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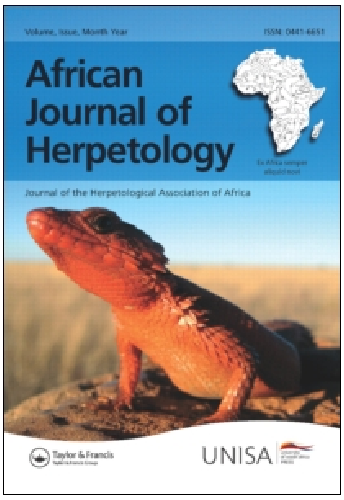

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Original article

Conservation assessment of the critically endangered frog *Mantella aurantiaca* in Madagascar

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Abstract.—*Mantella aurantiaca* is a small, bright orange, terrestrial amphibian that is endemic to the island of Madagascar. The species has attracted significant attention from herpetologists and captive breeders but relatively little effort has been given to its conservation in the wild. We surveyed 33 reported breeding localities of the species to determine sites of conservation importance and aspects of habitat use and seasonality. We found a total of 471 *M. aurantiaca* in 26 different localities, all of which were characterised by intact or degraded humid forest on sloping ground alongside temporary lentic ponds in narrow valleys. Additional monitoring at a single site revealed that adult *M. aurantiaca* predominantly used the ponds and surrounding humid forest habitat during the austral summer and moved upslope at the beginning of the austral winter. Effective conservation for this species should therefore include measures to safeguard both forest and aquatic habitat features. Although 62% of localities occurred in sites with a positive conservation status (provisional protected areas or Ramsar sites), there is currently heavy pressure from artisanal mining, logging and agriculture in these areas. Because a further 15% of sites occur on land due to be impacted by mining and an additional 23% were at sites without any biodiversity management, the future of *M. aurantiaca* in the wild is precarious. A species conservation strategy is therefore needed to produce a cohesive plan for the future which aims to secure as many sites as possible for conservation.

Key words.—*Mantella aurantiaca*, amphibian, mining, protected area, Ramsar sites

The recent attention given to the world's amphibians due to their global decline has led to an impressive amount of information on their conservation status and diversity, as well as broad consensus on conservation priorities and threat mitigation (Gascon *et al.* 2007). Madagascar's amphibian fauna is diverse and remains the focus of ongoing conservation and research activities (Andreone *et al.* 2008; Vieites *et al.* 2009). These have traditionally focused on describing the amphibian assemblages of key sites and developing a better understanding of systematics and biogeography. Conservation efforts that focus on individual amphibian species have been comparatively rare (Andreone *et al.* 2005). In the last few years, however, more attention has been given to assessing the conservation status of highly threatened species to ensure a dynamic and transparent IUCN Red List, as well as identifying

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priority sites for amphibian conservation at the local scale (Andreone *et al.* 2005, 2008; Rabemananjara *et al.* 2008b). Given the multiple threats facing Malagasy amphibians, including chytrid fungus, increased effort is needed to conserve the most threatened species (Andreone *et al.* 2008).

Mantella poison frogs are endemic to Madagascar and are among the most threatened amphibians in the world (Andreone *et al.* 2005, 2006). There are currently 16 described taxa and three of these are Critically Endangered, five are Endangered and three are Vulnerable on the IUCN Red List of Threatened Species (IUCN 2009). Although the loss of native forest is the principle threat to Malagasy frogs, all of the Critically Endangered poison frogs also have restricted distributions, with some known from only a few localities (Vences *et al.* 1999; Andreone *et al.* 2005; Rabemananjara *et al.* 2005; Vieites *et al.* 2005; Bora *et al.* 2008). The bright colours and striking patterns that characterise many *Mantella* species have made them desirable in the amphibian pet trade and have probably also contributed to elevated levels of interest amongst researchers and conservationists (Andreone *et al.* 2006).

Mantella aurantiaca, the golden mantella, has a highly restricted global distribution and is found only in the humid forests around the Moramanga District in eastern Madagascar, where it is thought to be associated with *Pandanus* spp. screw palms (Vences *et al.* 1999; Andreone *et al.* 2005; Anon. 2008). However, within the geographic area in which it occurs, *M. aurantiaca* has a disjointed distribution and is absent from putatively suitable areas of humid forest (e.g. Vallan 2002). Although advances have been made in understanding the evolution and feeding habits of *M. aurantiaca* relatively little is known about its general ecology (Chiari *et al.* 2004; Woodhead *et al.* 2007; Bora *et al.* 2008). The conservation status of *M. aurantiaca* remains perilous because none of the sites where it is known to occur is found within the Madagascar protected area system (Chiari *et al.* 2004; Woodhead *et al.* 2007; Bora *et al.* 2008).

Bora *et al.* (2008) collated all of the available existing information on the distribution of *M. aurantiaca* and concluded that the species occurred in 16 different localities, although many of these were in close proximity and may not represent separate populations. Most of the sites were in small patches of humid forest subject to ongoing anthropogenic pressure. A contemporary assessment of the status of this species and its essential habitats is therefore needed. Accordingly, the objective of our study was to determine the current distribution of *M. aurantiaca* and to identify priority localities and habitats for immediate conservation effort. Additionally, we also sought to investigate any seasonal changes in relative abundance or habitat use.

