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The conservation status of a poorly known range-restricted mammal, the Nimba otter-shrew *Micropotamogale lamottei*

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Abstract: We have a poor understanding of the ecology of many African small mammals due to a lack of basic research. This has important conservation implications, particularly for range-restricted species in tropical regions. In this study, we provide new insight into the distribution and ecology of one such species, the Nimba otter-shrew (*Micropotamogale lamottei* Heim de Balsac 1954). We apply niche and occupancy modeling to inform on the range and habitat use of this semi-aquatic species. We estimate that its global range [extent of occurrence (EOO)] is 14,725 km^2. Using occupancy modeling, we show that mining has a direct impact on the occurrence of this species. We also provide preliminary observations of its movements through radio-tracking. Using maximum entropy (Maxent) modeling, we identify the North Lorma National Forest and the Wonegizi range (northern Liberia) that appear suitable for this species, but where it has not yet been recorded. We suggest that the Nimba otter-shrew has a global distribution centered on the Mount Nimba region, straddling the borders of Liberia, Guinea and Côte d'Ivoire, and that it requires urgent conservation attention to ensure its long-term persistence. Finally, we provide evidence to support an uplisting of its IUCN Red List conservation status to Vulnerable.

Keywords: Afrotheria; Liberia; Maxent; mining; Mount Nimba; occupancy; Potamogalidae.

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Introduction

Roughly three-quarters of all mammal species are "small" in size (typically <1 kg), yet conservation effort and attention is heavily skewed in favor of the larger and more charismatic species (Entwistle and Stephenson 2000). For example, many large mammals [such as lion, *Panthera leo* (Linnaeus 1758), and African elephant, *Loxodonta africana* (Blumenbach 1797)] have multiple international organizations dedicated to raising funds for that one specific species, yet not one of the 39 threatened species of sub-Saharan rodents (Monadjem et al. 2015) receives such targeted attention. There are many reasons for this bias in conservation focus, including the fact that larger mammals have more charismatic appeal and are typically better studied (Entwistle and Stephenson 2000, Brodie 2009, Kingdon et al. 2013, Conenna et al. 2017).

Small mammals are increasingly seen as important components of ecological systems (Kunz et al. 2011). For example, they typically form a critical part of the food web (Memmott 2009), allowing for the persistence of larger vertebrates, such as snakes, birds of prey and carnivorous mammals (Lidicker 2000, Lima et al. 2002). They also, *inter alia*, aerate soil, alter soil nutrients, disperse seeds and pollinate flowers (Letten and Midgley 2009, Hurst et al. 2014, Lacher et al. 2016). Many species of small mammals may be highly specialized, localized, threatened with extinction or taxonomically distinct (Schipper et al. 2008, Kingdon et al. 2013, Monadjem et al. 2015, Everson et al. 2016). However, many small mammals are vulnerable to anthropogenic changes and range-restricted species might be lost before their basic ecology and role in the ecosystem has even been described (Blois et al. 2010). This paper deals with one such example of a poorly known African small mammal, the Nimba otter-shrew (*Micropotamogale lamottei* Heim de Balsac 1954).

The Nimba otter-shrew is a rat-sized mammal (mass c. 80 g) belonging to the family Potamogalidae, which contains just two other species, all three of which are endemic to Africa, with their closest relatives being the tenrecs of Madagascar (Vogel 2013a, Everson et al. 2016). All three species are semi-aquatic, hunting crabs and other aquatic macro-invertebrates in relatively small forested streams (Rahm 1961, Dubost 1965, Vogel 1983). From 1990 onward the Nimba otter-shrew was listed as globally "Endangered", but was then downlisted to "Near Threatened" in 2016. The justification for this was as follows: "Whilst the species distribution is unclear, the estimated extent of occurrence is 22,540 km^2, suggesting it qualifies as Near Threatened. This is a larger extent of occurrence than previously estimated so the assessment suggests it is less threatened than originally thought (Endangered in 2008), though further field work is essential to confirm this" (Stephenson 2016).

