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Watching extinction happen: the dramatic population decline of the critically endangered Tanzanian Turquoise Dwarf Gecko, *Lygodactylus williamsi*

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Abstract. The turquoise dwarf gecko (*Lygodactylus williamsi*) is endemic to two small forests in eastern Tanzania, where it exclusively dwells on screwpines (*Pandanus rabaiensis*). To assess its population status, we surveyed its habitats at the Kimboza Forest Reserve and (under different assumptions) estimated the population size of the territorial *L. williamsi* based on habitat availability, using *Pandanus* abundance as a proxy. Furthermore, threats to the species, especially the impact of the international pet trade on the population, were studied. Our results suggest a severe population decline, as the observed population size is one third smaller than its potential size based on habitat availability (i.e., *Pandanus*). We estimate that in a period of four and a half years, at least 15% of the potential population were collected for the pet trade, making it a major threat to *L. williamsi* next to habitat degradation. Based on our results, we consider this species to be threatened with extinction (Critically Endangered).

Key words. Squamata, Gekkonidae, *Pandanus rabaiensis*, Kimboza Forest Reserve, pet trade, population size, conservation status.

Introduction

Dwarf geckos, genus *Lygodactylus* Gray, 1864, comprise more than 60 mostly African and Malagasy species of small diurnal lizards (Röll et al. 2010). Both species richness and endemism of *Lygodactylus* are remarkably high in Tanzania, with currently 20 recorded species and subspecies, half of them endemic to this country (Broadley & Howell 1991, Spawls et al. 2004). A striking example is the turquoise dwarf gecko, *Lygodactylus williamsi* Loveridge, 1952, which is characterized by a distinct sexual dichromatism: males have a turquoise-blue dorsum while females are greenish bronze (Fig. 1).

This dwarf gecko is currently known from two forest patches, Kimboza Forest (type locality) and Ruvu Forest, Morogoro Region, Tanzania (Doggart et al. 2001, Loveridge 1952, Spawls et al. 2004), in the foothills of the Uluguru mountains at altitudes between 170 and 480 m a.s.l. (Fig. 2). Both forests, covering an area of approximately 4 and 30 km², respectively, have been officially declared as Catchment Forest Reserves (Doggart et al. 2001). *Lygodactylus williamsi* has been reported as territorial and exclusively dwelling on the screwpine, *Pandanus rabaiensis* (Bayliss 1994, Lambert 1985, Weinsheimer & Flecks 2010, Fig. 1). Further knowledge about overall distribution, ecology and biological traits of *L. williamsi* is lacking or based on observations made in captivity (e.g., Röll 2011). Spawls et al. (2004) consider it to be 'endangered'.

Although most of the species' known range lies within protected areas (Fig. 3), illegal logging of timber, pole cutting, firewood collection, hunting activities, clearing for agriculture, fires and mining are threatening the habitat of the turquoise dwarf gecko (Hymas 2000). These Catchment Forest Reserves were initially declared by the Tanzanian government to protect water catchment, but since the Forest Act 2002 also serves to "ensure ecosystem stability through conservation of forest biodiversity, water catchments and soil fertility", both are classified as IUCN Category IV Protected Areas as well. An additional threat to the species has emerged only in the recent years. As a result of its extraordinary and attractive male colouration, which is also reflected by its trade name 'Electric Blue Gecko', demand by the international pet trade has rapidly been increasing since 2004. There is no particular protection sta-

tus of *L. williamsi,* but legislation (see above) prohibits any poaching inside the reserves and as a consequence includes the collection of geckos. Furthermore, collection and export of this species have never been licensed by Tanzanian authorities according to officials of the Tanzania Wildlife Research Institute. Hence, wild-caught specimens are illegally collected and exported under fake names (e.g., as *L. capensis*), allowing neither to control nor to account for numbers of exported individuals. These are expected to be dramatically high, based on the high numbers of specimens collected for export (this study) and specimens imported into, e.g., the European Union (personal communications by different anonymous traders). Due to its limited natural distribution and the increasing demand for wild-caught *L. williamsi*, the species' long-term survival is threatened by over-collection.

In the course of this study, we compiled field data to evaluate the population and conservation status of *L. wil-*

