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Abstract: The northern Madagascar spider tortoise (*Pyxis arachnoides brygooi*), is endemic to the coastal Mikea forests of southwest Madagascar. Very little is known of *P. a. brygooi's* ecology; however, it is suspected that the range is now very fragmented, with remaining populations facing significant threats from habitat destruction and poaching for food and the pet trade. A line-transect survey was undertaken that systematically surveyed the suspected historical range of this subspecies. The results were incorporated into a GIS database, which revealed that the distribution was confined to 20.5% of the suspected historical range, across three fragmented populations covering 499.6 km^2. It appears that a zone of intergradation has developed in a transitional area between the southern range of *P. a. brygooi* and the northern range of *P. a. arachnoides*. The results of this survey are currently being applied to management plans for newly gazetted protected areas in the region, in an effort to safeguard these relatively small remaining populations.

Key words: Chelonian; Madagascar; *Pyxis arachnoides brygooi*; Range fragmentation; Tortoise

The reliable estimation of the range of any threatened or endangered species with sparse or fragmented populations is important if the species is to be conserved and managed effectively (Buckland et al., 2001). The spider tortoise (*Pyxis arachnoides*), Madagascar's least studied critically endangered chelonian (Pedrono, 2008; Walker, 2009) is endemic to the coastal spiny ecoregion of southwest Madagascar. The species is thought to be divided into three genetically and morphologically distinct subspecies (Chiari et al., 2005; Pedrono, 2008), with the defining character being a mobile plastral lobe present in the southern form (*Pyxis arachnoides oblonga*), a semimobile lobe present in *P. a. arachnoides*, and a completely rigid plastral lobe in the northern subspecies (*P. a. brygooi*). *Pyxis arachnoides brygooi* inhabits the Mikea forests and has the least known ecology and conservation status of the three subspecies (Pedrono, 2008); the northern extremity of *P. arachnoides*'s range is in the dry coastal forests of southwest Madagascar (Bour, 1981; Durrell et al., 1989; Pedrono, 2008). However, to date the current literature contains only speculation about the exact current range of this tortoise (Bour, 1981; Durrell et al., 1989; Pedrono, 2008). Some authors have suspected a recent decline in numbers and fragmentation of the populations (Bour, 1981; Pedrono, 2008; Raxworthy and Nussbaum, 2000), as a result of habitat destruction brought about by subsistence agricultural practices (Seddon et al., 2000), collection to support the exotic pet trade (Pedrono, 2008; Walker et al., 2004), and collection as a local food source (Pedrono, 2008).

Pedrono (2008) and Chiari et al. (2005) stated that the conservation of *P. a. brygooi* needs to be treated separately from that of *P. arachnoides*, because the animal faces regionally specific threats such as harvesting by local communities for food, which could have resulted in its extinction throughout some of its former range (Pedrono, 2008). *Pyxis arachnoides brygooi* is thought to have the most restricted range of the three subspecies (Pedrono, 2008), is the only subspecies not to occur inside any protected area (Pedrono, 2008), and as a result is considered to be the most threatened of the three subspecies (Leuteritz and Walker, 2008; Pedrono, 2008). Therefore, Leuteritz and Walker (2008) and Pedrono (2008) stated that *P. a. brygooi* requires priority conservation action. This study aims to investigate the current extent of the range of the *P. a. brygooi* and establish the extent to which its range has contracted from the suspected historical area of occurrence.

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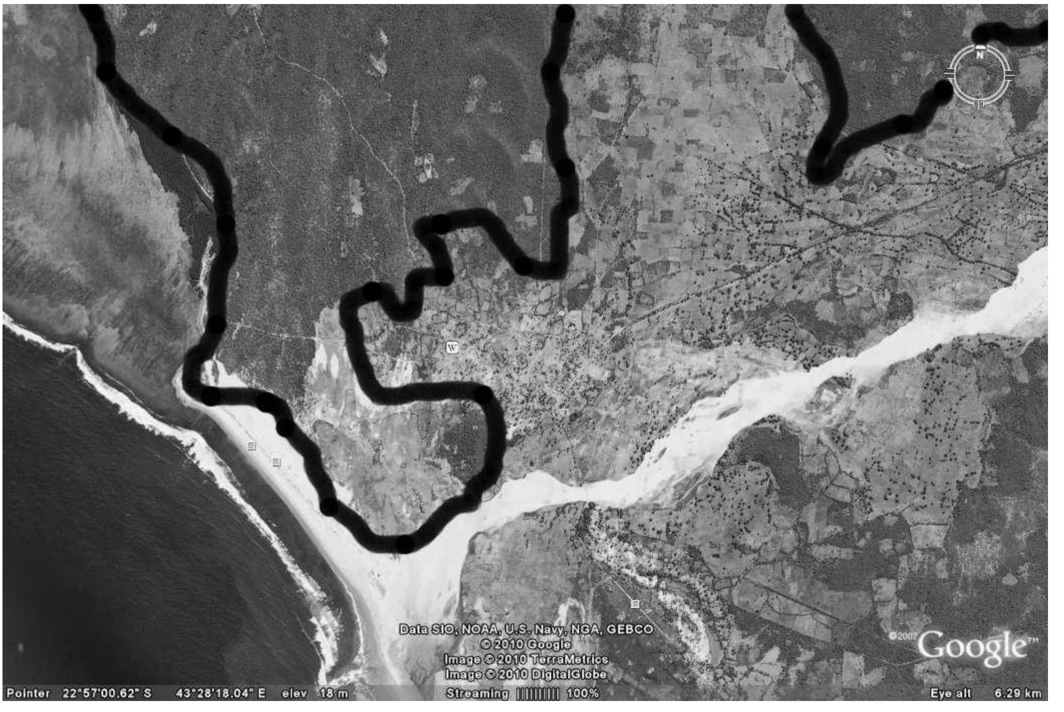

