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Cover: A female Javan Leopard *Panthera pardus melas* in rehabilitation phase at Cikananga Wildlife Center. © Yayasan Cikananga Konservasi Terpadu.



Range extension and new ecoregion records of the Crocodile Monitor *Varanus salvadorii* (Peters & Doria, 1878) (Reptilia: Varanidae) in Papua New Guinea

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Abstract: The Crocodile Monitor *Varanus salvadorii* is one of the longest lizards and an apex predator in New Guinea. Limited information is available on its ecology and distribution, mainly due to its arboreal lifestyle and preference for inaccessible primary forest habitats. Here we provide the first published record, using camera trapping technology in the Torricelli Mountain Range, of *V. salvadorii* living at a higher elevation than previously recorded in montane rainforest habitat. This range extension implies the occupation of a distinctive ecoregion for the species: the Northern New Guinea Montane Forest, a substantially cooler region from the formerly known distribution area. We present trail camera images of an active animal at an elevation of 1,500 m & at 18°C temperature and we discuss the implications of this finding for understanding the behaviour & conservation of the Crocodile Monitor.

Keywords: Distribution, monitor lizard, Northern New Guinea Montane Forest, Tenkile Conservation Alliance, threats, Torricelli Mountain Range.

Tok Pisin Abstract: Birkpela stori bilong dispela wok: Dispela pukpuk nem bilong em Monitor *Varanus salvadorii* em wanpla bigpla na longpela palai tru na i stap namba wan long Niu Gini olsem animol we i save killim na kaikai olgeta arapela animol. Bikos dispela pukpuk i save laik long stap antap tu long ol diwai na laikim tumas bigpela bush we nogat man i save go, yumi nau no save tumas long ples we dispela pukpuk i save stap long em na tu yumi no klia gud yet long wonem hap kona blo kantri tru dispela pukpuk igo kamap pinis. Mipla painim aut sampla moa nupla samtin long dispela pukpuk na nau mipla wokim namba wan toksave long kantri na olgeta man meri long ples graun olsem dispela pukpuk *V. salvadorii* i stap tu long maunten ples antap moa we ol lain bipo ino bin lukim long em bikos ol i bin painim em tasol long bus blo liklik maunten lo nambis sait tasol. Mipela usim kamera olsem trap bilong kisim foto long dispela pukpuk antap long maunten blo Torrecelli Range. Dispela luksave nau i soim olsem pukpuk *V. salvadorii* i go stap antap long ol maunten na nupla hap tu: Em long hailens bus na maunten bilong Sepik we ples i kol na bipo dispela pukpuk ino bin stap long em. Ol dispela piksa mipla i soim em bilong dispela pukpuk i raun painim kaikai we kemera i kisim long em antap long maunten i sanap olsem 1,500 m na ples i kol olsem long 18oC. Mipla i stori tu long wonem samtin i mas kamap nau antap long dispela save na wonem wei tru yumi ken wok wantaim long lukautim dispela pukpuk Monitor *V. salvadorii*.

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Author contributions: Both authors have participated in organizing and analyzing the data. BR wrote the manuscript and JT wrote the methods and revised the manuscript.

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INTRODUCTION

New Guinea is considered a high-biodiversity wilderness area, an important region for conservation that combines a large percentage of intact habitats with rich endemism, exceptionally diverse biota, and low human population density (Richards 2007; Mittermeier et al. 2011). With the remaining natural forest cover extending over 90% of its land, Papua New Guinea (hereafter PNG) is one of the least explored regions in the world (Mittermeier et al. 2003; Vizzuality 2010; PNG Data Portal 2021). The Torricelli Mountain Range is among the remotest areas of this island (Diamond 1985; Flannery 1995; Kraus & Allison 2006; Beehler & Prawiradilaga 2010; Thomas 2014). Located primarily in Sandaun Province (northwestern PNG), the Torricelli Mountains form the northern coastal range of PNG together with Prince Alexandre and Bewani Mountains stretching from the East Sepik Province to the Keerom regency in Papua province (Indonesia) in the west (Image 1). These mountains are part of the New Guinea north coastal ranges which also includes the Cyclops, Foja, and Van Rees mountains located in Papua province. The Torricelli Mountains consist of limestone and montane forest and harbours several endemic vertebrate and invertebrate species, and the description of new species is considered very likely (Flannery 1995; Allison 1996; Wikramanayake et al. 2002; Kraus 2010; Thomas 2014). Furthermore, this area is considered the third most diverse region for lizards in New Guinea (Heads 2002). The Torricelli Mountain Range is enveloped by two key biodiversity areas (KBAs), the East and West Torricelli's, and is a proposed conservation area (Dalsgaard & Pedersen 2015; Schwartz et al. 2021).