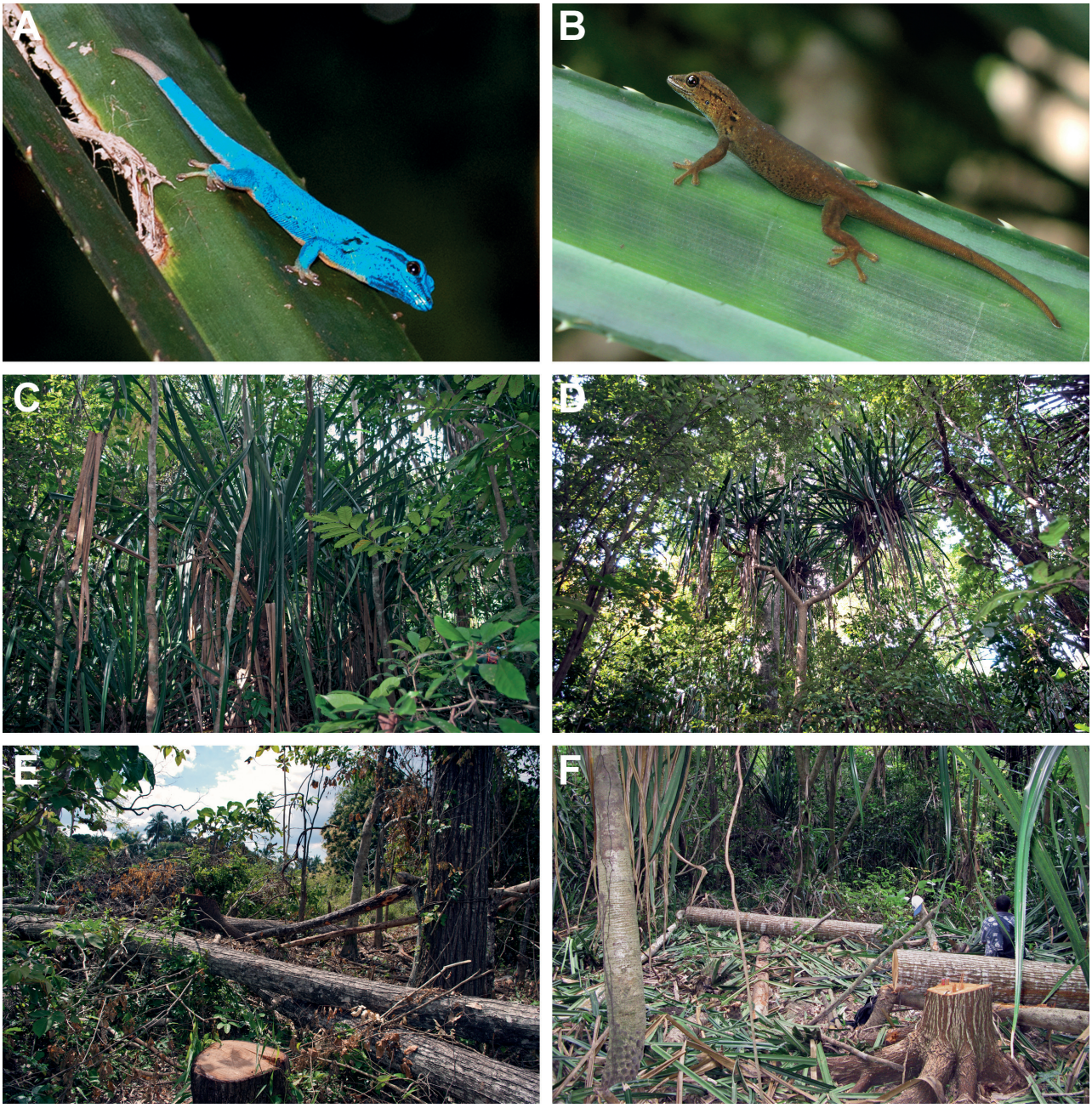

Figure 1. *Lygodactylus williamsi* and its habitat: (A) adult male; (B) adult female; (C) *Pandanus rabaiensis*; (D) large *P. rabaiensis* with multiple crowns; (E) logging site inside the Kimboza Forest Reserve; (F) *Pandanus* damaged by logging activities inside the Kimboza Forest Reserve.