The Nimba otter-shrew is endemic to the Upper Guinea Forest block that extends from western Ghana through Côte d'Ivoire and Liberia, to eastern Sierra Leone and the extreme southeast of Guinea (Vogel 2013b). However, within this region, it has only been recorded from Mount Nimba and surrounding hills, with two outlying "populations" in the Putu Mountains (eastern Liberia) and Sérédou (southeastern Guinea) less than 200 km away, with an imprecisely known estimated extent of occurrence (EOO) that was recently stated to be 57,436 km^2 (Decher et al. 2016), which is almost three times that given by the International Union for Conservation of Nature (IUCN) Red List account for the species (Stephenson 2016). Beyond this, practically nothing is known about the range and habitat requirements of this species.

The predominant threats to this species are thought to be habitat degradation and destruction through mining and agriculture, as well as mortality of individuals accidentally captured and drowned in crab and fish traps (Stephenson 2016). However, to date, none of these presumed impacts have yet been quantified or tested on the Nimba otter-shrew. In addition, this species is on the list of the top 100 Evolutionarily Distinct and Globally Endangered (EDGE) species (www.edgeofexistence.org/mammals), emphasizing its phylogenetic uniqueness. Therefore, the downgrading of the conservation status of this species might lead to the loss of an evolutionary distinct species.

The aim of this study is to provide new insight into the distribution and ecology of the Nimba otter-shrew to inform the assessment of its conservation status. We apply niche and occupancy modeling to the range and habitat use of this poorly known species. Our objectives are (1) to use a climatic envelope model of the species' distribution to test whether other suitable habitat patches may occur outside of its known range; (2) to test the impact that iron-ore mining is having on its distribution and abundance and (3) to quantify its daily foraging movements and home range by radio telemetry.

Materials and methods

Study area

This study was conducted at Mount Nimba, which straddles Liberia, Guinea and Côte d'Ivoire. The mountain rises to 1768 m above sea level (in Guinea), and extends for 30 km from about 7°40′N, 8°22′W in the northeast to 7°29′N, 8°32′W in the southwest. Mount Nimba has a high degree of endemism (including several plants, invertebrates and vertebrates restricted to the massif), with at least one bat (*Hipposideros lamottei* Brosset 1985) endemic to the mountain and a second one (*Hipposideros marisae* Aellen 1954) a near-endemic (Brosset 1984, Monadjem et al. 2016 and references therein). The current study was conducted on the Liberian side of the mountain, in the area previously held as a mining concession by the Liberian–American–Swedish Minerals Company (LAMCO) during the 1960s up until the early 1990s. The mining concession for this area is currently held by ArcelorMittal Liberia (hereafter referred to as the AML concession). A brief summary of the geography, climate and vegetation is presented below and is taken from Coe (1975).

On the Liberian side of Mount Nimba, altitude ranges from below 500 m asl at the base of the mountain to just over 1300 m asl at the summit. Rainfall varies with altitude, with around 2000 mm falling at lower altitudes, rising to over 3000 mm at the highest elevations. Rainfall is also highly seasonal with most of the precipitation falling in May to October with a pronounced dry season in December and January. Mean annual temperature ranges from 25°C at the base of the mountain decreasing to 20°C at the summit. The dominant vegetation until a few decades ago was deciduous forest, with small patches of naturally occurring grassland. As a result of clearing by mining activities and slash-and-burn agriculture, forest cover has been reduced and greatly fragmented.

Most of the AML concession currently does not enjoy effective conservation protection. However, in 2003, Liberia proclaimed the East Nimba Nature Reserve (ENNR) that covers most of the Liberian section of the mountain. This reserve is run by the ENNR Co-Management Committee that includes participation (and hence support) by the local community and Government. The operational costs are currently subsidized by ArcelorMittal that views the reserve as an offset site for its operations (Monadjem et al. 2016). Other mountains in the area include Mount Gangra, Mount Yuelliton and Mount Tokadeh, all of which have peaks between 800 m and 950 m above sea level (Figure 1).