Materials and Methods

We surveyed this species in the District of Moramanga, Alaotra Mangoro Region, Madagascar. We visited a single site (at Bejofo, Ambohibary Commune) on a regular basis between November 2007 and June 2008 to follow temporal variation in *M. aurantiaca* abundance. This period includes the austral summer and winter which is associated with high rainfall and low temperatures respectively. A number of other sites were visited between January and March 2008.

Locality Selection

We focussed our surveys in areas that had previously been reported to contain *M. aurantiaca* (Zimmerman & Hetz 1992; Behra *et al.* 1995; Ramilison 1997; Chiari *et al.* 2004, Bora *et al.* 2008). Additional information on other localities was obtained from informal discussions with semi-professional amphibian collectors based in Moramanga. One of us (RR) was present during each survey to ensure that standard methods and protocols were always used. At each site we conducted a transect survey for *M. aurantiaca* and recorded descriptive information on habitat features.

Transect Survey

We aimed to obtain a relative assessment of the abundance of *M. aurantiaca* at all sites visited to identify the priority areas for conservation. We placed a 50-m tape measure (transect) parallel to the edge of the putative breeding pool around which the frogs were located. *Mantella aurantiaca* are active in the vicinity of small forest ponds during the austral summer and these are assumed to be linked to their breeding requirements. Conclusive evidence of the use of these ponds for breeding (i.e. presence of tadpoles) was beyond the scope of this study. Two additional transects were placed parallel to the breeding pond but 30–50 m uphill and on the nearest ridge top because we were interested in the spatial distribution of *M. aurantiaca* with respect to the slope and waterbody. At each 5-m interval along the 50-m transect we searched for *M. aurantiaca* in a 5×5 m square. Search time varied according to vegetation cover and a longer time was spent in areas with thick undergrowth. Each *M. aurantiaca* was removed from the square for later processing which involved measuring the snout-vent length with a ruler and weighing body mass (g) on a Pesola spring balance (Pesola, Switzerland). Sex was determined based on the presence of femoral glands in males. A small number of individuals were sacrificed for voucher specimens and lodged in the collection at the Département de Biologie Animale, Université d'Antananarivo.

Habitat Assessment

We used simple proxies for habitat disturbance; such as the number of cut stumps and cut trees or stumps with recent fire damage within 1 m of the transect line. Because of the putative association between *M. aurantiaca* and screw palms we also counted all *Pandanus* spp. plants in each square. Canopy cover was estimated by eye to the nearest 5% by a person standing in the middle of the square. We measured the maximum length and width of the standing water and the product of these values provided an estimate of surface area of the ponds. Water pH was recorded at breeding pools using a pH meter (Hanna Instrument 98129 and 98130) and air temperature was noted before each search using a digital thermometer (Oregon RA 123).

Analysis

Survey effort, 3×50 m, was equal at all sites. We used the number of *M. aurantiaca* found across all three lines as a measure of abundance per site in statistical analyses to compare between the three topographical settings. We tested whether the abundance of *M. aurantiaca* had a significant temporal trend by including the number of days since 1 January as a covariate in an ANCOVA which had topography as the factor. Because Cyclone Ivan (http://en.wikipedia.org/wiki/Cyclone_Ivan) caused a significant amount of rainfall during our survey we also investigated whether *M. aurantiaca* abundance declined in the post-cyclone period. We investigated relationships between continuous data variables using Pearson or Spearman Rank correlations according to normality. Using geographic point localities, taken at each pond with a GPS, we calculated the Extent of Occurrence and Area of Occupancy following IUCN guidelines (IUCN Standards and Petitions Working Group 2008). "Extent of occurrence is defined as the area contained with the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred, or projected sites of present occurrence of a taxon" (IUCN 2008). We calculated this by constructing minimum convex polygons in ArcView for each forest area where *M. aurantiaca* was found. "Area of occupancy is defined as the area within its extent of occurrence which is occupied by a taxon" (IUCN 2008). We calculated this by over-laying the point locality distribution map with a grid (2×2 km) and counting the number of squares where *M. aurantiaca* was found during the survey.

Results

Abundance and Distribution

We surveyed 33 localities that were reported to have breeding populations of *M. aurantiaca.* We found 471 *M. aurantiaca* individuals from 26 localities during the survey (Table 1). We were unable to find *M. aurantiaca* at seven sites. All sites shared a similar topographical setting; an area of waterlogged soil and/or standing water situated close to a vegetation-covered slope. We counted 230 female, 211 male and 30 juvenile individuals during the study. The number of *M. aurantiaca* per site using square searches varied from 1 to 17 juveniles (median = 0), 1 to 39 females (median = 1) and 1 to 60 males (median = 2). Fewer than 10 individuals were counted in sixty percent of the localities and an excess of 50 frogs were found at only five sites (Table 1). The seven of these sites where we did not detect *M. aurantiaca* had all undergone significant habitat changes, because of fire or converting marshland into farmland, within the previous five years according to local informants.