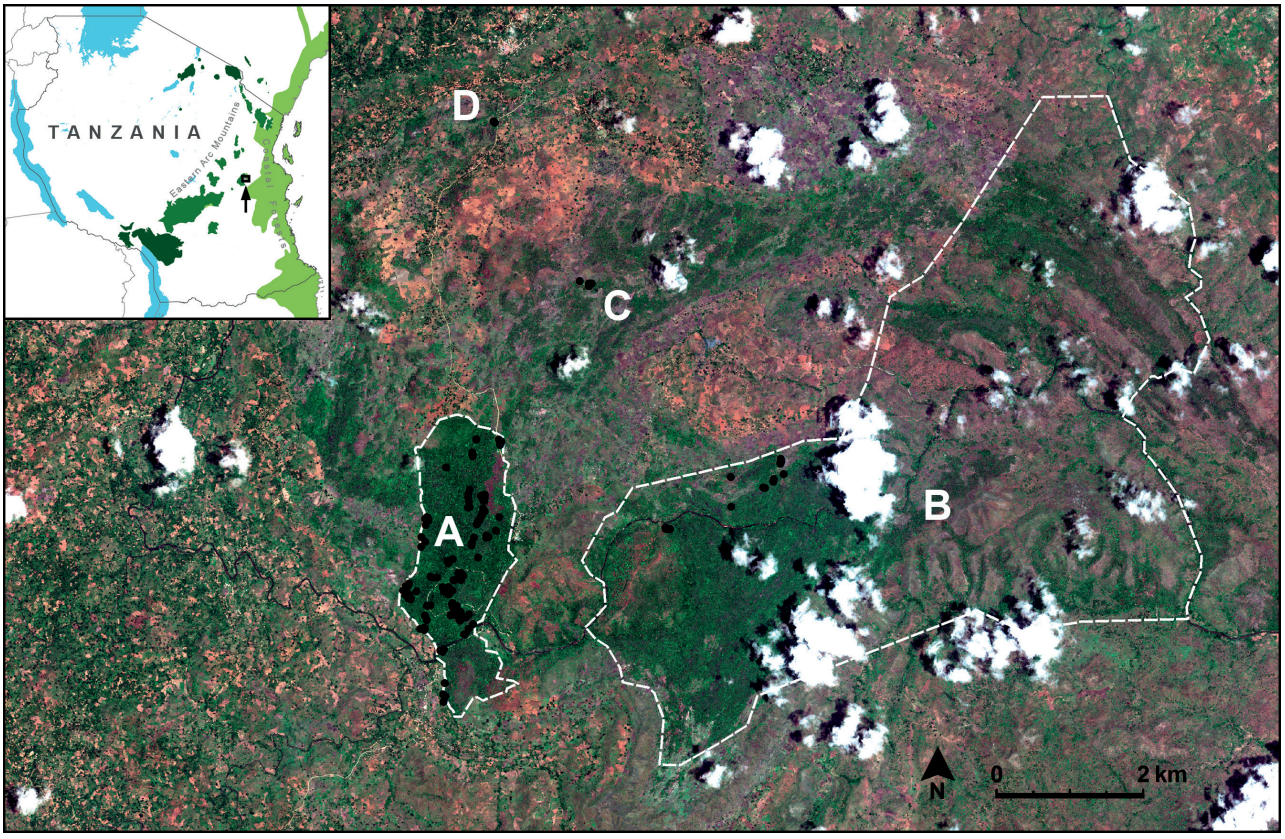

Figure 2. Distribution of *Lygodactylus williamsi*. Dashed lines indicate the reserve borders of the Kimboza Forest Reserve (A) and Ruvu Forest Reserve (B); dots mark individual localities (i.e., inhabited plants) of measured specimens, including the newly discovered populations at Muhalama (C) and Mbagalala (D). Satellite image from Google Earth/GeoEye.

liamsi. Our main objectives were (i) to comprehensively survey its distributional range and social structure; (ii) to assess the species' microhabitat preferences, habitat availability and population size; and (iii) to evaluate threats affecting this gecko, especially to quantify the impact of collections from the wild for the pet trade.

Material and methods

Distribution, social structure and microhabitat preferences

Between 1 August and 10 October 2009, we studied populations and habitat preferences of *Lygodactylus williamsi* at the Kimboza and Ruvu Forest Reserves as well as in surrounding areas. Visual Encounter Surveys (Heyer et al. 1994) were conducted by three persons in the mornings and afternoons. Due to its diurnal and non-secretive lifestyle, we consider this method to be adequate for detecting dwarf geckos. Geographic coordinates of *Pandanus* plants inhabited by geckos were recorded using a hand-held GPS (Magellan Triton 500). A total of 282 specimens from 157 different *Pandanus* individuals from throughout the known range of *L. williamsi* (Fig. 2) were caught to obtain data on snout–vent length (SVL) and sex. SVL was measured with a digital calliper to the nearest 1 mm. Specimens with blue colouration and precloacal pores were classified as adult males, non-blue specimens without pores and a SVL equal to or larger than the smallest male (30 mm) were classified as adult females. The remaining specimens were classified as juveniles/subadults and excluded from our census analysis (see below). The number of specimens on each *Pandanus* plant and characteristics of the inhabited plant were recorded (see below). All specimens were released to their respective home plants immediately after data recording, and surveyed plants were marked to avoid pseudo-replication, as these animals are territorial (Bayliss 1994) and restricted to individual plants (see below).

Habitat availability

For the purpose of obtaining information on habitat availability, remotely obtained online and our own field data (dates given above) were processed with ESRI ArcGIS 9.3. Satellite images of the Kimboza Forest and surrounding areas obtained from IKONOS-2 (Geo Ortho Kit with panchromatic resolution 1 m, multispectral resolution 4 m)

