Herpetological Journal

Short term monitoring reveals the rapid decline of southern Madagascar's Critically Endangered tortoise species

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Southern Madagascar supports two of the world's most threatened chelonians, *Pyxis arachnoides* and *Astrochelys radiata*, both thought to be rapidly declining as a result of habitat loss and poaching; however, to date quantitative data on this decline is lacking. We applied a conventional distance sampling procedure, monitoring populations twice over a 24-month period across the species' respective distributions. Population density for *P. arachnoides* dropped from 2.4 tortoises/ha (95% CI; 1.6–3.4) to 1.5/ha (95% CI; 0.8–2.8). *Astrochelys radiata* dropped from 2.1 tortoises/ha (95% CI 1.2–3.5) to 1.5/h. (95% CI 0.7–3.3). Local community-based conservation initiatives need to be expanded to combat this decline.

Key words: Astrochelys radiata, conservation, distance sampling, *Pyxis arachnoides*

Historically, chelonians have suffered some of the greatest population crashes of any vertebrate taxa as a result of human interventions, such as harvesting for food or trade or by habitat destruction, with between 48 and 54% of species thought to be threatened with extinction (Rhodin et al., 2011). Madagascar's four endemic species of Critically Endangered tortoises are thought to represent 10% of the world's top 40 most threatened species of chelonians (Rhodin et al., 2011), with two of these species, the spider tortoise (*Pyxis arachnoides*) and the radiated tortoise (*Astrochelys radiata*), widely sympatric within their remaining distribution (Fig. 1) and endemic to the southern dry forests of Madagascar. These species occur within a habitat that is generally considered to be the most threatened ecosystem within Madagascar, largely as a result of small scale, unsustainable agricultural practices and fuel wood harvesting (Harper et al., 2007).

Habitat loss is regarded as the greatest threat to *P. arachnoides* (Walker et al., 2012), and *A. radiata* is facing increasing pressures from illegal collection to fuel the local bushmeat market within Madagascar (Walker & Rafeliarisoa, 2012a). In addition, recent political instability within the country has opened smuggling channels (Walker et al., 2013), whereby it is suspected that thousands of individuals of both of these CITES Appendix I species are being illegally exported to the pet and food markets of southeast Asia each year (Rhodin et al., 2011).
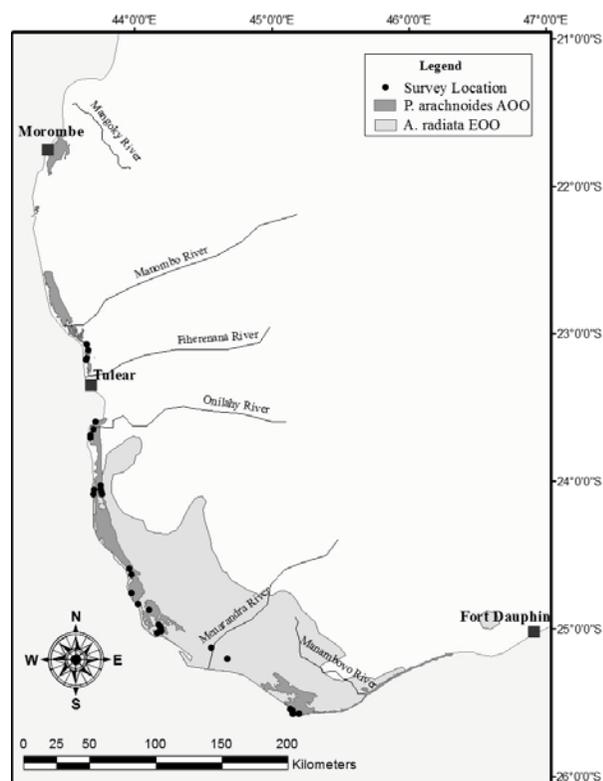
Fig. 1. The area of occupancy (AOO) of *P. arachnoides* and extent of occurrence (EOO) of *A. radiata* as described by Walker et al. (2013) and Rafeliarisoa et al., (2013), with the locations of monitoring points for both species within southwest Madagascar.

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Recent spatial distribution studies for both species clearly show rapid and significant declines in the range of both species. Walker et al. (2013) report that the current area of occupancy of *P. arachnoides* encompasses eight fragmented populations covering 2,464km², compared with the historical extent of occurrence of 8,482km² suspected by Bour (1981). Similarly, *A. radiata*'s extent of occurrence has declined from 42,883km² in the mid-1800s to 15,020km² in 2011 (Rafeliarisoa et al., 2013). However, there has been no robust monitoring of these species across their range to quantify suspected rates of declines. From a conservation management perspective, it is important to attain empirical data to better quantify such rapid population declines and to allow management strategies to be developed (Smallwood et al., 1999). This study reports a short-term distance sampling survey, documenting population density across multiple sites within the core of the range of *P. arachnoides* and *A. radiata* between 2010 and 2012.