FIG. 1.—Google Earth image of a section of survey area within southwest coastal Madagascar, with the dark line delineating intact habitat to the north of the line that was selected for surveying, and with degraded land south of the line characterized by parcels of agriculture and livestock corrals. These high-resolution images were also used in conjunction with the Landsat imagery in Fig. 2 to identify the limits of the polygon boundaries for parcels of habitat that support tortoise populations and to identify areas of degraded habitat and areas devoid of tortoises.

METHODS

Study Area

Pyxis arachnoides brygooi inhabits the coastal, dry Mikea forest (Durrell et al., 1989; Pedrono, 2008; Figs. 1–2), a habitat unique to southwestern coastal Madagascar that historically stretched from the north of Toliara to approximately 30 km north of Morombe (Seddon et al., 2000; Fig. 2). The Mikea Forest has long been identified as extremely important for its biodiversity (Domergue, 1983; Ganzhorn et al., 1997; Seddon et al., 2000), and in particular its reptiles (Raxworthy and Nussbaum, 2000). However, the Mikea forest habitat is contracting in size and becoming increasingly degraded (Sussman and Rakotozafy, 1994), and currently receives negligible formal protection (Nicoll and Langrand, 1989; Seddon et al., 2000).

I have decided not to identify specific survey points where tortoises were discovered in this study, because the species has suffered greatly in the recent past from illegal harvesting to support the exotic pet trade (Pedrono, 2008; Walker et al., 2004), and identifying specific locations of the last remaining strongholds may directly contribute to further declines, as has been the case for other rare commercially valuable species when their locations have been documented in the scientific literature (Guterman, 2006; Stuart et al., 2006).

Field Techniques

Unlike *Astrochelys radiata*, a species sympatric in part of its range with *P. arachnoides*, spider tortoises are seldom found in degraded habitats, such as areas cleared for charcoal production or agriculture (Pedrono, 2008; Fig. 1). Therefore, only areas of reasonably intact habitat were selected for surveying, across and just beyond the range described by Bour (1981) and Pedrono (2008). High-resolution remotely sensed imagery (IKONOS and QuickBird) derived from Google Earth™