The Crocodile Monitor *Varanus salvadorii* is the largest lizard of New Guinea and an apex predator on this island (Heinsohn & Hope 2006). A handful of studies exist on this elusive species in captivity (Adams 1995; Waterloo & Bayless 2006; Mays 2007; Trout 2007; Camina et al. 2013; Reh et al. 2021) but *V. salvadorii* has been poorly studied in the wild, mainly because it is restricted to commonly inaccessible forests, strictly avoids contact with humans, and predominantly displays arboreal behaviour (Horn et al. 2007; Pattiselanno 2007; Shea et al. 2016).

The distribution of the species includes lowland and hill forests around most of the coastal lowlands of New Guinea. However, it has not been reported to occur in habitats above 600 m. The species has previously been reported from open woodland habitats within the Trans-Fly region, and lowland and mangrove forests on the

islands of Salawati, Warir, and Selat Sagawin (north-west tip of Papua) (Allison 2006; Horn et al. 2007; Borja Reh pers. comm. 1.xii.2009). Crocodile Monitors are excellent swimmers, and individuals have been observed in forests along rivers (Marshall & Beehler 2011).

Here we report the first discovery of Crocodile Monitors in the Torricelli Mountain Range captured with trail camera traps at elevations above 1,000 m.

MATERIALS AND METHODS

The Tenkile Conservation Alliance (TCA) has been conducting research in the Torricelli Mountain Range since 2002. From 2002 a total of 16 sites have been established for sampling, specifically point transect sampling and initially for scat surveys for tree kangaroos. Each research site consists of 20 transects with a total of 150 transect points for scat surveys and setting camera traps. Camera trapping began in 2010 with six camera traps. From 2013 to 2018, the number of cameras increased to 30, and in 2019 the number reached to 50 camera traps.

TCA uses Reconyx cameras (models 650 and 850) that are rotated for each survey, and no more than 25 are deployed at any one time. The cameras are attached to a tree 30 cm above the ground, the area is cleared of debris and tested before being set for each survey. Camera traps are left in the field for three months before being collected, and then results are analysed. Further information regarding camera trap setup by the TCA can be found at the link <https://tenkile.com/wp-content/uploads/2022/02/Camera-Trap-Field-Manual.pdf>

Each camera trap survey consists of a team of 12 people from the villages close to the research site. Each team consists of four research officers and eight rangers.

The trail cameras provide temperature data, time of capture, and moon phase. When triggered by motion sensors, predefined settings of the trail cameras are to take three photos at three-second intervals and leave a 10-minute delay to prevent repeated photography of the same individual.

The elevation is recorded at each trail camera location with a Garmin GPS and confirmed using the map of global terrain elevations by Yamazaki et al. (2017).

The images collected are reviewed by experts looking at key indicators of species such as colour pattern, size, posture, and the shape of the body. The animals are also compared with sympatric species of the same family.