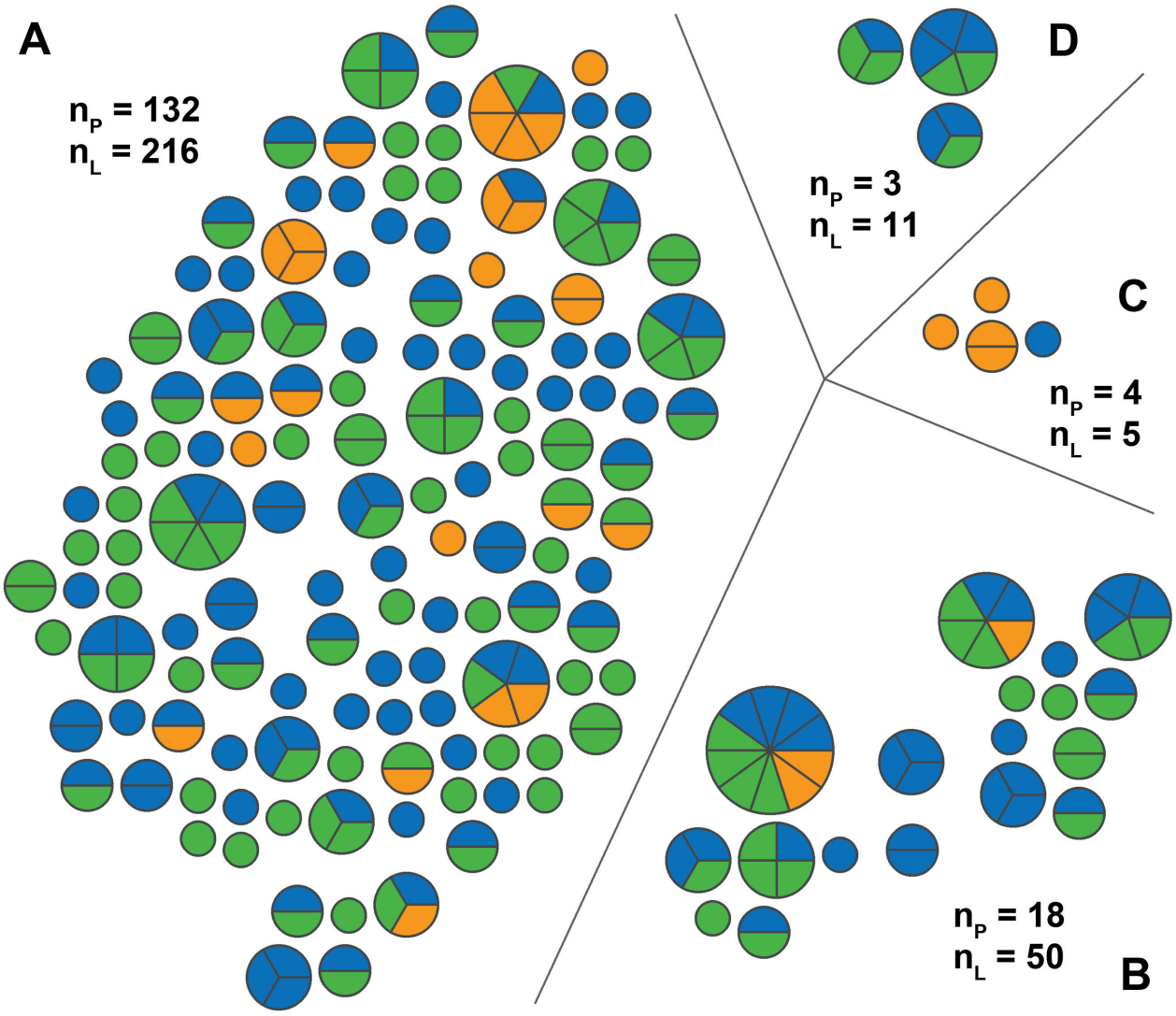

Figure 3. Number of specimens of *Lygodactylus williamsi* per plant. Each circle represents a single surveyed *Pandanus* plant; the diameter is relative to the number of specimens also indicated by segments; the number of segments equals the number of males (blue), females (green) and juveniles (orange). Letters refer to localities in Figure 2; n_P and n_L are the sample size per locality of *Pandanus* plants and *Lygodactylus* specimens, respectively.

and Google Earth (GeoEye-1) were used to assess habitat features across a larger scale surrounding the Kimboza and Ruvu Forests. Spatial information on reserve borders were obtained from Bayliss (1994) and refined by own GPS waypoints recorded during fieldwork. The actual size of the habitat available to *Lygodactylus williamsi* within the Kimboza Forest Reserve was assessed by mapping the spatial distribution of *Pandanus* plant stocks. Habitat availability at the Ruvu Forest Reserve could not be assessed owing to the limited study period.

Pandanus rabaiensis is not uniformly distributed all over the Kimboza Forest, but occurs in patches, where it is commonly a dominant vegetation element. These patches were scoured along their perimeters by foot, and GPS-waypoints were taken at ten-metre intervals to record outlines of the distribution of *P. rabaiensis*. Accordingly, the reserve area was sectioned as '*Pandanus* forest' vs. 'regular forest'. The latter contained all remaining forest types, with *P. rabaiensis* being either absent or only occurring as single scattered plants (these were considered to not significantly contribute to '*Pandanus* forest'). Subsequently, we established 20 study plots of 20 × 20 m each; ten within each of the two forest classes, to assess the predominant extent, structure and abundance of *Pandanus* plants. We recorded the total number of plants per plot, the number of crowns per plant, trunk heights (four classes: < 1, 1 to < 2, 2 to < 3 m, ≥ 3 m) and maximum leaf lengths (four classes: < 1, 1 to < 2, 2 to < 3 m, ≥ 3 m). Plants with a leaf length < 1 m were excluded from analyses (see below). Subsequently, the average number of crowns with a leaf length ≥ 1 m ob-

tained from the survey plots were projected to the respective forest classes on a 20 × 20 m raster map comprising the whole area of the Kimboza Forest Reserve. This provided an estimate of the total number of *Pandanus* plants within the Kimboza Forest Reserve.