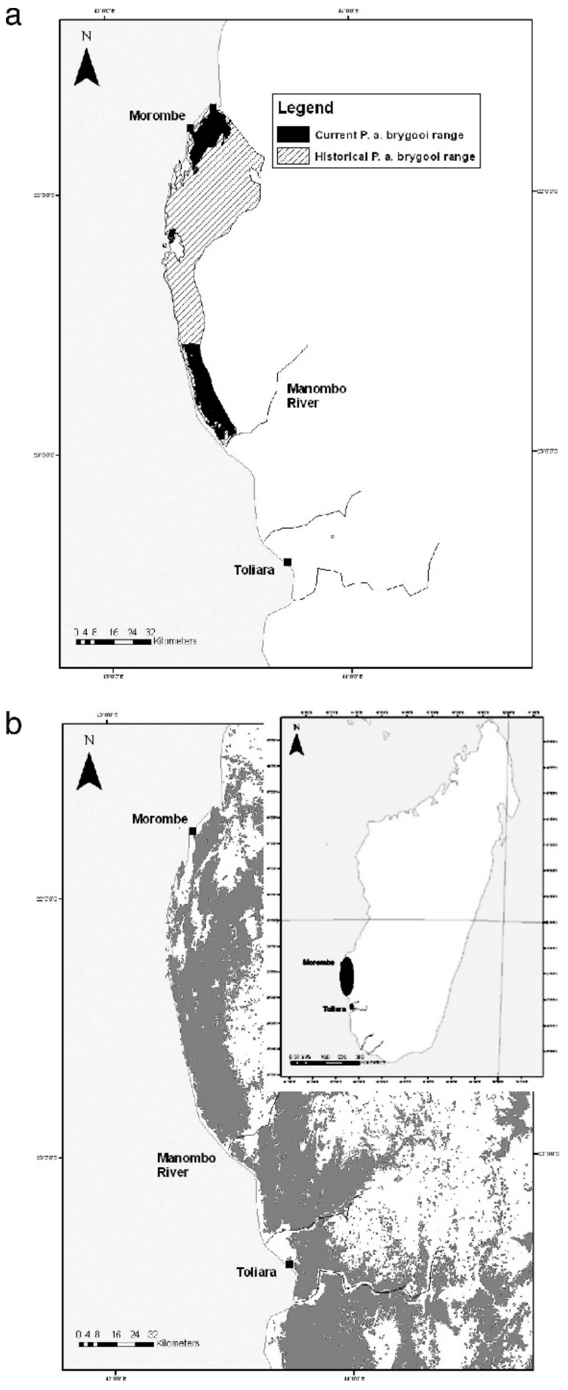

FIG. 2.—Suspected historical area of occurrence of *Pyxis arachnoides brygooi* (a), as documented by Bour (1981) and Pedrono (2008), with current range shown as areas of forest known to be occupied by *P. a. brygooi*. Current extent (2005) of the southern Mikea forest north of Toliara (b).

were used to select 34 suitable survey areas prior to field work. Within these 34 survey areas, 61 1-km transects were surveyed. Field work was undertaken during January and February 2009, during the annual period of heightened tortoise activity (Pedrono, 2008; Walker et al., 2007) due the rainy conditions. Surveying was limited to 0630–1030 h and 1530–1830 h during the cooler parts of the day, when these crepuscular tortoises are most active (Jesu and Schimmenti, 1995; Pedrono, 2008; Walker et al., 2007).

Upon reaching each survey point, two observers traversed each transect, taking an easterly bearing. The surveyors walked side by side, each carefully searching visually for tortoises on their respective side of the transect line and directly in front of them. Surveyors moved very slowly, with transects taking on average 77.3 (±40.2) min to traverse, with the time being dependent upon terrain, density of the vegetation, and number of tortoises encountered. Spider tortoises do not spend time under the ground in burrows, unlike some species of desert tortoises such as *Gopherus* spp.; so if transects are walked slowly and methodically, with careful attention paid to low-lying vegetation, then tortoises will be detected. Because of their small size, tortoises were normally detected only within 3 m of the middle of the transect line. Each detected tortoise was marked using a small dot of nail polish on the top of the carapace to avoid duplicate counting.

Data Analysis

Establishing population distribution.—The waypoints marking the start of each transect were plotted in a GIS database of habitat cover for southwest Madagascar, derived from Landsat TM 7 imagery interpretation using the program ArcMap (ArcGIS 9.0). Each waypoint was coded as either having a presence or absence of tortoises recorded within the transect. The GIS shape-file data representing Mikea forest cover in 2005 were loaded into the GIS database (Fig. 2), and tortoise presence or absence was added as a layer. By zooming into the GIS and using the high-resolution data available through Google Earth (Fig. 1), it was possible to identify areas of degraded habitat, which often surrounded pockets of vegetation. It was then possible to visually interpret areas of habitat where tortoises were recorded as present and areas that appeared, from these results, to be devoid of tortoises. Each occupied area of habitat was assigned a polygon, forming polygons of areas containing populations of tortoises. The reliance of spider tortoises upon intact habitat (Pedrono, 2008) and their low dispersal rates (Eubanks et al., 2003) suggest that *P. a. brygooi* will generally not move across large open degraded areas. Thus, the delineated polygons represent a reliable estimation of the size and extent of *P. a. brygooi*'s range. Finally, using the area calculation function in ArcGIS 9.1, it was possible to establish the area (in km^2) of suspected historical occurrence (Bour, 1981; Pedrono, 2008) and the area of the polygons occupied by tortoises.

Results

Tortoises are now confined to three isolated sites across the area of what was thought to be *P. a. brygooi*'s historical range. The last remaining populations are confined to the extreme north of the range within the forests east of the coastal town of Morombe, the extreme south of the range north of the Manombo River and a small isolated coastal forest within the center of what was considered the historical range. Large expanses of habitat appear to be devoid of tortoises, in particular toward the middle of what was thought to be the historical range (Fig. 2). Tortoise density was highly variable, ranging from 0 to 46 (±6.2) tortoises recorded per linear km of transect, with a mean encounter rate of 1.7 (±6.2) tortoises. Tortoises now occupy a total area of 499.6 km^2 (Fig. 2), compared to the 2,438.8 km^2 area of suspected occurrence described by Bour (1981) and Pedrono (2008). This current range represents a reduction of 1,939.2 km^2 (79.5%) from the suspected range stated in previous studies.

