.9	8
Viverra megaspila	Large-spotted civet/LSC	6.9	7.9	13.4	6.3	10.5	8
Hystrix brachyura	Malayan porcupine/MP	6.9	5.3	4.6	6.3	5.3	4
Macaca leonina	Northern pig-tailed macaque/NPTM	3.5	5.3	4.6	12.5	5.3	10
Paradoxurus hermaphroditus	Common palm civet/CPC	3.5	2.6	0	0	3.5	2
Herpestes urva	Crab-eating mongoose/CREM	0	2.6	0	0	0	2
Martes flavigula	Yellow throated marten/YTM	0	0	0	3.1	0	2
Total		100	100	100	100	100	100

Table 3
Mean number of photographs ± standard deviation (Mean ± SD), Species richness, species diversity, and evenness index of mammals in Khao Phaeng Ma Non-Hunting Area.

Water source	Mean ± SD		Species richness (*S*)		Shannon index (*H*′)		Evenness (*E*)	
	2020	2021	2020	2021	2020	2021	2020	2021
Standard artificial pond (AP#1)	6	14 ±22.5	1	4	0	0.67	0	0.48
Standard artificial pond (AP#2)	84 ±153.2	267.3 ±450.9	7	4	0.85	0.74	0.44	0.53
Water pan (WP#1)	262.2 ±453.6	45.3 ±57.1	10	10	1.38	0.45	0.6	0.2
Water pan (WP#2)	251.8 ±613.1	208.3 ±240.1	9	11	0.69	1.13	0.31	0.47
Natural water spring (WS#1)	92.8 ±169.4	0	5	0	0.58	0	0.36	0
Natural water spring (WS#2)	20 ±21.9	25.2 ±39.1	8	6	1.57	1.23	0.76	0.69

Table 4
The similarity index among water sources of mammals in Khao Phaeng Ma Non-Hunting Area.
WS = natural water spring; WP = Water pan; AP = Standard artificial pond; the correlation among water sources in 2020 (blue color); and 2021 (red color).

Water source	WS#1	WS#2	WP#1	WP#2	AP#1	AP#2
WS#1	1	0.04	0.09	0.04	0.04	0.04
WS#2	0.08	1	0.09	0.04	0.04	0.04
WP#1	0.04	0.04	1	0.09	0.14	0.04
WP#2	0.08	0.04	0.04	1	0.09	0.04
AP#1	0.04	0.04	0.08	0.04	1	0.04
AP#2	0.04	0.04	0.04	0.04	0.09	1

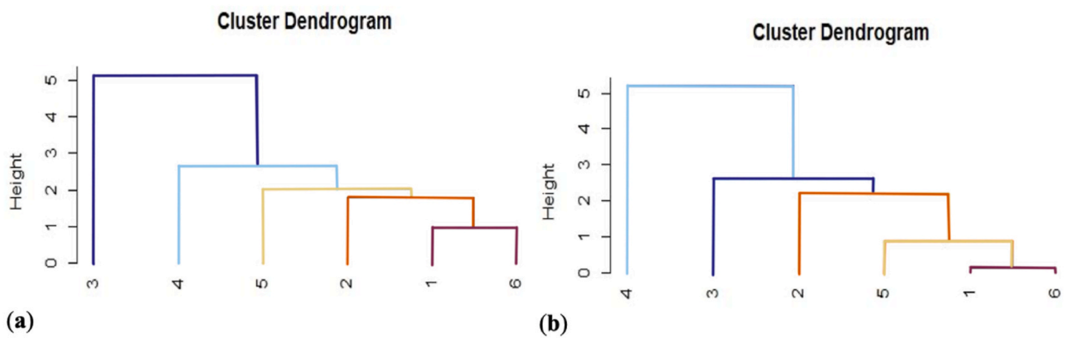

Fig. 4. The cluster dendrogram at 50 % (Height > 5) showed the similarity of the water sources based on the use of mammals in Khao Phaeng Ma Non-Hunting Area in 2020 (a); and 2021 (b). 1 = standard artificial pond number 1 (AP#1), 2 = standard artificial pond number 2 (AP#2), 3 = water pan number 1(WP#1), and 4 = WP#2; 5 = natural water spring (WS#2); 6 = WS#1.

distance to the nearest road (Road), and higher slope (Slope). Water pan number 1 (WP#1) and water spring number 2 were strongly correlated with water level in the wet season (SeasonWet) and water level in the whole year (Year). Standard artificial pond number 1 (AP#1) and standard artificial pond number 2 (AP#2) were strongly correlated with grassland (GL), elevation (Elev), number of species (Nospp), and number of mammalian photograph event (NoEven) [Fig. 5(a)]. Furthermore, many mammals, such as gaur (GA), and dhole (DH) were associated with water pan 1 in both the wet and the dry seasons. At standard artificial pond 1, only sambar deer (SA) were found, and at standard artificial pond 2, only northern red muntjac (NRM) was found (Table 5).