Population status

Large *Pandanus* plants with crowns at a height of > 3 m (these plants can grow up to 8 m tall, Fig. 1) are difficult to access, and a mark-recapture study based only on shorter plants would certainly lead to a non-quantifiable bias. Given the complex habitat structure characterized by dense and often inaccessible vegetation, a 'perfect' detection rate of every single specimen that inhabits a surveyed plant would have required extensive vegetation clearing and was not in line with the purpose of our survey. Therefore, we used the abundance of available habitats as a proxy to estimate the population size of the territorial *Lygodactylus williamsi* under three assumptions that our field observations on the species' preferred microhabitat features suggested (see below): (i) all animals are uniformly distributed within the surveyed area; (ii) the number of specimens per *Pandanus* plant of a given size is identical throughout the range; (iii) plants with leaf length of less than 1 m do not provide suitable microhabitats for *L. williamsi*. To explore population trends, we also estimated the potential population size of *L. williamsi* under two further assumptions: (iv) the minimum population size on a single *Pandanus* plant of sufficiently large size is one male and one female; (v) the number of females per plant is equal to or larger than that of males..

Interviews

In order to assess the magnitude of exported *Lygodactylus williamsi*, we conducted open non-standardized interviews (Atteslander 1974) with members of the local environmental committee and people involved in collecting *L. williamsi*. Interviewees were asked to provide information on the number of specimens collected per month and their observations on abundance and population trends. Interviews were conducted in groups and repeated to confirm the results (not statistically tested).

Results and discussion

Distribution, social structure and microhabitat preferences

Besides its presence in the Kimboza Forest, the occurrence of *Lygodactylus williamsi* in the Ruvu Forest, which has already been mentioned by Doggart et al. (2001), was confirmed through records from multiple spots within this forest. Additionally, two new populations were discovered a few kilometres north of the known distribution (Fig. 2). At Mbagalala (6°57'42.55" S, 37°48'41.15" E, 408 m a.s.l.), the habitat consists of a remainder of only 14 *Pandanus* plants that are left in the shelter of large protruding rocks after the surrounding area was cleared for banana cultivation. A similar situation was found at the other new locality named Muhalama (6°58'53.72" S, 37°49'22.29" E, 383 m asl). Surveys including opportunistic searches and the interviewing of locals at other sites in the Uluguru and Udzungwa Mountains failed to detect *L. williamsi*, even though *Pandanus rabaiensis* were present. In concert with previous authors, we consider the turquoise dwarf gecko to exclusively dwell on this plant, in particular its leaves (Bayliss 1994, Lambert 1985, Weinsheimer & Flecks 2010). According to our field observations, intraspecific interaction like courtship, mating and territorial behaviour solely takes place on *Pandanus* leaves, and the plant's axillae are used for oviposition. *Pandanus* plants were occasionally temporarily left, but this was associated with foraging only. Furthermore, *L. williamsi* was never found at localities within the study area where *P. rabaiensis* were absent.

During our fieldwork, *L. williamsi* was exclusively found on leaves of ≥ 1 m in length. Leaf width is apparently a limiting factor to the species' presence and correlated with leaf length. The number of crowns per plant is associated with trunk height, as trunk heights ≥ 3 m are highly correlated with multiple-crowned plants ($p < 0.0001$) and trunk heights < 1 m with single-crowned plants ($p = 0.05$). However, except for a correlation of leaf lengths < 1 m with trunk heights < 1 m and with single-crowned plants (i.e., young plants), leaf length is not determined by trunk height or the number of crowns. As these young plants are not inhabited due to their small leaf size, *L. williamsi* presence is not dependent on trunk height or the number of crowns.

The number of specimens of turquoise dwarf gecko inhabiting a single plant has been reported to consist of one male, one female and several juveniles (Bayliss 1994), which is a social structure similar to that of closely related congeners (Röll 2000). According to our observations, the territory of such a group covers a single crown of a *Pandanus* plant. The largest number of adult males detected on one crown was four, together with four adult females and two subadults. However, 58% of the surveyed *Pandanus* individuals yielded only a single adult specimen (either male or female) and in 44%, more males than females were captured (Fig. 3). The mean number of adult specimens observed per plant was 1.6 ± 1.2 (1.8 ± 1.3 when including juveniles). As this does not reflect the supposed social structure of the species and may be the result of recent collections for the international pet trade, the number of specimens was adjusted for each plant, resulting in 2.5 ± 1.1 adult specimens per plant. The adjustment of the number of specimens per plant was in accordance with both our own observations and data published prior to the onset of collection activities for the pet trade (Bayliss 1994). We suggest the adjusted mean value of specimens per plant to constitute a reasonable estimate to calculate a potential population size, which neglects the impact the pet trade (see below) has on the actually observed population size.

Habitat availability and population status

According to our GIS analyses, the '*Pandanus* forest' covers 17.6% of the total area of the Kimboza Forest Reserve. Numbers of plants and crowns and proportional contribution of plant sizes per survey plot are shown in Figure 4. A total of 481 *P. rabaiensis* plants with 705 crowns were counted in the sample plots within the '*Pandanus* forest' (P1–P10) and only five plants with nine crowns in the 'regular forest' plots (P11–P20). Consequently, these 17.6% of the area harbour 95% of the reserve's *Pandanus* stock. Projecting the mean value from the plots of each forest class onto the whole reserve area gives an estimate of 93,808 individuals of *P. rabaiensis* with 138,945 crowns. Excluding crowns of inadequate size (i.e., those with a leaf length < 1 m that are not inhabited), the available habitat for *L. williamsi* comprises 93,374 crowns of *P. rabaiensis*. Accordingly, the population size of *L. williamsi* based on observed numbers of specimens per plant and habitat availability within the Kimboza Forest Reserve is 148,684 ± 112,365 adult individuals, equalling a population density of 353 specimens ha^{-1}. The potential population size is 234,921 ± 103,376 adult individuals (557 specimens ha^{-1}).

