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COMMUNICATION

Artificial deepening of seasonal waterholes in eastern Cambodia: impact on water retention and use by large ungulates and waterbirds

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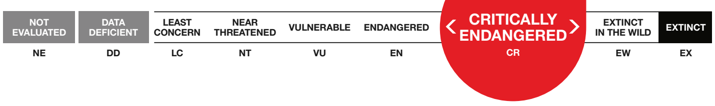
Abstract: Natural seasonal waterholes (trapeang in Khmer) are an important feature of the deciduous dipterocarp forests of eastern Cambodia and are utilised by a number of globally threatened species of large ungulates and waterbirds. However at the end of the dry-season (April) only a small proportion of waterholes retain water. In 2011, we artificially deepened six waterholes in the core area of Mondulkiri Protected Forest, eastern Cambodia, removing 3m^3 to 24m^3 of earth (mean 16.5m^3) from each. Surveys prior to deepening demonstrated that only one of these waterholes, and 10% of all waterholes surveyed in the study area (n=50), held water at the end of the dry-season. Following modification five of the six deepened waterholes (83%) held water at the end of the subsequent dry-season. From four camera traps over 448 trap-nights, 23 species including two globally threatened large ungulates, Banteng *Bos javanicus* and Eld's Deer *Rucervus eldii*, and two Critically Endangered Ibises (Giant *Thaumatibis gigantea* and White-shouldered Ibis *Pseudibis davisoni*), were photographed foraging and drinking at the deepened waterholes between March and June 2012. Our results suggest that artificial deepening of natural waterholes does not cause damage, and makes these waterholes suitable for use throughout the dry-season. In the face of changing climate it is suggested that management plans should have a programme for the survey and determination of the status of waterholes every year and improve the use of water resources by artificial deepening.

Keywords: Climate change, conservation evidence, dry forest, Indochina, protected area management.

Thaumatibis gigantea
Giant Ibis



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INTRODUCTION

The deciduous dipterocarp forests of eastern Cambodia form part of the Lower Mekong Dry Forests Ecoregion and are globally significant for biodiversity conservation (Tordoff et al. 2005; Gray et al. 2012a). These forests support particularly important populations of large ungulates, including the largest global population of the Banteng *Bos javanicus* (Gray et al. 2012b) which is declared by IUCN Red List of Threatened Species as 'Endangered A2cd+3cd+4cd' from 2008 (Timmins et al. 2008), and large waterbirds including two species of Ibis which are listed as 'Critically Endangered' by the IUCN Red List of Threatened Species (Wright et al. 2012a).

Deciduous dipterocarp forests in the Eastern Plains Landscape are affected by strong monsoon creating a highly seasonal environment with long periods of water stress during the dry-season. The total annual precipitation is approx 1500–1800 mm, and the dry season lasts from November to April when less than 10% of annual precipitation is recorded (Bruce 2013). One of the key features of the deciduous dipterocarp landscape in the eastern plains is that the landscape is studded by natural seasonal waterholes (trapeang in Khmer). By the end of the dry-season (March–April) a majority of the waterholes in the landscape do not retain water (Koehncke 2010).

Waterholes that retain water throughout the dry-season are increasingly disturbed (WWF-Cambodia, internal data) as human activities across the landscape are on the increase, collection of non timber forest products is legally permitted, and there is illegal fishing and hunting of wildlife. This is considered detrimental to a number of threatened species including Eld's Deer *Rucervus eldii*, which do not drink from other water-sources, e.g., pools in seasonal rivers, and Ibis for which waterholes are key foraging resources (Wright et al. 2012b, 2013). Predicted changes in precipitation and temperature associated with climate change are also likely to affect water retention during the dry-season in the landscape (Beaumont et al. 2011).

Artificial manipulation of water availability through modifying natural waterholes, or developing entirely new water sources, is widely used in tropical savannah and dry forest ecosystems for ungulate conservation (Owen-Smith 1996; Smit et al. 2007). However, attempts to modify natural waterholes in South-east Asian deciduous dipterocarp forest for conservation have not been documented previously. The aims of this study were to experimentally deepen waterholes in the core area of Mondulkiri Protected Forest, eastern Cambodia to examine, (1) whether deepened waterholes held water for longer periods during the dry-season than prior to modification and (2) whether artificially deepened waterholes could be used by globally threatened large ungulates and large waterbirds.