Distance sampling is widely regarded as the most effective method for assessing population densities of tortoises in arid forest environments, including *P. arachnoides* and *A. radiata* (Leuteritz et al., 2005; Walker & Rafeliarisoa, 2012b). We surveyed 28 and 17 transects (1000m in length) within the core of the ranges of *P. arachnoides* and *A. radiata*, respectively (Fig. 1), during February 2010 and again during February 2012. We selected sites using high-resolution remotely sensed imagery (IKONOS and QuickBird) derived from Google Earth™ to establish areas of representative tortoise habitat, within the area of occupancy of *P. arachnoides* (Walker & Rafeliarisoa, 2012a) and the extent of occurrence of *A. radiata* (Rafeliarisoa et al., 2013, Fig. 1). Using this distribution and remotely sensed data,

we established a waypoint marking the start of each survey transect. Following this, we projected a transect end waypoint 1000m from the start point on an easterly bearing and repeated this for the 28 *P. arachnoides* transects and the 17 *A. radiata* transects. We loaded the waypoints and transect tracks into a handheld GPS. We undertook surveying in February, during the height of the active season for both species, due to high levels of rainfall (Walker & Rafeliarisoa, 2012b; Rafeliarisoa et al., 2013). *Pyxis arachnoides* is a crepuscular species (Walker et al., 2012), and *A. radiata* often displays a less active period during the warmer part of the day (Walker & Rafeliarisoa, 2012a); we therefore limited surveying to the cooler parts of the day between 0630–1030 and 1530–1830 hours. We navigated to the waypoint marking the start of each transect, using the hand held GPS. Two observers traversed each transect, walking side-by-side on the easterly track, in a roughly linear direction using the tracking function of the GPS until the surveyors reached the waypoint marking the end of the transect. Surveyors searched carefully for tortoises on their respective sides of the transect line and directly in front them. Upon encountering a tortoise, surveyors measured the perpendicular distance from the centre of the transect line (where the observer was standing) in cm to the middle of the carapace at the point of first detection using a 50 m retractable steel tape measure.

We combined the perpendicular distance data for each species for both years and examined these data in a histogram of eight intervals of 100cm increments for *P. arachnoides* and 16 intervals of 100cm for *A. radiata*. This preliminary analysis investigated any responsive movement to the observer and subsequent clumping of observations (Thomas et al., 2010). We detected no

Table 1. Each of the four Distance models used to estimate the density of *P. arachnoides* and *A. radiata* across the study area during 2010 and 2012. Each model for each species displays the corresponding ΔAIC (global), mean density per ha (with upper and lower 95% confidence limits), % coefficient of variation (% CV), and chi squared goodness of fit tests.

Species	Model	Year	ΔAIC	D per ha	95% CL	%CV	χ²
Pyxis arachnoides	uniform+cosine	2010	2.29	2.57	1.79–3.71	18.03	2.45 df=3.00, *p*=0.48
		2012		1.63	0.85–3.11	32.41	5.02 df= 3.00, *p*=0.17
	uniform+simple polynomial	2010	0.00	2.37	1.63–3.44	18.52	1.36 df= 3.00, *p*=0.71
		2012		1.45	0.76–2.78	32.76	4.45 df = 3.00, *p*=0.21
	half normal+hermite polynomial	2010	4.86	2.41	1.34–4.32	29.94	2.32 df = 2.00, *p*=0.31
		2012		1.67	0.85–3.38	35.06	5.11 df = 3.00, *p*=0.16
	Hazard rate+simple polynomial	2010	7.72	1.93	1.33–2.79	18.21	2.81 df = 2.00, *p*=0.25
		2012		1.15	0.60–2.21	32.90	7.05 df = 2.00, *p*=0.03
Astrochelys radiata	uniform+cosine	2010	0.00	2.05	1.20–3.50	26.49	2.03 df=3.00, *p*=0.57
		2012		1.52	0.71–3.25	38.01	1.89 df= 3.00, *p*=0.60
	uniform+simple polynomial	2010	2.42	1.65	1.00–2.75	24.78	2.28 df= 3.00, *p*=0.52
		2012		1.40	0.65–3.03	38.36	2.07 df = 2.00, *p*=0.36
	half normal+hermite polynomial	2010	0.00	2.05	1.20–3.50	26.49	2.03 df = 3.00, *p*=0.57
		2012		1.52	0.71–3.25	38.01	1.89 df = 3.00, *p*=0.60
	Hazard rate+simple polynomial	2010	3.10	1.82	1.03–3.22	33.54	1.85 df = 3.00, *p*=0.34
		2012		1.87	0.71–4.91	42.21	0.94 df = 2.00, *p*=0.63

strong evidence of evasive movement within either data set for either species; therefore we analysed data as automatically adjusted data of five intervals, truncated to 700cm for *P. arachnoides* and 1200cm for *A. radiata* to improve model robustness (Thomas et al., 2010).