Although adjacent areas were not as thoroughly surveyed as the Kimboza Forest Reserve, based on our surveys, we suggest the Kimboza Forest to have the highest abundance of *P. rabaiensis* in the region. Ruvu Forest's drier eastern regime does not provide proper conditions for the

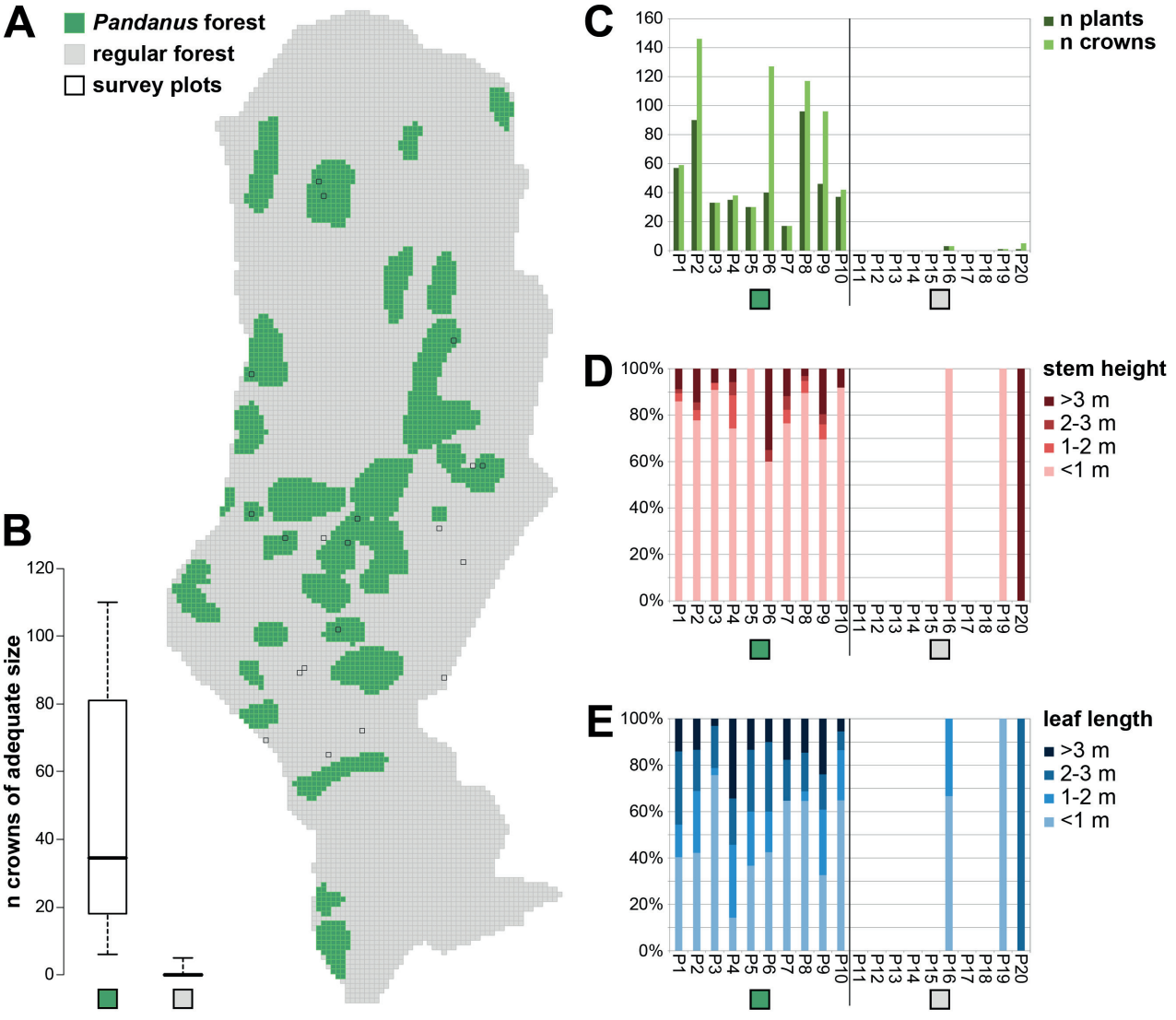

Figure 4. Distribution of *Pandanus rabaiensis* in the Kimboza Forest Reserve: (A) Forest classification map based on a grid with a resolution of 20 m; (B) boxplot diagram showing observed variances in number of *Pandanus* crowns suitable for hosting *L. williamsi*; (C) absolute number of *Pandanus* plants and crowns; (D) proportional contributions of trunk height categories; (E) proportional contributions of leaf length categories. B to E refer to data from the survey plots (P1-P20), which are marked by dark framing on map A.

growth of *Pandanus*, but even in the western part, *Pandanus* plants appeared to be more scattered than in the Kimboza Forest, rarely forming patches where they dominate the vegetation. The geographical extent and size of the population of *L. williamsi* in the Ruvu Forest require further studies. The two newly discovered populations extend the species' range in respect of the extent of occurrence (EOO; Gaston & Fuller 2009), but due to their small size regarding both area and available habitat their contribution to the total number of *L. williamsi* and area of occupancy (AOO) seems insignificant.