Distribution

We found *M. aurantiaca* present in 23 squares which provided an area of occupancy of 92 km^2. Its extent of occurrence was calculated as 112 km^2.

Land Tenure and Conservation

The 26 localities with *M. aurantiaca* were located in two distinct regions, to the south-west and north-east of Moramanga respectively (Fig. 1). The former cluster of sites is situated in the Andranomena-Mangabe forest (called Mangabe from here

Table 1. A summary of the results of our survey from the 26 localities where we found *Mantella aurantiaca* during 2008. We provide the local name of the sites and information on current management or exploitation regimes.

Survey date	Site name	Site status	Land use	Females	Males	Total
28.02.2008	Ampananona Nord	Open access	Agriculture	17	10	28
01.02.2008	Andranomiditra	Open access	Agriculture	0	2	2
04.02.2008	Amboalaboaka	Provisional protected area (Mangabe)	Conservation zone	3	1	4
10.02.2008	Bekalalao	Ramsar (Torotorofotsy)	Conservation zone	1	4	5
14.02.2008	Menalamba	Ramsar (Torotorofotsy)	Conservation zone	8	16	24
27.02.2008	Andranomena	Provisional protected area (Mangabe)	Conservation zone	3	10	13
27.02.2008	Ankaraobe	Provisional protected area (Mangabe)	Conservation zone	1	1	2
04.03.2008	Ambohimena	Provisional protected area (Mangabe)	Conservation zone	27	23	51
05.03.2008	Mangabe	Provisional protected area (Mangabe)	Conservation zone	22	16	38
06.03.2008	Sahazora	Provisional protected area (Mangabe)	Conservation zone	39	40	83
08.03.2008	Antavindambo	Provisional protected area (Mangabe)	Conservation zone	4	5	9
13.03.2008	Sasarotra	Provisional protected area (Mangabe)	Conservation zone	33	14	48
13.02.2008	Antsampandrano	Provisional protected area (CAZ)	Conservation zone	1	2	3
29.02.2008	Bejofo	Provisional protected area (Mangabe)	Conservation zone	8	9	33
07.02.2008	Ranomena	Commercial forestry	Managed exploitation	7	6	16
29.02.2008	Ampananona Sud	Provisional protected area (Mangabe)	Managed exploitation	20	7	27
06.04.2008	Madiofasina	Commercial forestry	Managed exploitation	0	2	2
07.03.2008	Ampahatra	Provisional protected area (Mangabe)	Managed exploitation	14	15	33

Table 1 (*Continued*)

Survey date	Site name	Site status	Land use	Females	Males	Total
08.03.2008	Behory	Commercial forestry	Managed exploitation	8	10	18
09.03.2008	Andranohofa	Provisional protected area (Mangabe)	Managed exploitation	2	1	3
11.03.2008	Benanana	Commercial forestry	Managed exploitation	10	12	22
20.01.2008	Ambatovy	Nickel Mine (MP3)	Mine buffer zone	0	1	1
19.01.2008	Ambatovy	Nickel Mine (MP4)	Mine buffer zone	1	1	2
18.01.2008	Ambatovy	Nickel Mine (MP5)	Mine footprint	0	2	2
20.01.2008	Ambatovy	Nickel Mine (MP2)	Mine footprint	1	0	1
20.01.2008	Ambatovy	Nickel Mine (MP6) and Ramsar (Torotorofotsy)	Mine pipeline	0	1	1

on) and all but one of the sites is on the eastern bank of the Mangoro River. The north-eastern cluster of sites includes the Torotorofotsy wetland and surrounding forests in Analamay and Ambatovy.

Twelve (46%) of the 26 localities with *M. aurantiaca* during the time of the survey were found at Mangabe (Table 1). This site is subject to ongoing work with local communities to develop a sustainable use area and it was awarded provisional protected status from the Malagasy government in October 2008. Within the provisional boundaries of this protected area there were nine *M. aurantiaca* localities within areas that have been allocated as conservation zones in a participatory process. These are logical foci for future conservation efforts. An additional three sites fell within zones from where controlled exploitation of the forest is planned. There were a further six sites in the vicinity of Mangabe, either in commercial forestry or open access sites, where no biodiversity management was evident and *M. aurantiaca* habitats are particularly threatened.

Four localities were found within the multiple use mine area of the Ambatovy Project and another alongside its nearby pipeline, which was designed to bypass a known locality for *M. aurantiaca* (Table 1). The latter locality is also included within the Torotorofotsy Ramsar site, along with two other localities where stakeholders are working with communities to protect and sustainably use biodiversity. A single locality was found in a new protected area (Zahamena – Ankeniheny Corridor [CAZ]).