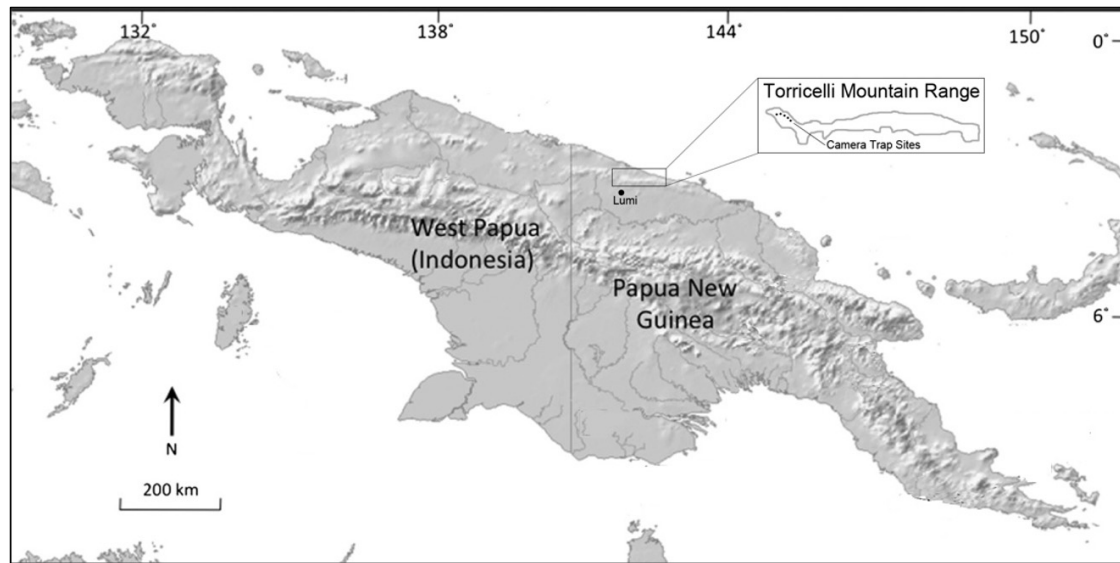


Image 1. Location of the Torricelli Mountain Range in Papua New Guinea. Tenkile Conservation Alliance.

RESULTS

Over the study period, TCA could collect data from 140 GPS camera monitoring sites ranging at elevations 700–1,600 m, corresponding to the Northern New Guinea Montane Forest ecoregion (Wikramanayake et al. 2002) (Image 2). More than 10,000 images have been collected from the camera traps. Birds and mammals account for the majority of animal photos. Only two reptile species (*V. salvadorii* and *V. doreanus*) were recorded by camera traps.

Two Crocodile Monitors were photographed, with camera traps in the Torricelli Mountain Range. The first was at the ‘Waliapilk’ research site in 2012, and at the second at the ‘Birr’ research site in 2015. Both sites are outside the previously known elevation distribution range for the species (Image 3).

Individual 1, a suspected adult of unknown gender was captured at 1032 h on 12 August 2012, at ground level and 1,522 m elevation with an air temperature of 18 °C. GPS location 3.4075 °S & 142.1819 °E. Although a series of three images were taken, only the first image shows enough of the animal to identify the species (Image 4).

Individual 2, a suspected adult of unknown gender was captured at 1114 h on 8 August 2015, at ground level and 1,200 m elevation when the air temperature was 20°C. GPS location 3.4038 °S & 142.2205 °E. The animal was walking at a normal pace (Image 5).

DISCUSSION

Elevation distribution data of *V. salvadorii* were compiled by Horn et al. (2007) based on available data. The authors reported 25 locations from museum specimens and 20 specimens from the literature and direct observations. Most individuals were recorded below 200 m, with two exceptions at 550 and 600 m. Pattiselanno et al. (2007) reported one Crocodile Monitor in the Arfak Mountains at 650 m. The locations we describe herein confirm an elevational range extension of Crocodile Monitors based on reliable photo records of the species in the Torricelli Mountain Range. Moreover, it indicates the tolerance of Crocodile Monitors to a new ecoregion, the Northern New Guinea Montane Forest.

Although principally deployed to capture images of tree kangaroos, camera traps set by TCA in the Torricelli Mountain Range have successfully recorded species of all terrestrial vertebrates (Thomas 2014). The Tenkile and Weimang tree kangaroos are the flagship species for TCA; however, unexpected results, such as those for *V. salvadorii*, are welcomed and emphasise the importance of protected areas and biodiversity monitoring.

The present findings also shed some light on the possibility of *V. salvadorii* occurring in the North Coastal Ranges of PNG (Bewani-Torricelli-Prince Alexander Mountain Ranges) after several reports of ‘kundu drums’ made with Crocodile Monitor skin in villages in that region (Horn et al. 2007). The species has been ever-present in the area, being revered, feared and respected. Traditional stories by the Tambuna tribe people suggest the animal can attain great lengths and consume village hunting dogs.