Threats and conservation status

Next to collecting for the international pet trade (see below), we regard habitat fragmentation and forest degradation as a second major threat to *Lygodactylus williamsi*. The dense human population around the Kimboza and Ruvu Forests (Morogoro Catchment Forest Office 2004) has led to clearing of the natural vegetation for farming nearly everywhere outside the protected forests. Only inaccessible areas, like closed rock formations, are today left with natural vegetation. Even inside the protected forests, illegal timber logging (Fig. 1) and clearing (e.g., for agriculture) can be witnessed, large trees topping the closed canopy have already been extracted, and pristine forest is virtually absent (Doggart et al. 2001, Lovett & Pocs 1993). Although *Pandanus rabaiensis* is not a valuable timber or used otherwise, it is collaterally damaged when adjacent timber is logged (Fig. 1). After clearing, invasive trees of the genus *Cedrela* replace indigenous tree species (Doggart et al. 2001) and likely prevent the recovery of indigenous vegetation.

The strict dependency of *L williamsi* on *P. rabaiensis* further limits the remaining distributional range of this gecko, as *Pandanus* plants occur only in a fraction of the forested areas. Additionally, forest fragmentation and the lack of *Pandanus* in between leaves the four known populations (Kimboza Forest, Ruvu Forest, Muhalama and Mbagalala) disconnected from each other. Nevertheless, within this range, the species is still relatively abundant and can be found on nearly every *Pandanus* individual of sufficient size. However, all interviewed local people independently agreed in that the turquoise dwarf gecko used to be found in much larger numbers until a few years ago. One reason, with no doubt, is the increasing exploitation for the international pet trade, which started as recently as in December of 2004. According to the interviewees, the total number of specimens collected between December 2004 and July 2009 ranges between 32,310 and 42,610 (Fig. 5). Specimens are typically stored by the local collectors un-

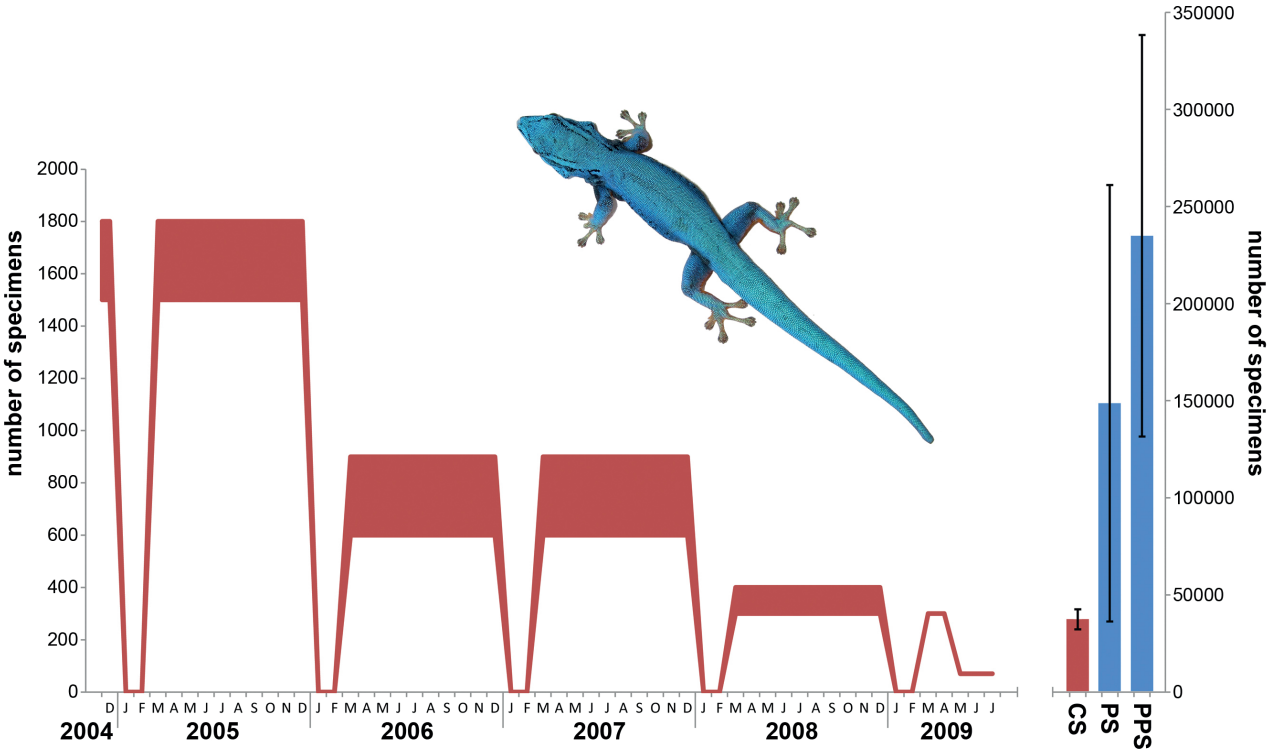

Figure 5. Harvest trends for *Lygodactylus williamsi* per month between December 2004 and July 2009. The upper bound of the red line represents the maximum, the lower bound the minimum numbers of specimens collected each month for the international pet trade. Bar charts show total numbers of specimens collected (CS, black line shows range) compared to the estimated population size (PS, black line shows standard deviation) and potential population sizes (PPS, black line shows standard deviation).