Site Characteristics

Sites with *M. aurantiaca* had a mean elevation of 980 m above sea level ($\pm$ 10.4 SE) and ranged from 867 m to 1 054 m. Slopes ranged from 10° to 50° at sites with *M. aurantiaca* and the median value was 32°. Estimated canopy cover was

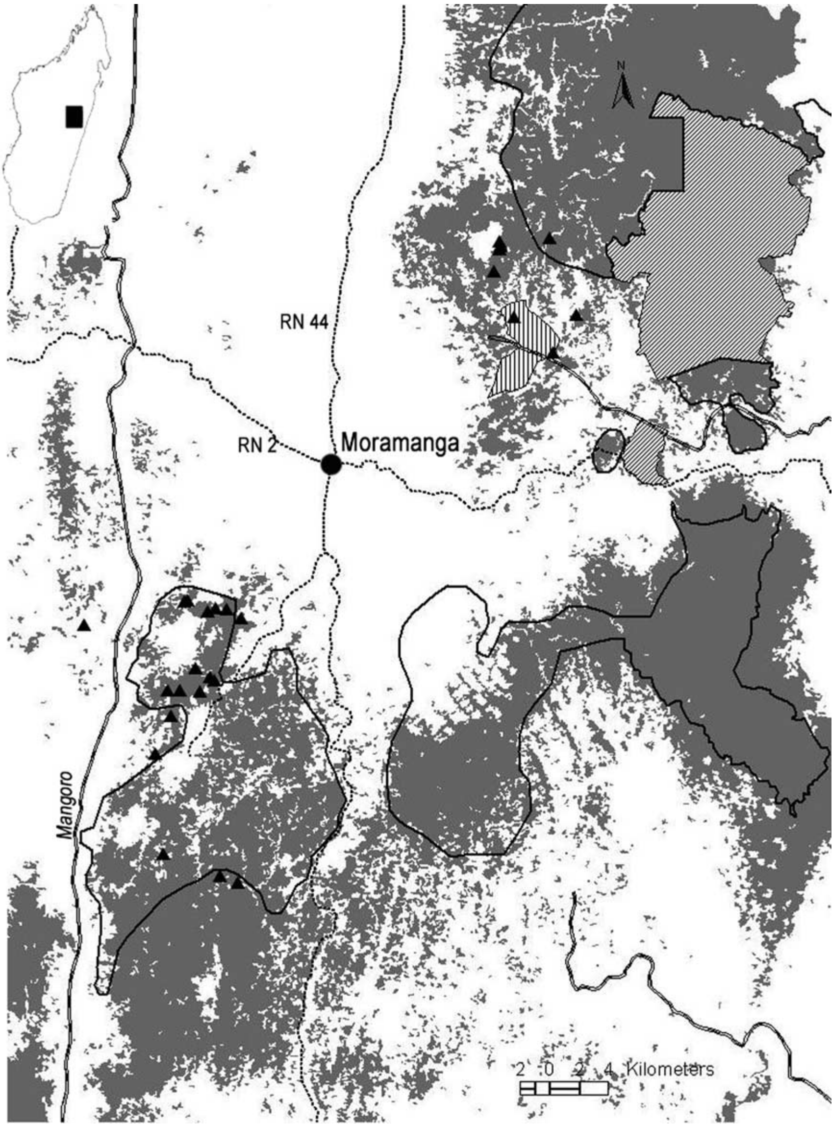

Figure 1. A map of the survey area showing localities where *M. aurantiaca* was found (black triangles) and main vegetation (grey: humid forest), protected area (diagonal hatched: Mantadia National Park and Analamazoatra Special Reserve; black line: provisional protected areas Mangabe and Zahamena-Ankeniheny) and Torotorofotsy Ramsar (vertical hatched) boundaries.

41.4% $\pm$ 2.57 and ranged from 4.1% to 63%. Ponds that we attributed to breeding sites at 13 localities had standing water varying in maximum length from 10.0 m to 100.0 m (mean 51.1 m $\pm$ 9.16 SE) and maximum width from 2.5 m to 50.0 m (mean 21.0 m $\pm$ 3.96 SE). The surface area of the water ranged from 50 m^2 to 5 000 m^2 (mean 1 257.9 m^2 $\pm$ 397.35 SE). The mean pH of these ponds was 6.7 and varied between 5.9 and 8. There was no significant correlation between the surface area of the breeding pool at the time of the survey and the abundance of *M. aurantiaca* (Pearson correlation, $r_{17} = 0.36$, $P = 0.15$). There was a significant negative relationship between the numbers of *Pandanus* spp. plants and *M. aurantiaca* abundance (Spearman Rank correlation, $r^s_{17} = -0.49$, $P = 0.02$). Although the highest abundance of *M. aurantiaca* was detected at sites with a low abundance of burnt trees, the relationship was not significant because there was a high abundance at Sasarotra despite evidence of a recent fire (Spearman Rank correlation, $r^s_{17} = 0.03$, $P = 0.73$).

Habitat Use

Days since 1 January was a significant covariate of abundance and there was an interaction, although not significant, with topography because *M. aurantiaca* was predominantly observed on slopes during the latter part of the study (ANCOVA $F_{2,63}$ topography $= 2.62$, $P = 0.08$, $F_{1,63}$ days since 1 January $= 9.30$, $P = 0.003$; $F_{2,63}$ interaction $= 5.63$, $P = 0.005$; Fig. 2). Females were only observed at the bottom of the slopes during January and February but males were present throughout the study in these areas although they also showed a gradual up-slope shift in abundance towards the end of March (Fig. 2).