Principal component analysis showed that artificial water sources, such as water pans, must be constructed in areas that can provide water supply by gravity force. Large water surface area and depth of standard artificial ponds may not be important for supporting mammals, especially at higher elevations. Standard artificial pond developments could result in population declines of some mammal species if forage, rather than water, is the limiting resource [73,74]. Indeed, in has been suggested that the addition of standard artificial ponds in arid areas will concentrate foraging by native ungulates, and decrease forage on a local scale [13,73]. If

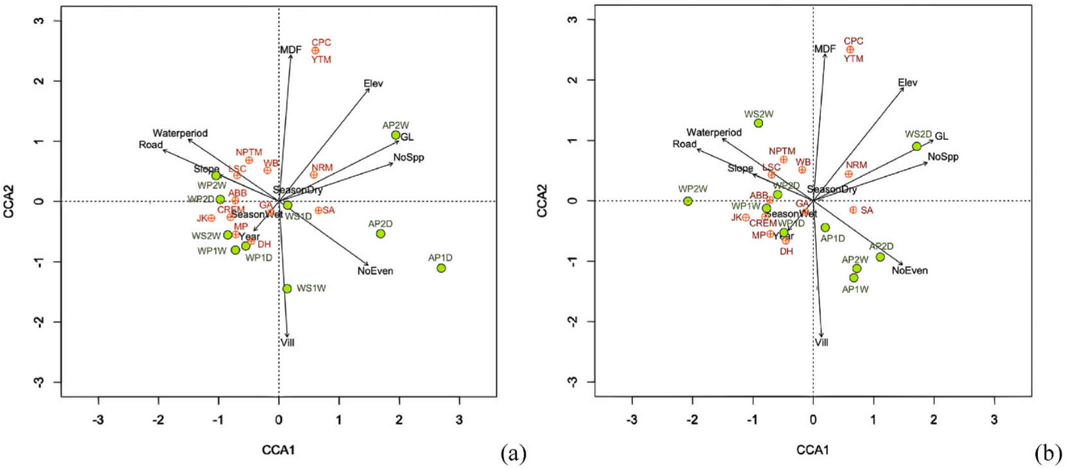

Fig. 5. The relationships among mammal species, water sources and their environmental factors in 2020 (a); 2021 (b) in Khao Phaeng Ma Non-Hunting Area. GA = *Bos gaurus*, ABB = *Ursus thibetanus*, NRM = *Muntiacus vaginalis*, CREM = *Herpestes urva*, CPC = *Paradoxurus hermaphroditus*, DH = *Cuon alpinus*, JK = *Canis aureus*, LSC = *Viverra megaspila*, MP = *Hystrix brachyura*, NPTM = *Macaca leonine*, SA = *Rusa unicolor*, WB = *Sus scrofa*, YTM = *Martes flavigula*.

native ungulates stay relatively close to water during times of water scarcity, the resulting increase in foraging intensity could reduce the availability of forage nearby; such effects should be evident in the vegetation surrounding standard artificial ponds, or in differences in forage biomass between areas near and far from standard artificial ponds. However, Marshal et al. [13] reported no effect of standard artificial ponds on forage biomass, and no change in gradient of forage biomass between desert washes with standard artificial ponds and those without.

While most standard artificial ponds are intended to benefit gaur, they are also intensively used by other mammals, including bats and a variety of birds [53,68,75,76]. The high concentration of mammal species may increase the concentration of carnivores, and increase the mortality rate of prey in water improvement areas [76]. A study of reintroduced bighorns in the deserts of western USA indicated that the congregation of animals in riparian areas near water may facilitate the spreading of diseases and parasites [75,76].

In terms of management implications, our results show that water pans are the most suitable structure for supporting mammalian species; in contrast, standard artificial ponds are too deep and cannot support mammalian species, especially during the dry season. Constructing small water pans in areas that cannot provide water to mammalian and bird species, especially during the dry season, would increase mammalian and bird diversity.