A transitional zone was discovered within the coastal zone south of the Manombo River and north of Toliara where populations of tortoises displayed variable morphology. Individual tortoises in this zone displayed three distinctly different morphologies; some individuals were characteristic of the subspecies *P. a. brygooi*, some animals displayed characteristics consistent with the midrange subspecies *P. a. arachnoides*, and there appeared to be intergrades between both of these subspecies.

Discussion

Authors as far back as the late 1970s were reporting suspected declines of *P. arachnoides* populations (Pedrono, 2008). Bour (1981) stated that although the spider tortoise's potential range is relatively large, populations may be fragmented from one another and contain variable numbers of individuals. Raxworthy and Nussbaum (2000) estimated that there are probably more than 10 populations of *P. arachnoides*, thus recognizing that the population was probably fragmented to some degree and that the suspected area of occurrence was probably not accurate. However, until now no quantitative data have ever been collected to quantify this fragmentation for any of the three subspecies.

The results of this study show that the tortoises are now confined to three isolated areas of forest across *P. a. brygooi*'s historical suspected area of occurrence. Habitat destruction and fragmentation has had, and could continue to have, wide-ranging impacts for the conservation of *P. a. brygooi*. Aponte et al. (2003) have demonstrated that habitat fragmentation amongst forest tortoises (in this case *Chelonidis carbonaria*) can result in altered age structure, population density, and body growth being associated responses.

P. arachnoides was up-listed from Vulnerable to Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List (A4cd+E) during 2008 (Leuteritz and Walker, 2008) based on the criteria of habitat loss and increasing direct exploitation during the past decade to support the pet trade (Walker et al., 2004). These threats still pose problems despite the species being listed in Appendix I of Convention on International Trade in Endangered *Species* in 2004. However, possibly the greatest immediate threat to *P. a. brygooi* is the void created by declining populations of radiated tortoises (a larger and preferred species for local human consumption). This decline of radiated tortoises (*Astrochelys radiata*) is having a particular impact as the tribes of the northern Mikea forest turn their attention to the smaller species after having hunted *A. radiata* to extinction in this part of its range (R. C. J. Walker, personal observation; O'Brien et al., 2003; Pedrono, 2008). Indeed, this pressure is evident throughout *P. a. brygooi*'s historical range, where many areas are now devoid of tortoises despite supporting suitable habitat (Fig. 2).

The spider tortoise is probably still considered common when compared against *Pyxis planicauda* and *Astrochelys yniphora*, the rarest of Madagascar's four species of tortoises that are listed as Critically Endangered on the IUCN Red List for Threatened Species. Both species occupy even smaller fragmented ranges than *P. a. brygooi* and suffer similar pressures, such as habitat destruction and harvesting for the pet trade (Smith et al., 1999; Young et al., 2008); there may be as few as 200 individuals of *A. yniphora* remaining in the wild. These factors highlight discrepancies in the red listing process (Mrosovsky and Godfrey, 2008).

Clearly, some form of management is required to address the conservation issues facing *P. a. brygooi*. Currently, *P. a. bryooi* is the only one of the three subspecies that does not occur within any protected areas. However, Madagascar's government is in the process of expanding its protected areas by threefold as part of its commitment to the "Durban Vision" made during the Vth World Parks Congress (Kremen et al., 2008; Mittermeier et al., 2005). Southwestern Madagascar has been targeted as a region of conservation priority due to its current lack of protected areas. Recent additions to the protected area network (Rabearivony et al., 2010) now mean that almost all of the remaining range of the subspecies falls within protected areas. The northern reaches of the northern population fall under the jurisdiction of the Mangoky/Ihotry Protected Area Complex, and the southern portion of this population falls within the Mikea National Park Complex. The small population in the middle of the historical range is covered by the Velondriake Community Managed Marine and Coastal Protected Area and the southern population by the Mikea National Park Complex. Protecting the habitat is only part of the solution to the problems faced by *P. a. brygooi*. The issue of poaching for both food and the pet trade needs to be addressed through tighter regulation of illegally exported animals from Madagascar and education programs in the receiving counties that highlight the conservation issues associated with endangered populations of animals from wild sources. The most complicated issues to be addressed will be the development and culture-related issues that force local communities into harvesting and consuming tortoises. These issues can only be addressed though targeted education and poverty alleviation programs.

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