Temporal Variation

Mean abundance of *M. aurantiaca* was significantly higher (Mann Whitney U-test, $n = 32$, $U = 235$, $P = 0.002$) during survey work after Cyclone Ivan (22.0 individuals $\pm$ 5.88 SE) than before (4.3 individuals $\pm$ 1.78 SE). This result was also evident in a significant difference in mean abundance between January (3.8 individuals $\pm$ 7.46 SE), February (10.4 individuals $\pm$ 14.5 SE) and March (32.8 individuals $\pm$ 23.52 SE; Kruskal–Wallis test, $n = 32$, $H = 10.6$, $P = 0.004$).

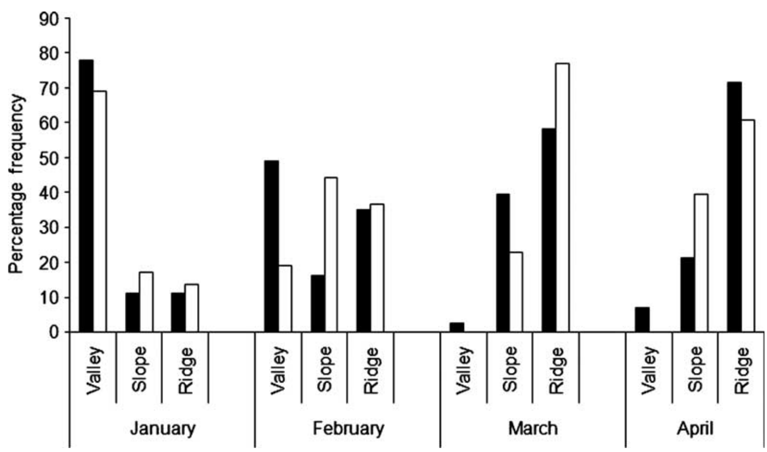

Figure 2. Frequency distribution of *M. aurantiaca* over a period of four months in the 2008 austral summer in three different topographical settings across all survey sites (males: closed bars, females: open bars) shows that both sexes gradually move upslope, away from the ponds towards the end of the March.

Temperature recorded during the time of the survey was not significantly related to the abundance of *M. aurantiaca* (Pearson correlation, $r_{33} = -0.28$, $P = 0.22$).

At the site where we made regular visits to count *M. aurantiaca* (Bejofo, in Mangabe) we encountered between 33 and 71 individual *M. aurantiaca* on each visit from November until May and only in June was there a notable decrease in the number of individuals visible during the searches (Table 2). The highest number of individuals was recorded during the month of March. There was a noticeable shift in the distribution of individual *M. aurantiaca* from areas close to ponds (valley bottom) in November, to an increase in the use of ridges between January and March, culminating in the majority of amphibians located on ridges during April and May. Two individuals were located near the pond in June, but overall sample size during this month was very low. Patterns of habitat use by males and females were broadly similar, although it appeared that females started the upslope movement away from the breeding site in January, before the males (Table 2).

DISCUSSION

Mantella aurantiaca was found in 26 different localities. This species is currently listed as Critically Endangered on the IUCN Red List because of an area of occupancy less than 10 km^2, a fragmented distribution and declines in both the habitat and populations of the frogs (Vences and Raxworthy 2004; Andreone *et al.* 2005). The additional populations of *M. aurantiaca* discovered during this study and those already described by Bora *et al.* (2008) increase its known extent of occurrence slightly beyond the surface area threshold for a Critically Endangered species (100 km^2). However, the area of occupancy is below the threshold for a Critically Endangered species and *M. aurantiaca* should become a conservation priority in Madagascar.

Table 2. Counts of *M. aurantiaca* over a period of seven months at the Bejofo breeding site along transects placed near a pond, on the adjacent vegetated slope and the top of the slope. This table shows that *M. aurantiaca* is found near ponds in the early dry season and gradually moves upslope until June when few frogs were found in the study site.

	Males			Females			Juveniles			
Month	Pond	Slope	Ridge	Pond	Slope	Ridge	Pond	Slope	Ridge	Total
November 2007	8	19	2	9	11	0	14	4	0	67
January 2008	15	0	4	3	5	4	4	3	10	48
February 2008*	2	5	1	0	6	3	2	8	6	33
March 2008	8	3	16	4	3	16	14	7	0	71
April 2008	0	1	12	0	0	20	0	0	4	37
May 2008	0	0	21	0	0	23	0	0	0	44
June 2008	1	0	0	0	0	1	1	0	0	3
Total	34	28	56	16	25	67	35	22	20	303

Note: *, survey included in Table 1.

This survey has highlighted a number of issues that are relevant to amphibian conservation in Madagascar. Firstly, certain threatened amphibian species have unique or unusual habitat requirements and are unlikely to be included in conservation priority-setting exercises that use a multi-taxa approach (Kremen *et al.* 2008). This point was highlighted by Rakotobe *et al.* (2008) who drew attention to that fact that key areas for the conservation of *M. aurantiaca* and *Mantella cowani* in Madagascar were unprotected. Key sites for amphibian conservation need to be identified and when they occur outside of existing priority sites, threat assessments followed-up by appropriate conservation initiatives are required. Particular effort needs to be directed towards sites that are away from major roads and existing protected areas to overcome sampling bias (Vieites *et al.* 2008). Projects to conserve *M. cowani* and *M. aurantiaca* are good examples of amphibian-focused initiatives that might be appropriate for other herpetofaunal taxa in Madagascar that have distributions which are highly limited and located outside of protected areas (Rabemananjara *et al.* 2008b).