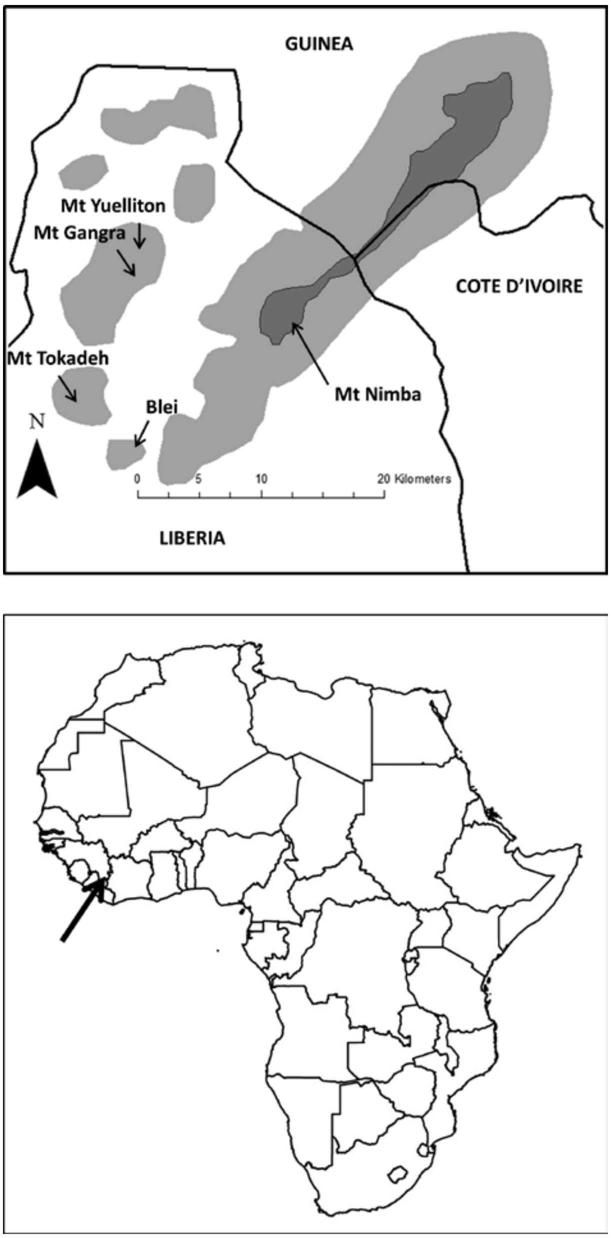

Figure 1: Map of Mount Nimba showing the locations of the sites mentioned in the text.
The thick lines show international boundaries. Areas above 600 m and 1000 m are shown in light and dark gray, respectively. The inset shows a map of Africa with the arrow pointing to the study area. Map adapted from Monadjem et al. (2016). The ArcelorMittal mining concession effectively encompasses the Liberian portion of this map and includes Mount Nimba to the east, Blei to the south, Mounts Tokadeh, Gangra and Yuelliton to the west and the Guinea border to the north.

Mount Tokadeh was originally mined during LAMCO days. Mining resumed here in 2011 with mining activity expanding rapidly in 2012 resulting in much clearcutting of forest. Mount Gangra was relatively untouched by mining activities (except for digging of exploratory adits by LAMCO and later exploratory drilling by AML) until preparations for mining began in early 2017. Hence, during this study, it was an unmined area. Mount Yuelliton, which is situated very close to Mount Gangra, was not surveyed during this study, but it is possible that this mountain will be mined in the near future (Figure 1).

Data collection

We conducted surveys at 30 sites, specifically located to compare a mining area with one where mining had not yet been conducted. The non-mined area was on Mount Gangra where 12 sites were located. The mining area was on Mount Tokadeh approximately 10 km to the south of Mount Gangra (Figure 2) where 18 sites were located. At each site, 50 wire funnel traps were set across a stream (Figure 3), spread out over a maximum distance of about 100 m along the stream. Traps were self-baited with crabs (using oil palmnuts to attract the crabs) and set for five nights per site. The total trapping effort at Mount Gangra was 3000 trap-nights, and at Mount Tokadeh was 4345 trap-nights. Trapping at Mount Gangra was conducted at the end of the raining season in October 2016, and at Mount Tokadeh during the late dry season in February and March 2017. We have no reason to suspect any changes in detectability of this species during this period. A previous multi-year survey of this species did not detect any changes in trappability of the Nimba otter-shrew between seasons (Monadjem unpublished data).

We conducted surveys at an additional 46 sites between January 2013 and May 2015, primarily to determine the presence/absence of the Nimba otter-shrew in relation to habitat and environmental features (see below). For this part of the study, we set 12–150 (but mostly 50–80) wire and traditional funnel traps (Figure 2) baited with crabs for 2–5 nights at each site. The total trapping effort was 12,110 trap-nights.