MATERIALS AND METHODS

Study Area

Mondulkiri Protected Forest (MPF) located in eastern Cambodia is approximately 2120km^2, and forms part of the Eastern Plains Landscape, a protected area complex of over 13,000km^2 including Yok Don National Park in Dak Lak province, Vietnam. The study area is largely flat and dominated by deciduous dipterocarp forest (Pin et al. 2013) with smaller patches of bamboo and riverine gallery forest. The study was conducted within approximately 450km^2 inside the proposed core zone of MPF (approx. location 13^{0}05'N & 107^{0}30'E). This area supports the highest ungulate densities in the Eastern Plains Landscape, at approximately six individuals per km^2, (Gray et al. 2013) and is the only area in MPF from which Eld's Deer are regularly recorded. The study area, and modified waterholes, are all more than 30km away from the nearest village and not used at all by domestic ungulates. Based on remotely sensed imagery the total number of waterholes in the entire core area of MPF is 430 (WWF-Cambodia, internal data). Between January and April 2010 (mid to late dry-season) 50 waterholes within the study area were surveyed for water availability during three survey visits (Koehncke 2010; Fig. 1). These waterholes were a sub-set of the 64 waterhole within the study area.

Waterhole manipulation

In April 2011 six totally dry natural waterholes (henceforth modified waterhole) in the study area were artificially deepened up to 100cm, from their centre (Image 1; Table 1). Extracted earth was moved to the edge of the modified waterhole and spread over an area 2–3 m from the modified waterhole ensuring that access for ungulates was not impacted. Deepening was done manually without the use of machines. Sub-contracted local villagers were engaged at a total cost of approximately 3,000 US$. The deepening work of each waterhole took approximately 2–3 days. Five modified waterholes were deepened by 50–100 cm with 16m^3 to 24m^3 (mean 19.2m^3) of earth removed (Table 1). Due to a hard rock-like substrate forming the bottom of one of the modified waterhole #6 it was deepened by only