The second key message is that within an area broadly defined as important habitat for amphibians, there are likely to be critically important patches of habitat that are essential for the species' survival. In the case of *M. aurantiaca*, the ephemeral ponds and marshy depressions around which the frogs aggregate during the breeding season appear to be key microhabitats for this species. These breeding habitat patches provide useful foci for communities, conservationists and biologists alike and should be protected. In many ways this conforms to the traditional pond-based approach to amphibian conservation which is frequently associated with maintaining viable meta-populations (e.g. Marsh & Trenham 2001; Smith & Green 2005). However, although breeding pond isolation is a key factor in amphibian ecology and conservation, it applies mainly to species with limited dispersal and little is known about inter-population movement by *Mantella* frogs (Smith & Green 2005). Local habitat quality is also likely to be an important factor (Marsh & Trenham 2000), but for *M. aurantiaca* questions remain regarding its use of terrestrial habitats and in particular its association with *Pandanus* spp. plants, for which we found little evidence. Our results have demonstrated that this species can withstand a certain degree of disturbance to the forest surrounding these ponds if the integrity of the water body is maintained. We found a relatively high abundance of *M. aurantiaca* at one site immediately after fire but fire-damaged sites were generally characterised by a low abundance. Fire and severe habitat disturbance caused by converting forest into agriculture represents a clear and present danger to *M. aurantiaca* but it may be able to withstand, or recover from, the occasional bush fire. Other authors have noted this species to survive the passage of fire (Andreone *et al.* 2005; Bora *et al.* 2008). The main threats encountered were the conversion of breeding ponds into agriculture or agricultural activities nearby that influenced the water-table. The degradation of humid forest adjacent to these small wetlands was also a threat. Discarded wood chip from logging in the forest was observed in some ponds. A complete conservation plan for this species should therefore aim to conserve the wetlands as well as the adjacent forested slopes (Semlitsch 2002; Crawford & Semlitsch 2007). A more thorough understanding of the core terrestrial habitat use of *M. aurantiaca* would help to inform direct conservation action and serve to assist any future plans involving translocations or habitat restoration or captive breeding projects.

None of the sites where we encountered *M. aurantiaca* during the 2008 survey had a formal conservation status and all were located outside of Madagascar's protected area network. However, the cluster of ponds in the Mangabe forest led to a conservation initiative to establish a community-managed protected area. Although considerable work is still needed to complete this, part of the Mangabe forest was included in a provisional list of new protected areas by the Malagasy government in October 2008. Despite ongoing conservation efforts the forest and wetlands at Mangabe are threatened by illegal artisanal gold mining, conversion to agriculture and commercial logging (R. Randrianavelona, pers. obs.). The *M. aurantiaca* ponds will become the focus of community conservation projects in the future at Mangabe. The long term management of the *M. aurantiaca* populations overlapping the Ambatovy mine footprint remains to be defined in the Mantella Management Plan of the Ambatovy Project, but it is expected that some essential habitat for this species will be lost. Known *M. aurantiaca* sites at the Torotorofotsy Ramsar have undergone severe fire damage in recent years but the remaining ponds are deserving of renewed conservation effort (Andreone *et al.* 2005). The future of the 26 *M. aurantiaca* localities visited in this survey therefore remain unsecured. The majority of localities with *M. aurantiaca* are subject to some form of management that takes biodiversity conservation into account but the framework and implementation has so far been relatively weak and these sites remain threatened. A few localities are expected to be lost entirely, either because they occur in areas due to be cleared for open cast mining or because they occur in heavily exploited sites without any form of conservation management. Mitigating the loss of the localities at the mine site will be a challenge for all stakeholders.

Rabemananjara *et al.* (2008a) found higher numbers of *M. aurantiaca* at Torotorofotsy compared to two sites in Mangabe and our survey may have underestimated the importance of the former site. Our assessment of the relative abundance might have been biased by climatic factors because of the sequential sampling protocol that we adopted. Better assessments could be achieved by conducting simultaneous surveys at a sample of *M. aurantiaca* or from combining data from a few years to provide a relative abundance assessment. Nevertheless, numbers of *M. aurantiaca* across all breeding pools varied between a maximum of 75 (this study) and calculated population sizes of 201 Rabemananjara *et al.* (2008a), which suggests that high concentrations are rare. Although some *Mantella* species form sex-specific aggregations which can introduce additional complications to interpreting survey data (Rabemananjara *et al.* 2008a), *M. aurantiaca* males and females congregated at breeding ponds between December and February. Standard counts, or mark-recapture studies of frogs at these breeding sites provides a suitable approach to assessing relative abundance between sites and years. The next step will be to apply the mark recapture methods used by Rabemananjara *et al.* 2008a) to estimate the number of individuals present at selected breeding ponds. Information on the population size at individual sites can then be used to develop prudent harvest levels in collaboration with Madagascar's CITES Authorities, local communities and *Mantella* exporters.