In 2021, CCA showed that water pan number 1 (WP#1), water pan number 2 (WP#2), and water spring number 1 (WS#1) had the strongest correlation with water duration (Waterperiod); water dried up in the dry season [62]. Greater distance to the nearest road (Road) and higher slope (Slope) were other reasons that these water sources had difficulty to providing water, especially in the dry season, which limited the used and distribution of many mammalian species, including gaur [34]. Water spring number 2 (WS#2) in the dry season was strongly correlated with grassland (GL), elevation (Elev), and number of species (Nospp), but could not support mammal species living areas far from the grassland at high elevation [77]. Standard artificial pond numbers 1 (AP#1) and 2 (AP#2) were significantly correlated with the number of mammalian photographs (NoEven) [Fig. 5(b)]. Furthermore, many mammals, such as gaur (GA), and dhole (DH), were associated with water pan number 1 (WP#1) in both the wet and the dry seasons, as they can provided water to mammals in both season, support the functions, predators, and preys of the ecosystem [78]. At standard artificial pond numbers 1 (AP#1) and 2 (AP#2), only sambar deer (SA) was found; at water spring number 2 (WS#2) in the dry season, only northern red muntjac was found (Table 5).

4. Conclusions

Mammals were found mostly at water springs rather than artificial ponds. Springs can provide water for mammals during both the wet and dry seasons, and water is the main environmental factor that can controlling the abundance and diversity of mammals, especially during the dry season. The development of water sources has allowed resident species to extend their distribution throughout the area. Gaur are more dependent on water sources than are other Large herbivores. Mammals of smaller size avoid the artificial ponds, which have steeper slopes and are located in more open areas when compared with other water sources. Water storage in artificial ponds was found only during the wet season; as such, they could not support mammalian species during the dry season. The mammalian species found at water pans and springs were similar and, unlike at artificial ponds, were observed in both the wet and dry seasons. The results show that water pans are the most suitable approach to support the mammalian species and increase mammalian and bird diversity.

Table 5
The relationships between mammal species and environmental factors in the canonical correspondence analysis (CCA) in the wet and dry seasons in Khao Phaeng Ma Non-Hunting Area.

Species/Environmental Factor	Abbreviation	CCA1	CCA2	CCA3
Eigenvalue		0.246	0.133	0.117
Bos gaurus	GA	−0.131	−0.184	0.107
Ursus thibetanus	ABB	−0.72	0.018	−0.239
Muntiacus vaginalis	NRM	0.583	0.446	0.69
Herpestes urva	CREM	−0.799	−0.259	−1.158
Paradoxurus hermaphroditus	CPC	0.608	2.507	−0.618
Cuon alpinus	DH	−0.456	−0.655	−0.065
Canis aureus	JK	−1.119	−0.274	0.033
Viverra megaspila	LSC	−0.691	0.434	0.602
Hystrix brachyura	MP	−0.714	−0.545	−0.245
Macaca leonina	NPTM	−0.491	0.686	−0.794
Rusa unicolor	SA	0.661	−0.147	−0.242
Sus scrofa	WB	−0.187	0.518	−0.347
Martes flavigula	YTM	0.608	2.507	−0.618
Water source				
Artificial pond #1 (2001, wet season)	AP1W_2001	0.6748	−1.279	−0.201
Artificial pond #1 (2000, dry season)	AP1D_2000	2.692	−1.104	−2.074
Artificial pond #1 (2001, dry season)	AP1D_2001	0.202	−0.446	−0.92
Artificial pond #2 (2000, wet season)	AP2W_2000	1.937	1.106	2.536
Artificial pond #2 (2001, wet season)	AP2W_2001	0.724	−1.125	0.012
Artificial pond #2 (2000, dry season)	AP2D_2000	1.686	−0.533	−0.008
Artificial pond #2 (2001, dry season)	AP2D_2001	1.112	−0.935	−0.271
Water pan #1 (2000, wet season)	WP1W_2000	−0.726	−0.805	0.422
Water pan #1 (2001, wet season)	WP1W_2001	−0.77	−0.129	−0.414
Water pan #1 (2000, dry season)	WP1D_200)	−0.555	−0.736	−0.615
Water pan #1 (2001, dry season)	WP1D_2001	−0.483	−0.53	0.243
Water pan #2 (2000, wet season)	WP2W_2000	−1.049	0.431	−0.635
Water pan #2 (2001, wet season)	WP2W_2001	−2.074	−0.012	−0.543
Water pan #2 (2000, dry season)	WP2D_2000	−0.978	0.036	−0.759
Water pan #2 (2001, dry season)	WP2D_2001	−0.588	0.098	−0.523
Water spring #1 (2000, wet season)	WS1W_2000	0.133	−1.445	0.542
Water spring #1 (2000, dry season)	WS1D_2000	0.141	−0.06	1.852
Water spring #2 (2000, wet season)	WS2W_2000	−0.854	−0.553	0.081
Water spring #2 (2001, wet season)	WS2W_2001	−0.902	1.282	3.478
Water spring #2 (2000, dry season)	WS2D_2000	0.346	3.556	−1.293
Water spring #2 (2001, dry season)	WS2D_2001	1.718	0.897	−0.155
Environmental Factor				
water level in the wet season (m)	SeasonWet	−0.339	−0.195	0.472
water level in the whole year (m)	Year	−0.14	−0.163	0.028
Distance from the village (km)	Vill	0.045	−0.752	−0.119
Distance from road (km)	Road	−0.643	0.285	0.018
Elevation (asl; m)	Elev	0.499	0.625	0.162
Slope (%)	Slope	−0.333	0.146	0.4
Distance from grassland (km)	GL	0.662	0.335	0.291
Distance from mixed deciduous forest (km^2)	MDF	0.065	0.811	0.176
Water time (months)	Waterperiod	−0.503	0.344	0.332
Number of species (species)	NoSpp	0.629	0.211	−0.263
Number of mammalian photograph event (events)	NoEven	0.493	−0.354	−0.296