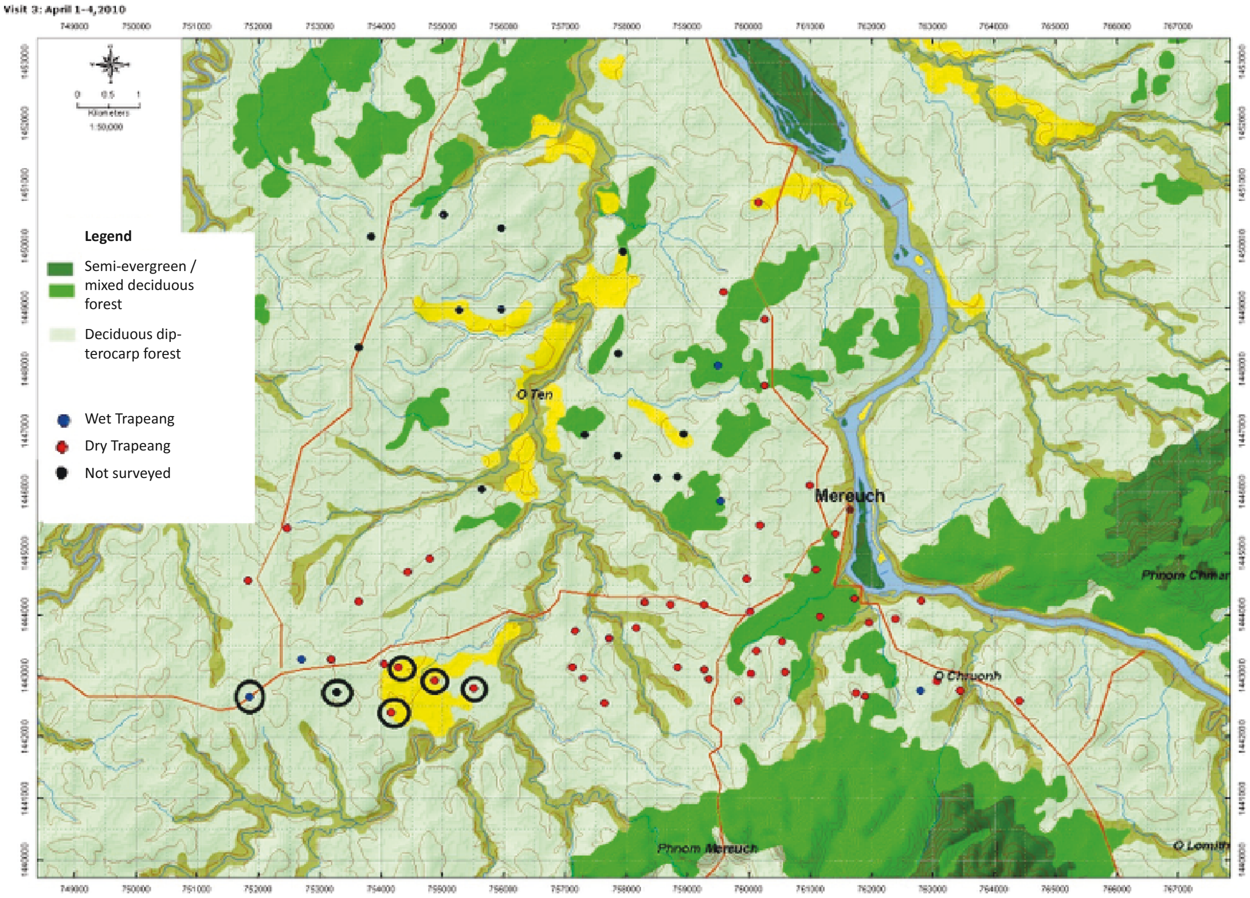

Figure 1. Waterholes within the study area of Mondulkiri Protected Forest, Cambodia indicating status of water-level in early April 2010. Waterholes not surveyed are in black. Circled locations show waterholes modified in 2011. All modified waterholes, except the southern-most were provided camera-traps in 2012.

Table 1. Estimated dimensions of the open area and of water in early dry-season 2010 prior to modification (from Koehncke 2010; waterhole #3 not visited) for six artificially deepened waterholes in Mondulkiri Protected Forest, eastern Cambodia. Maximum depth deepened (cm) and total earth excavated (m^3) during April 2011, for each waterhole, indicated.

Waterhole ID	Open area	Water spread	Max depth deepened (cm)	Total excavated (m^3)
1	50m x 60m	25m x 40m	50	20
2	30m x 30m	20m x 25m	100	18
3	n/a	n/a	50	18
4	15m x 40m	7m x 15m	100	16
5	30m x 40m	20m x 15m	100	24
6	20m x 600m	15m x 50m	20	3

Image 1. Waterhole # 2 following artificial deepening (to depths of 50 and 100-cm; total earth excavated 18-m^3) in April 2011.

approximately 20cm with a total of $3m^3$ earth removed (Table 1).

Monitoring use by ungulates and large waterbirds

Between March and June 2012 (late dry-season to early wet-season) automatic camera-traps (Reconyx

RapidFire Professional PC90; Reconyx) were placed at each of the modified waterholes to photograph animals using the waterholes. The camera-trap at waterhole # 4 malfunctioned without producing any data. Although a robust study was not designed, the exercise could provide data from the remaining five modified waterholes. Records for a total of 448 camera-trap nights, with a range of 86–92 nights per waterhole were collected.

RESULTS

Patterns of water retention prior to modification

In late January 2010, 43 (86%) out of 50 waterholes held water. The number declined to five (10%) in early April 2010. The 50 waterholes surveyed in 2010 included five of the waterholes modified later in 2011. Four of these held water in early March, but only one (#6) in April.

Patterns of water retention following modification

Five of the six modified (i.e., 83%) waterholes retained water in April 2012 (i.e., post-modification). At the same time of the year in 2010, i.e., before modification, only one of these waterholes (20%), and 10% of all waterholes surveyed (n=50) had retained water. On 14 March 2012 all six of the modified waterholes contained water; on the 27 April 2012 five of the modified waterholes contained water with only waterhole (#6) dry. Assuming that the pattern of water retention in the unmodified waterholes across the study area were the same as during the 2010 surveys the manipulation of waterholes doubled the amount of waterholes holding water within the study area at the height of the 2012 dry-season

Use of modified waterholes by large mammals and waterbirds

Following the definition for 'independent encounter' by Phan et al. (2010), a total of 242 'independent' camera-trap photographs of 23 species, including 10 globally threatened species, were obtained from five waterholes under study (Table 2 and 3; Images 2,3). The species included Banteng from all five waterholes and Eld's Deer from three. Six species of large waterbirds—three stork, two ibis, and Sarus Crane, were photographed foraging within the modified waterholes (Table 2). Giant Ibis was recorded from all five modified waterholes and White-shouldered Ibis from three (Image 4).

Table 2. Globally-threatened species of mammals and bird, plus all ungulate and large waterbird species, recorded by camera-trapping from five artificially deepened waterholes in Mondulkiri Protected Forest during the 2012 dry-season.. LC - Least Concern; NT - Near Threatened; VU - Vulnerable; EN - Endangered; CR - Critically Endangered.