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Voucher Specimens

Mantella aurantiaca UADBA 43078-92; UADBA 49166-261.

REFERENCES

ANDREONE, F., J.E. CADLE, N. COX, F.R. GLAW, R.A. NUSSBAUM, C.J. RAXWORTHY, S.N. STUART, D. VALLAN & M. VENCES. 2005. Species review of amphibian extinction risks in Madagascar: Madagascar: conclusions from the Global Amphibian Assessment. Cons. Biol. 19: 1790–1802.

ANDREONE, F., A.I. CARPENTER, N. COX, L.D. PREEZ, K. FREEMAN, S. FURRER, G. GARCIA, F. GLAW, J. GLOS, D. KNOX, J. KOHLER, J. MENDELSON, V. MERCURIO, R.A. MITTERMEIER, R.E. MOORE, N. RABIBISOA, H. RANDRIAMAHAZO, H. RANDRIANASOLO, N. RAMINOSOA, O.R. RAMILIJAONA, C. J. RAXWORTHY, D. VALLAN, M. VENCES, D.R. VIEITES & C. WELDON. 2008. The challenge of conserving amphibian megadiversity in Madagascar. PLos Biology 6: e118.

ANDREONE, F., V. MERCURIO & F. MATTIOLI. 2006. Between environmental degradation and international pet trade: conservation strategies for the threatened amphibians of Madagascar. Natura-Soc. it. Sci. nat. Museo civ. Stor. Nat. Milano 95: 81–96.

ANON. 2008. Review of significant trade in specimens of Appendix-II species. Twenty-third meeting of the Animals Committee Geneva (Switzerland), 19–24 April 2008. AC 23 Doc. 8.2 Convention on International Trade in Endangered Species of Wild Fauna and Flora.

BORA, P., D. DOLCH, R.K.B. JENKINS, O. JOVANOVIC, F.C.E. RABEMANANJARA, J. RANDRIANIRINA, J. RAFANOMEZANTSOA, L. RAHARIVOLOLONIAINA, O.R. RAMILIJAONA, N. RAMINOSOA, R. RANDRIANAVELONA, A.P. RASELIMANANA, B. RAZAFIMAHATRATRA & M. VENCES. 2008. Geographical distribution of three species of Malagasy poison frogs of high conservation priority: *Mantella aurantiaca*, *M. crocea* and *M. milotympanum*. Herp. Notes 1: 39–48.

BEHRA, O., F. RABEMANANJARA, N. RABIBISOA, O. RAMILISON & A. RAVONINJATOVO. 1995. Etude de la répartition et du niveau de population de deux espèces d'amphibiens de Madagascar (*Mantella aurantiaca* et *Mantella crocea*, sous-famille Mantellinae, Laurent, 1946). Report to Direction des Eaux et Forets, Madagascar. P. 39. BIODEV Madagascar, Antananarivo.

CHIARI, Y., M. VENCES, D.R. VIEITES, F.C.E. RABEMANANJARA, P. BORA, O.R. RAMILIJAONA & A. MEYER. 2004. New evidence for parallel evolution of color patterns in Malagasy poison frogs (*Mantella*). Mol. Ecol. 13: 3763–3774.

CRAWFORD, J.A. & R.D. SEMLITSCH. 2007. Estimation of core terrestrial habitat for stream-breeding salamanders and delineation of riparian buffers for protection of biodiversity. Cons. Biol. 21: 152–158

GASCON, C., J.P. COLLINS, R.D. MOORE, D.R. CHURCH, J.E. MCKAY & J.R. III MENDELSON. 2007. Amphibian Conservation Action Plan. 64pp. IUCN/SSC Amphibian Specialist Group, Gland, Switzerland and Cambridge, UK.

IUCN. 2009. IUCN Red List of Threatened Species. Version 2009.1. Available at: www.iucnredlist.org (accessed 2 July 2009).

IUCN STANDARDS AND PETITIONS WORKING GROUP. 2008. Guidelines for Using the IUCN Red List Categories and Criteria. Version 7.0. Prepared by the Standards and Petitions Working Group of the IUCN SSC Biodiversity Assessments Sub-Committee in August 2008.

KREMEN, C., A. CAMERON, A. MOILANEN, S.J. PHILIPS, C.D. THOMAS, H. BEENTJE, J. DRANSFIELD, B.L. FISHER, F. GLAW, T.C. GOOD, G.J. HARPER, R.J. HIJMANS, D.C. LEES, E.E. LOUIS, R.A. NUSSBAUM, C.J. RAXWORTHY, A. RAZAFIMPAHANANA, G.E. SCHATZ, M. VENCES, D.R. VIEITES, P.C. WRIGHT & M.L ZJHRA. 2008. Aligning conservation priorities across taxa in Madagascar with high resolution planning tools. Science 320: 222–225.

MARSH, D.M. & P.C.TRENHAM. 2001. Metapopulation dynamics and amphibian conservation. Cons. Biol. 15: 40–49.