5. Study limitations

In the present study, we successfully analyzed the requirements of mammalian diversity for different water resource types. However, experiments on the water resources could not be conducted systematically because all the structures in the study area are natural or had already been constructed at the time of study. Currently, it is impossible to reconstruct all of the water sources as desired. Potential biases of this study are associated with the efficiency of camera traps, such as detection limitations and habituation effects, which may have affected the accuracy of species abundance estimates. In future studies, we intend to redesign the water sources with the help of DNP before starting the experiment.

6. Resource availability

6.1. Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled bythe lead contact, Rattanawat Chaiyarat (rattanawat.cha@mahidol.ac.th).

6.2. Materials availability

This study did not generate new unique reagents.

6.3. Data and code availability

- Data reported in this paper will be shared by the lead contact upon request.
- This paper does not report original codes.
- Any additional information required to reanalyze the data reported in this paper is available from thelead contact upon request.

6.4. Experimental model and study participant details

This work did not need any unique experimental model.

6.5. Quantification and statistical analysis

Figures shown in the main text were produced by Origin 2022 and Microsoft PowerPoint from the raw data.

6.6. Additional resources

There are no additional resources needed to be declared in this manuscript, additional requests for thiscan be made by contacting the lead contact.

Funding and conflict of interest

This work was partia by Mahidol University. The authors do not have any conflicts of interest.

Data availability statement

All data has been included in article/supp. material/referenced in article.

Declaration of ethics statement

The authors declare that the animal experiments and ethics was approved by Mahidol University-Institute Animal Care and Use Committee (MU-IACUC 2022/006 No. F02-65-007, March 1, 2022).

CRediT authorship contribution statement

Rattanawat Chaiyarat: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Piyamaporn Thongkrathok:** Writing – original draft, Investigation, Formal analysis, Data curation. **Wanwipa Maisuwan:** Writing – original draft, Investigation, Formal analysis, Data curation. **Amornrat Chantra:** Writing – original draft, Investigation, Formal analysis, Data curation. **Jinda Chimplee:** Validation, Supervision, Data curation. **Nawee Jieychien:** Validation, Supervision, Data curation. **Songkrit Assawaklang:** Validation, Supervision, Data curation. **Namphung Youngpoy:** Visualization, Software, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rattanawat Chaiyarat reports financial support was provided by Mahidol University. Rattanawat Chaiyarat reports a relationship with Mahidol University that includes: employment and funding grants. Rattanawat Chaiyarat has patent licensed to Department of National Parks, Wildlife, and Plant Conservation record 243–258. We declare that all authors are not interpreting as a conflict of interest by the reader. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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