In order to map the distribution of the Nimba otter-shrew, all published records of the species were taken from the literature, using the records listed in Decher et al. (2016) as a starting point. Further information was gleaned from consultancy reports and other unpublished sources (ArcelorMittal & URS/Scott-Wilson Ltd. 2010, ArcelorMittal 2013). We estimated the EOO of the Nimba otter-shrew

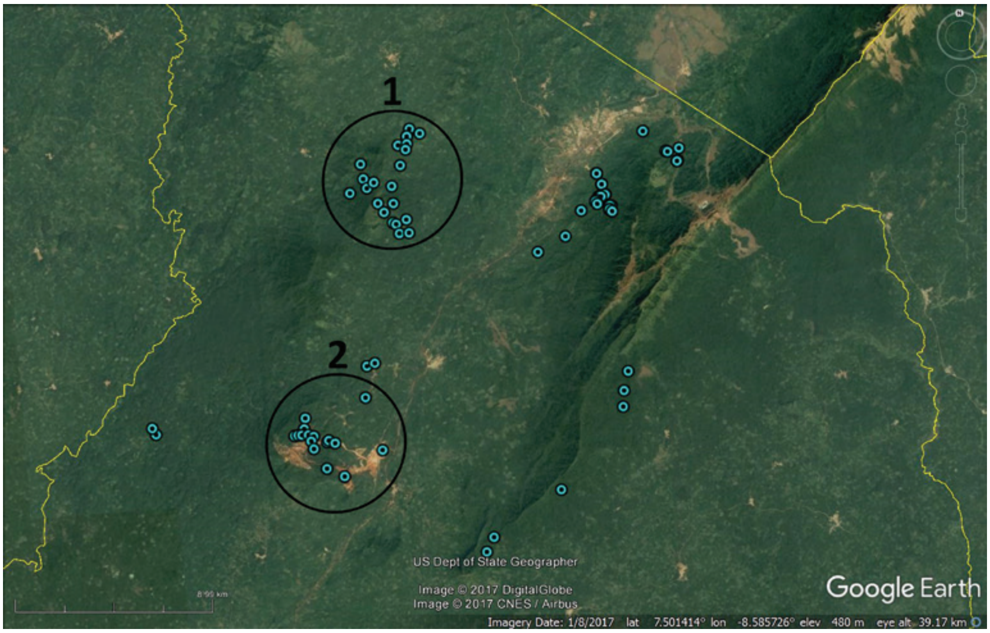

Figure 2: Map of Mount Nimba and surrounding hills where the 76 trapping sites were located (all within Liberia), overlaid on a Google Earth image.
The yellow lines show international boundaries. The circles refer to the two mining areas where Nimba otter-shrew occupancy was compared: Mount Gangra (1) and Mount Tokadeh (2).

by using the minimum convex polygon (MCP) method to connect the outermost localities in Quantum Geographic Information System (QGIS. Open Source Geospatial Foundation Project. http://qgis.osgeo.org).

At each of the 76 trapping sites, we measured several physical parameters associated with the stream. We measured the width of the stream to the closest 10 cm using a tape measure, and stream depth to the closest centimeter using a straight pole that was inserted into the stream at three points across where the traps were set. Water temperature, total dissolved solids (TDS) (ppm), electrical conductivity (µS) and pH were measured with a low range pH/conductivity/TDS (ppm) tester (Hanna Instruments, HI98129)

In order to quantify the home range and movement patterns of the Nimba otter-shrew, 11 animals were captured at Mount Nimba and fitted with a radio transmitter (M1540, Advanced Telemetry Systems, Inc. Isanti, Minnesota) that was glued between the shoulder blades. The radio collar (transmitter) had a mass of 4.2 g representing 6.9% of the body mass of the smallest tracked individual (61 g). Tracking commenced the night after the transmitters had been fitted, to allow the animals to settle down. One animal was tracked per night, starting before sunset and ending after sunrise between January 2014 and April 2015. Fixes were taken a minimum of 15 min after the previous fix, by "homing in" (Russo et al. 2002) on the tracked animal, and recording the location on a GPS.

Data analysis

Niche modeling has been used to predict species' ranges based on environmental conditions at locations where the species is known to occur (presence only data), and has become a popular and effective tool in conservation biology and biogeography (Lamb et al. 2008, Monadjem et al. 2013, Schoeman et al. 2013, Cooper-Bohannon et al. 2016). Of the various modeling techniques that have been developed for such "presence only" data, maximum entropy (Maxent) has consistently performed well (Elith et al. 2011, Radosavljevic and Anderson 2014).