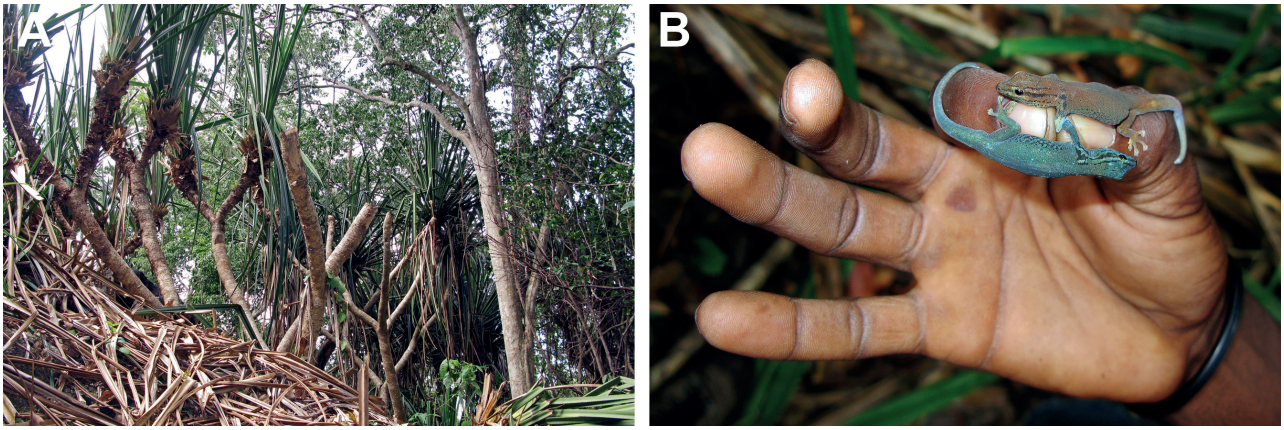

Figure 6. (A) *Pandanus* cut down to facilitate the capturing of *Lygodactylus williamsi* and (B) male and female of this species presented by a local collector.

til the ordered quantity is reached, then transported to the exporters in Dar es Salaam via middlemen in the regional capital Morogoro. Transport mortality is likely to be high (cf. Steinmetz et al. 1998), but could not be quantified by the interviewees. The annual hiatus in January and February may be explained by the intermission of exports due to low winter temperatures in the importing countries. Interestingly, the trend of a decrease in the numbers of specimens collected per month does not reflect the development of the markets in Europe and the USA, where the number of imported specimens has increased in the same time frame (personal communications by different anonymous importers). The collectors operate in groups, and the numbers above refer to one such group only. Our interviews corroborated the existence of more groups of collectors, which may explain the mismatch in our data and suggests the actual number of gecko specimens collected for the trade to be higher, yet not quantifiable.

Besides the direct impact of collection, catching techniques degrade the habitats and thus affect the population of *L. williamsi*. The most frequently employed technique comprises the destruction of inhabited *Pandanus* plants, which are partly, or sometimes completely, cut down to access the geckos (Fig. 6). Plants damaged or destroyed thus were a common sight in the study area. We consider the wild population of the turquoise dwarf gecko to be drastically declining, as the observed population size at the Kimboza Forest Reserve is approximately smaller by one third than the potential population size (Fig. 5). In conclusion, the impact by the international pet trade is dramatic, considering that at least 15% of the *L. williamsi* population of the Kimboza Forest Reserve was collected for that purpose between December 2004 and July 2009. However, the species might be able to buffer some of the collection pressure with its relatively high reproductive output, yet we did not quantify the turnover. Gravid females (n = 7), clutches (n = 1), juveniles and subadults of all sizes (n = 32) were found during the survey period, indicating a continuous reproduction throughout the year.

It would certainly support conservation efforts if the captive population that has so far survived in Europe and elsewhere could be (ideally coordinated) augmented through captive propagation to make future imports from the wild superfluous. Successful captive breeding is well possible if professional advice is heeded, as can be seen in the summarizing work by Röll (2011).

Nevertheless, considering the small distributional range and the threats identified, we suggest a listing of *L. williamsi* as 'Critically Endangered' according to IUCN Red List criteria. Both EOO (approximately 20 km²) and AOO (less than 1 km²) of *L. williamsi* are far below the respective IUCN standards. Conservation efforts and a formal national and international protection status are urgently required to keep this species from extinction. The commercial international reptile trade, especially in non-CITES species, is well established in Tanzania, which easily allows exporters to mask the illegal trade of *L. williamsi*. In March 2010, a workshop was held by one of the authors (JC) in cooperation with the Department of Zoology and Wildlife Conservation of the University of Dar es Salaam to raise awareness on the situation and to train Tanzanian duty staff to detect exports of *L. williamsi*. A listing in CITES should form the basis for action to stop trading in this species, either from the exporting or importing countries' side (cf. *Phelsuma* spp. or *Uroplatus* spp.).

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