Species	IUCN status	#1	#2	#3	#5	#6
Giant Ibis (*Thaumatibis gigantean*)	CR	X	X	X	X	X
White-shouldered Ibis (*Pseudibis davisoni*)	CR	X	X		X	
Red-headed Vulture (*Sarcogyps calvus*)	CR		X			
Eld's Deer (*Rucervus eldii*)	EN	X	X		X	
Banteng (*Bos javanicus*)	EN	X	X	X	X	X
Dhole (*Cuon alpinus*)	EN	X				
Green Peafowl (*Pavo muticus*)	EN	X				
Red Muntjac (*Muntiacus muntjak*)	LC	X	X	X	X	X
Wild Pig (*Sus scrofa*)	LC	X	X	X	X	X
Woolly-necked Stork (*Ciconia episcopus*)	LC	X	X	X	X	X
Black-necked Stork (*Ephippiorhynchus asiaticus*)	NT	X				
Large-spotted Civet (*Viverra megaspila*)	VU	X				X
Lesser Adjutant (*Leptoptilos javanicus*)	VU		X	X	X	
Sarus Crane (*Grus antigone*)	VU				X	

Image 2. Eld's Deer *Rucervus eldii* drinking from modified waterhole #2 on 18 March 2012

Table 3. Species-wise 'independent encounters' in March-June 2012 after modification of natural waterholes in five locations of Mondulkiri Protected Forest, eastern Cambodia

Species		Locations	Encounters
Wild Pig	*Sus scrofa*	5	90
Banteng	*Bos javanicus*	5	33
Wooly-necked Stork	*Ciconia epicopus*	5	29
Giant Ibis	*Thaumatibis gigantea*	5	22
White-shouldered Ibis	*Pseudibis davisoni*	3	16
Lesser Adjutant	*Leptoptilos javanicus*	3	8
Eld's Deer	*Rucervus eldii*	3	7
Red Muntjac	*Muntiacus muntjak*	5	6
Asiatic Jackal	*Canis aureus*	2	4
Sarus Crane	*Grus antigone*	1	4
Black-necked Stork	*Ephippiorhychus asiaticus*	1	3
Green Peafowl	*Pavo muticus*	1	3
Small Indian Civet	*Viverricula indica*	3	3
Black-collared Starling	*Sturnus nigricollis*	1	2
Common Palm Civet	*Paradoxurus hermaphroditus*	2	2
Dhole	*Cuon alpinus*	1	2
Large-spotted Civet	*Viverra megaspila*	2	2
Chinese Francolin	*Francolinus pintadeanus*	1	1
Jungle Cat	*Felis chaus*	1	1
Red Collared Dove	*Streptopelia tranquebarica*	1	1
Red-headed Vulture	*Sarcogyps calvus*	1	1
Siamese Hare	*Lepus peguensis*	1	1
Small Asian Mongoose	*Herpestes javanicus*	1	1

Image 3. Group of Banteng *Bos javanicus* drinking from waterhole #5 on 19 April 2012.

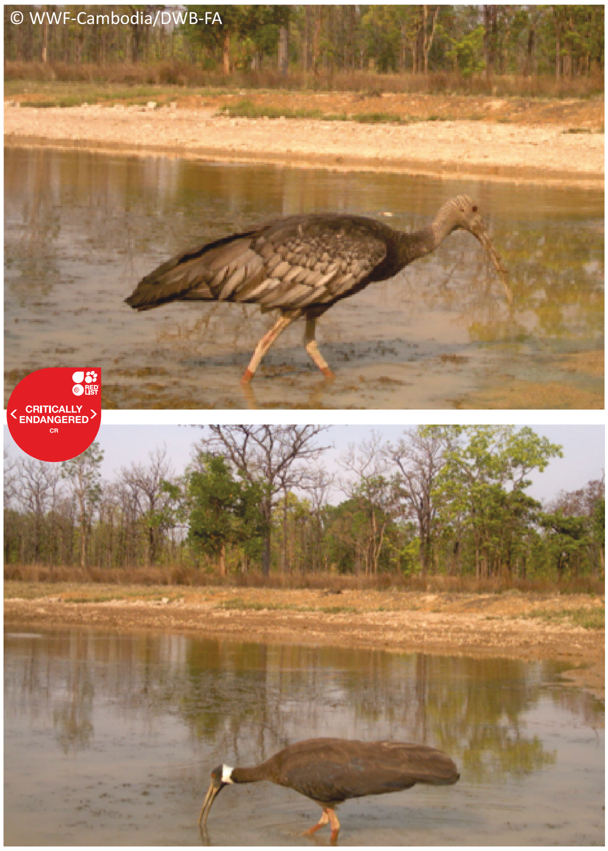

Image 4. Giant Ibis *Thaumatibis gigantea* (upper) foraging at modified waterhole #1 on 29 March 2012; and White-shouldered Ibis *Pseudibis davisoni* (lower) foraging at modified waterhole #1 on 20 March 2012.