We selected eight climatic variables to represent average, extreme and seasonal variations in temperature and rainfall, which have previously been used for small mammals in another mountainous region of Africa (Taylor et al. 2016). These eight BioClim variables were: Bio 01 (annual mean temperature), Bio 04 (temperature seasonality), Bio 05 (maximum temperature of the warmest month), Bio 06 (minimum temperature of the coldest month), Bio 12 (annual precipitation), Bio 13 (precipitation of the wettest month), Bio 14 (precipitation of the driest month) and Bio 15 (precipitation seasonality). We also included altitude and altitudinal roughness; all ten continuous variables were extracted from WorldClim (Hijmans et al. 2005, www.worldclim.org). Finally, we included two categorical variables: "ecoregion" and "biome" (Olson et al. 2001).

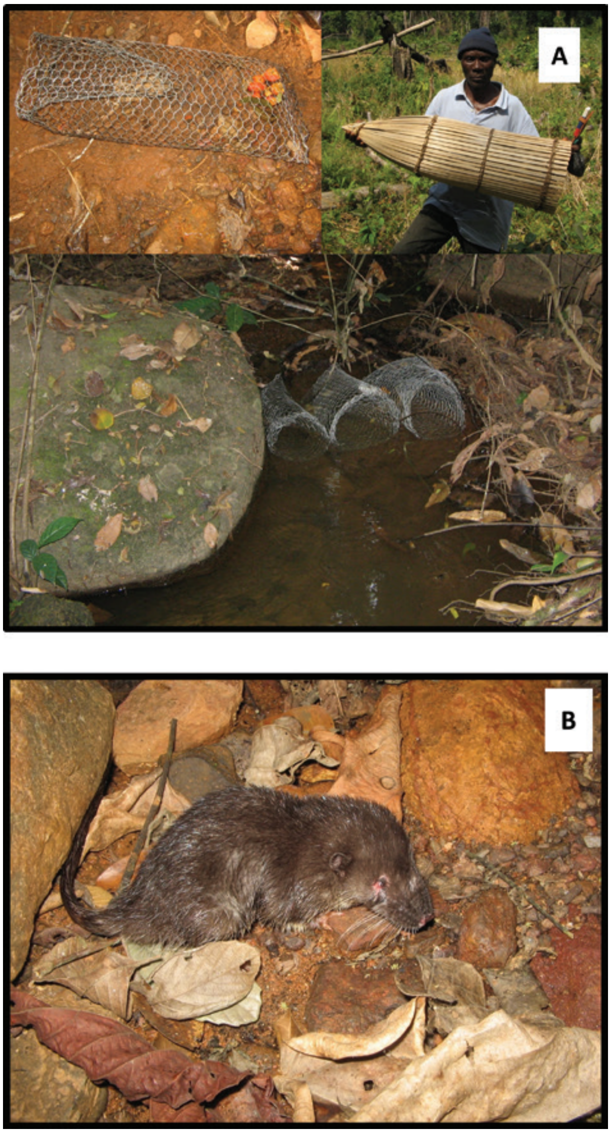

Figure 3: Photographs showing the traps used during this study (A): with wire funnel traps (top left), and traditionally made crab basket traps (top right). The traps were set in such a way as to block off a stream (if small enough) or portion of a river (if larger) as shown in the figure (bottom). Also shown (B) is an image of the Nimba otter-shrew capturing during this study (all images taken by Ara Monadjem).

All the environmental variables were resampled to a grid resolution of 2.5 arc min (roughly 4.7 × 4.7 km) and clipped to West Africa using ArcView 9.3 (Environmental Systems Research Institute, Redlands, CA, USA).

All models were run with the ten WorldClim variables and the two categorical variables. The Maxent model was run with 75% training and 25% random test data, and the regularization multiplier was set to 1 (Monadjem et al. 2013). All other Maxent settings were left on default. Model performance was evaluated by examining the area under the receiver operating characteristic curve (AUC), and by a jack-knife test which examines the importance of each environmental variable, first by removing one variable at a time and then each variable in isolation (Phillips et al. 2006).

Maxent provided an output of the relative suitability for a species as a continuous variable, which we converted into a binary variable by applying the logistic threshold "Equal Training Sensitivity and Specificity" because it gave the most realistic current distribution prediction for the Nimba otter-shrew and has recently been recommended as the best threshold to use for such purposes (Liu et al. 2013).