We used the program Distance v.5.0 to estimate density (Thomas et al., 2010). We first assessed if data from 2010 and 2012 could be combined by running detection functions for the two data sets (2010 and 2012) separately and then comparing the two Akaike Information Criterion (AIC) values generated with a combined detection function for both species (Cahill et al., 2006). The AIC for the detection function was lower for the combined model than the sum of the individual AIC values; therefore we used a global detection function with post-stratification by year. We ran the following models, all considered to be general and robust (Thomas et al., 2010): uniform/cosine, uniform+simple poly nomial, half-normal+hermite polynomial and hazard-rate+simple polynomial models. We assessed model fit using AIC values for both years (global), trading off the bias of simple models against the higher variance of more complex models (Thomas et al., 2010). Finally, we tested the fit of each model using Chi-squared goodness of fit test. Whilst the two variance components of the 2010 and 2012 density estimates were independent of each other (those associated with sampling effort and encounter rate), one (estimate of g(0), the probability of tortoise detection at distance 0 m) is shared between the two density estimates because we combined data across years.

We encountered 48 *P. arachnoides* and 40 *A. radiata* in 2010 and 31 *P. arachnoides* and 36 *A. radiata* in 2012. The uniform+simple polynomial model provided the best fit for the *P. arachnoides* data (2010: χ^2=1.36, df=3.00, p=0.71; 2012: χ^2=4.45, df=3.00, p=0.21), producing a mean density of 2.4 tortoises per ha (95% CI 1.6–3.4) in 2010. This density fell to 1.5 tortoises/ha (95% CI 0.8–2.8) in 2012, with lower precision for that years' data (Table 1). The uniform+cosine and half normal+hermite polynomial models provided identically good fits for the *A. radiata* data (2010: χ^2=2.03, df=3.00, p=0.57; 2012: χ^2=1.89, df=3.00, p=0.60). Mean *A. radiata* density dropped from 2.1 tortoises/ha (95% CI 1.2–3.5) in 2010 to 1.5/ha (95% CI 0.7–3.3) in 2012.

Mean population density declines of this magnitude within just two years are worrying for the long-term conservation of any species. Generally, conservation practitioners lack up-to-date, real-time, range wide population monitoring data for many of the world's Critically Endangered chelonians (Márquez et al., 2007; Gerlach, 2008). Here, we present detailed and timely data for immediate use in conservation decisions. However, our results should be interpreted with some degree of caution because of the relatively high confidence limits (often a problem when sampling for rare, threatened, or cryptic species; Thomas et al., 2010), resulting in the overlap in 95% confidence intervals between years. Nevertheless, similar range wide studies by Walker & Rafeliarisoa (2012b) and Rafeliarisoa et al., (2013) recently employed distance sampling across 64 survey sites, with sample sizes of >100 tortoises for each species, resulting in population density estimates for *P. arachnoides* of 2.3 tortoises/ha (95% CI 1.7–3.1) and 4.2 tortoises/ha (95% CI 2.7–6.6) for *A. radiata*, both having similarly high confidence intervals despite larger sample sizes.

There are sparse examples within the literature of such rapid declines in chelonian populations with most stemming from historical, largely anecdotal accounts. For example, the extinction in less than 50 years of *Cylindrapis borbonica* on Réunion through exploitation by sailors is reported by Gerlach (2004). Walker et al., (2012) reported an actual 10.8% decline in the Anakao population of *P. arachnoides* from 2003 to 2011 and demonstrated that pressure from the habitat loss of 1.2% per year is responsible for an annual 1.4% population decline of tortoises. Walker & Rafeliarisoa (2012a) estimate that 518,000 *A. radiata* are being removed from the wild annually, with the local bush meat trade being the overwhelmingly primary cause for this decline. Anecdotal evidence for these declines for both species between the 24-month sampling periods was evident during this fieldwork. Four transects traversed in 2010 were at least partially lost by 2012 due to forest loss resulting from land cultivation, highlighting the rate of forest loss within the region (Walker et al., 2012). In addition to this, some regions within the study area had probably been poached, whereby some sample sites were either completely devoid of tortoises or many of the larger animals had been removed between the sampling periods.

Most of the communities within the region are forced into non-sustainable, subsistence agriculture, which is having wide-ranging negative impacts upon this forest habitat (Harper et al., 2007) and the tortoise species within this habitat. High levels of poor governance within southwest Madagascar have resulted in low levels of law enforcement to prevent poaching, consumption, and smuggling of tortoises, even within protected areas (Walker & Rafeliarisoa, 2012b). Effective tortoise conservation within the region needs to have a bottom-up, community-focused approach. A number of NGOs are currently working with communities and have had some successful anti-poaching and sustainable livelihood strategies (Walker & Rafeliarisoa, 2012a); however, currently these programs are undertaken within relatively small areas of the species' ranges. To prevent these species from becoming extinct in the wild it is imperative to introduce community-focused strategies in a more geographically wide-ranging manner.

et de Forets and the forest communities of southwest Madagascar. This manuscript was improved through the constructive comments of two anonymous reviewers.

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