DISCUSSION AND CONCLUSIONS

Manipulation of water availability for rendering benefit to target species is one of the relatively common and direct conservation management actions in protected areas in southern Africa and Europe, but it is rare in Indochina (Owen-Smith 1996; Lacasa et al. 2010; Shrader et al. 2010). Instead, a number of temporary and innovative methods are practiced in protected areas in tropical Asia to overcome periods of water stress, but quantitative data showing their efficacy is limited or not accessible. Active provision of additional water into waterholes in South-east Asia may be unsustainable and logistically difficult.

Whilst it is unclear about the extent to which water limitation impacts survivorship and reproduction of threatened ungulates within Cambodian dry forest, it would be logical to conclude that water is a limiting factor and increased water availability could improve ungulate productivity. Radio-collaring of Eld's Deer in a similar forest in Myanmar suggested movements and home-ranges were larger in the dry-season and this is likely to be related to reduced water availability (Mint et al. 2001).

The results of the present study form a record for reference and refinement of ways in which waterholes can be artificially modified to retain water for longer periods in the dry season in future. The simple technique we used increased water retention post-manipulation, and modified waterholes were used by a suite of threatened species characteristic of the Lower Mekong Dry Forests Ecoregion. It also proved that the practice can be continued to other waterholes.

We do not believe that modification of waterholes to enhance water retention is likely to increase chances of disease transmission between animals. In effect, it may, through increasing availability of water during the dry-season across more waterholes, prevent high densities of animals concentrated in few places.

The extent to which additional precautions prior to deepening waterholes are required is unclear. Ideally detailed geological studies to assess water retention ability below certain depths of excavation would have to be conducted. However the levels of expertise for such studies is likely outside both the technical, and financial, capacity of most protected area managers in Indochina.

Several unfounded apprehensions appear to have prevented artificial deepening of natural waterholes in the past. However, our results have clearly shown that the method we employed does not prevent use of waterholes by threatened (Table 2) and non-threatened (Table 3) species of large ungulates and waterbirds. Camera-trap photographs clearly show both ibis and storks foraging (Imgae 4) and Eld's Deer and Banteng drinking (Images 2 & 3) at modified waterholes. When enhancing water availability within protected areas it is important that law enforcement and patrolling activities are focused to ensure modified water features are not targeted for illegal hunting or disturbance. Camera-trapping at the modified waterholes did not record any local people but unaccompanied domestic dogs were recorded from one waterhole on one occasion.

Whilst our results suggest that artificial deepening of natural waterholes is an effective technique for increasing dry-season water availability in highly seasonal deciduous dipterocarp forests, we recommend a number of future research activities into the process and ecological impacts of artificially deepening waterholes. Studies are required to assess the degree to which water availability is limiting for focal species in deciduous dipterocarp forests thus clarifying the extent to which waterhole manipulation is necessary. Recent studies have also suggested that dried substrates surrounding waterholes are an important breeding season resource for the Critically Endangered White-shouldered Ibis and thus retaining water throughout the dry-season in a majority of waterholes may be detrimental for this species (Wright et al. 2013). Studies are needed to compare large waterbird food resources between modified and unmodified waterholes across both dry and wet-seasons. The impacts of anthropogenic climate change on Indochina's lowland deciduous forests are not yet clearly understood, but altered rainfall and evaporation will probably affect waterhole hydrology especially during the dry-season when water stress is already high (Timmins 2011). Modeling has also demonstrated that water stress may negatively impact ungulate populations particularly those which are sedentary and largely grazers, i.e., Banteng and Eld's Deer (Duncan et al. 2012). Given that we have demonstrated the value of artificially manipulating waterholes for increasing water availability for large ungulates and waterbirds, our technique may be particularly valuable throughout South-east Asian deciduous dipterocarp forests in the face of a changing climate.

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Author Contribution: TNEG: designed the study, wrote the paper. WJM: designed the study, wrote the paper. AK: undertook fieldwork and data collection, wrote the paper. PS: undertook fieldwork and data collection. MW: designed the study, wrote the paper.