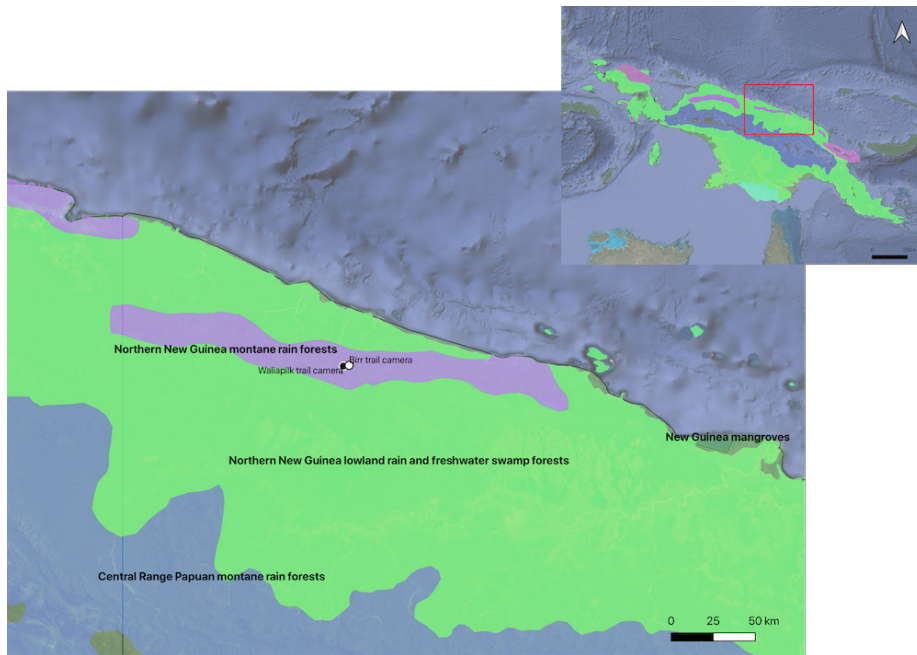


Image 2. Ecoregions of Papua New Guinea, and location of the trail cameras (Dinerstein et al. 2017).

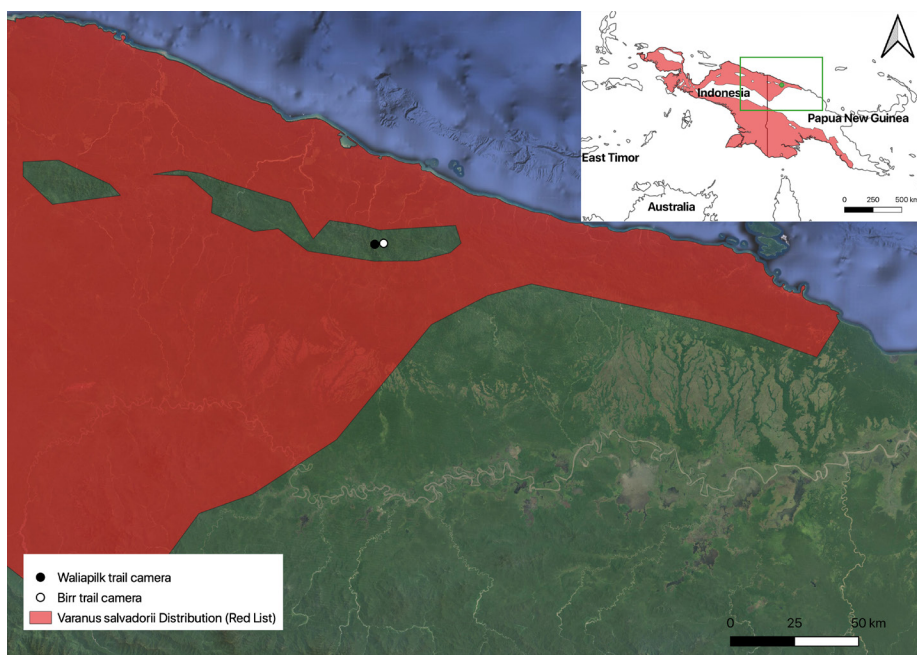


Image 3. New location of *Varanus salvadorii* in the Torricelli Mountain Range. inset shows the species global range according to its IUCN Red List Assessment (Shea et al. 2016).

Small animals have been caught, and their skins are used for making drums (Jim Thomas pers. comm. 10.xii.2021). However, due to their life history traits they are difficult to observe without camera traps.