RABEMANANJARA, F.C.E., P. BORA, J.E. CADLE, F. ANDREONE, E. RAJERIARISON, P. TALATA, F. GLAW, M. VENCES & D.R. VIEITES. 2005. New records, distribution and conservation of Mantella bernhardi, an Endangered frog species from south-eastern Madagascar. Oryx 39: 339–342.

RABEMANANJARA, F.C.E., P. BORA, T. RAZAFINDRABE, E. RANDRIAMITSO, O.R. RAMILIJAONA, N.R. RAMINOSOA, D. RAKOTONDRAVONY, D.R., VIEITES & M. VENCES. 2008a. Rapid assessments of population sizes in ten species of Malagasy poison frogs, genus *Mantella*. Pp. 253–264. *In* F. Andreone & H. Randriamahazo (Eds.), A Conservation Strategy for the Amphibians of Madagascar – Monografie XLV. Museo Regionale di Scienze Naturali, Torino.

RABEMANANJARA, F.C.E., N.H.C. RABIBISOA, N. RAKOTONDRAZAFY, R.K.B. JENKINS & F. ANDREONE. 2008b. Management of focal amphibian sites for conservation. Pp. 49–53. *In* F. Andreone & H. Randriamahazo (Eds.), Conservation Strategies for the Amphibians of Madagascar/Stratégies de conservation pour les amphibiens de Madagascar. Sahonagasy Action Plan. Museo Regionale di Scienze Naturali, Conservation International, IUCN/SSC Amphibian Specialist Group, Torino, Italy.

RAKOTOBE, Z.L., L. ANDRIAMARO, R. FINOANA, D.H. KNOX, H. RABARISON & H.H. RANDRIANASOLO. 2008. Key biodiversity areas as tools for identifying priority amphibian conservation sites in Madagascar. Pp. 385–397. *In* F. Andreone & H. Randriamahazo (Eds.), Conservation Strategies for the Amphibians of Madagascar/Stratégies de conservation pour les amphibiens de Madagascar. Sahonagasy Action Plan. Museo Regionale di Scienze Naturali, Conservation International, IUCN/SSC Amphibian Specialist Group, Torino, Italy.

RAMILISON, O.S. 1997. Contribution a l'étude d'une espèce amphibienne malgache *Mantella aurantiaca* Mocquard, 1900 (Anoures, Mantellidae): étude taxonomique, biologique et écologique dans la région de Moramanga. P. 70. Département de Biologie Animale, Université d'Antananarivo, Antananarivo.

SEMLITSCH, R.D. 2002. Critical elements for biologically based recovery plans of aquatic-breeding amphibians. Cons. Biol 16: 619–629.

SMITH, A.M. & D.M. GREEN. 2005. Sex, isolation and fidelity: unbiased long-distance dispersal in a terrestrial amphibian. Ecography 29: 649–658.

VALLAN, D. 2002. Effects of anthropogenic environmental changes on amphibian diversity in the rain forests of eastern Madagascar. J. Trop. Ecol 18: 725–742.

VENCES, M., F. GLAW & W. BOHME. 1999. A review of the genus *Mantella* (Anura, Ranidae, Mantellinae): taxonomy, distribution and conservation of Malagasy poison frogs. Alytes 17: 3–72.

VENCES, M. & C.J. RAXWORTHY. 2004. *Mantella aurantiaca*. *In* IUCN 2009. IUCN Red List of Threatened Species. Version 2009.1. Available at: www.iucnredlist.org (accessed 15 July 2009).

VIEITES, D.R., S. NIETO-ROMAN & M. VENCES. 2008. Towards understanding the spatial pattern of amphibian diversity in Madagascar. Pp. 397–410. *In* F. Andreone & H. Randriamahazo (Eds.), A Conservation Strategy for the Amphibians of Madagascar – Monografie XLV. Museo Regionale di Scienze Naturali, Torino.

VIEITES, D.R., F.C.E. RABEMANANJARA, P. BORA, B. RAZAFIMAHATRATRA, O.R. RAMILIJAONA & M. VENCES. 2005. Distribution and population density of the black-eared Malagasy poison frog *Mantella milotympanum* Staniszewski, 1996 (Amphibia: Mantellidae). Pp. 197–204. *In* B.A. Huber, B.J. Sinclair & K.-H. Lampe (Eds.), African Biodiversity. Springer, The Netherlands.

VIEITES, D. R., K.C. WOLLENBERG, F. ANDREONE, J. KOHLER, F. GLAW & M. VENCES. 2009. Vast underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. PNAS 106: 8267–8272.

WOODHEAD, C., M. VENCES, D.R. VIEITES, I. GAMBONI, B.L. FISHER & R.A. GRIFFITHS. 2007. Specialist or generalist? Feeding ecology of the Malagasy poison frog *Mantella aurantiaca*. Herpetol. J. 17: 225–236.

ZIMMERMANN, H. & S. HETZ. 1992. Vorläufige Bestandsaufnahme und Kartierung des gefährdeten Goldfröschchen, *Mantella aurantiaca*, im tropischen Regenwald Ost-Madagaskars. Herpetofauna 14: 33–34.

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