TCA has used camera traps in the Torricelli Mountain Range since 2010, but only two Crocodile Monitors have

so far been recorded. This could be due to an extremely low population density in the region or due to the setting of the cameras at low height not targeting this species specifically, or because no bait lures were used. Crocodile Monitors are mainly arboreal, spending most of their time in trees (Reh et al. 2021).



Image 4. Red arrow denotes a Crocodile Monitor captured by camera trap at the Waliapilk site in 2012. © Tenkile Conservation Alliance.

This species is known to inhabit a range of habitats, including rainforest vegetation such as mixed alluvial and mixed hill forest types, as well as lowland and riparian forests (Horn 2004; Horn et al. 2007). Additionally, the present data indicate that the Crocodile Monitors also inhabit the Northern New Guinea Montane Forest.

Our new reported localities also call into question the minimum preferred temperature range of *V. salvadorii*. Under captive conditions the species is known to significantly reduce activity levels at temperatures below 24 °C (Reh et al. 2021). However, images from the trail cameras show active individuals at 18 °C and 20 °C. Furthermore, the mean annual maximum and minimum temperatures at an elevation of 1,500 m range is between 24.9 °C and 14 °C, according to the PNG Resource Information System (Bryan & Shearman 2008).

There are several possible explanations for activity at higher and cooler environment; (1) individuals can elevate their body temperatures by basking on a tree or in patches of sunlight on the forest floor to permit activity, and (2) individuals may move along the ground to escape inter or intraspecific confrontations even at cooler temperatures (Borja Reh pers. comm. 21.xii.2021). Crocodile Monitors have keen senses that allow them to perceive and avoid threats. Using the ground is an excellent way to remain undetected, especially by conspecifics.

Crocodile Monitors are assessed as Least Concern (LC) by the IUCN Red List (Shea et al. 2016). However, their ecological role within habitats is not clear, and they should be considered a focal species for monitoring ecosystem health given their status as apex predators (Simberloff 1998; Sergio et al. 2008; Ray 2015).

New Guinea is experiencing one of the fastest deforestation rates in the world (Curtis et al. 2018;

Amindoni & Henschke 2020). The increasing trend of habitat loss due to logging concessions is affecting the primary forest habitat of Crocodile Monitors and other under-researched species, including those that remain undescribed (Allison 1996; Kraus 2010; Miettinen et al. 2011; Letsoin et al. 2020; PNG Data Portal, 2021). Habitat loss is an increasing concern for the conservation of Crocodile Monitors. However, the impact of this threat has not been studied.

Despite its remoteness and inaccessibility, the Torricelli Mountain Range is suffering one of the highest deforestation rates on the island due to clearing and logging (Bryan et al. 2015). Industrial logging persists and is increasing in the area, with new roads being proposed across the range.

Therefore, habitat loss must be considered an increasing concern for the conservation of Crocodile Monitors. The effect of this threat on the viability of *V. salvadorii* populations remains unexplored. It is thus critical that significant records and information of unknown species, such as the Crocodile Monitor, are published to trigger conservation measures and help protect their area.

Camera traps have proven to be effective in capturing large monitor lizards (Ariefiandy et al. 2013; Jessop et al. 2013) and may offer a suitable solution to more effectively describing the distribution range and behaviour of Crocodile Monitors and many other species that remain understudied in New Guinea (Thomas 2014). However, modifications to existing protocols – such as including meat-based baits or lures or deployment of arboreal camera traps might increase the number of monitors recorded as well as other wildlife unlikely to be detected at ground level (Gregory et al. 2014; Moore et al. 2021).



Image 5. Photo sequence. Crocodile Monitor captured by camera trap at the Birr site in 2015. © Tenkile Conservation Alliance.

With an expansion of methods with camera traps and increasing biodiversity surveys, the TCA aims to increase its' data collection for biodiversity via camera traps, phone applications and staff patrols into the Torricelli Mountain Range.

The present data highlight the limited information available about one of the top predators and larger animals in New Guinea. The Crocodile Monitor has been far more studied in captivity than in wild, where virtually nothing is known about their biological traits. Therefore, more in-depth field studies are needed to understand the distribution patterns and the impact of anthropogenic threats in order to take timely measures to conserve and protect the species in the long term.

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