We used occupancy modeling (MacKenzie et al. 2006) to evaluate the environmental variables affecting the occurrence of Nimba otter-shrew at Mount Nimba and specifically to compare mined and unmined sites. We converted captures at each site into detection histories based on the number of nights trapped and estimated occupancy (ψ) while accounting for detection (p). For both sets of data, we first optimized detection by comparing models that modified p while keeping ψ constant. We evaluated a null model and models that modified the trap night. We selected the best model for each data set based on their Akaike's information criterion corrected for small sample size value (AICc). We then modified and compared the best model for each data set by adding variables that might influence ψ. To examine the influence of environmental variables on the occurrence of Nimba otter-shrews, we fitted an additional 12 models to the best model. These models comprised the six variables of stream characteristics mentioned above, as well as a null model. For both suites of models we selected the top models based on AICc values and considered variables modifying detection and occupancy parameters to be a relevant predictor if their 95% confidence intervals (CI) did not include 0. We conducted our analysis using the program PRESENCE, version 6.1 (Hines 2006).

We conducted spatial analyses of the radio-tracked Nimba otter-shrews in the R package "Move" (http://cran.r-project.org/web/packages/move/index), which included daily distance moved and speed of movement. The linear distance covered by each Nimba otter-shrew along a stream was calculated in Google Earth, using the "Path" option under the "Ruler" tool.

Results

Based on the MCP of all the currently known records of the Nimba otter-shrew, its EOO covers 14,725 km^2

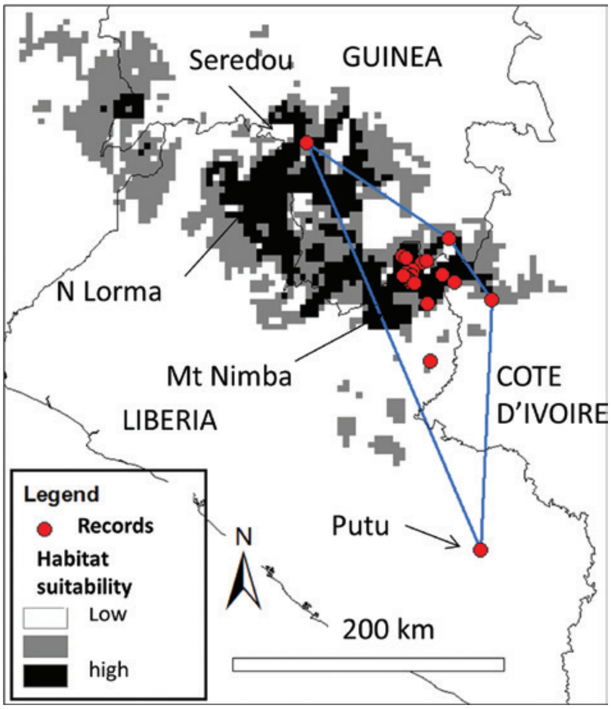

Figure 4: The distribution of all known Nimba otter-shrew records based on published accounts, museum specimens and recent unpublished surveys.
The Maxent model is shown in gray-scale shading. The Putu Mountains, Liberia and Sérédou, Guinea, are labeled, as is North Lorma National Forest (the Wonegizi range is too close to North Lorma to show up clearly on this scale, and hence not labeled). The extent of occurrence of the species is presented as a minimum convex polygon of all known localities (the solid blue line connecting the outermost points).

(Figure 4). The majority of the records are from Mount Nimba and surrounding hills, with an outlying population in the Putu Mountains (Liberia) about 100 km to the southeast, and another outlying population at Sérédou (Guinea) about 80 km to the northwest. The records from Mount Nimba come from all three countries that this mountain straddles, namely, Liberia, Guinea and Côte d'Ivoire.

The Maxent model shows the area of suitable habitat extending from Mount Nimba and surrounding hills, westward to northern Liberia and north to Sérédou in the adjoining region of Guinea (Figure 4). An area of lower suitability occurs in the extreme northeastern region of Sierra Leone (Figure 4). The total area of suitable habitat based on this Maxent model is 34,725 km^2.

A total of 18 Nimba otter-shrews were captured at 13 different sites, during this study (Figure 5). Five of these sites fall within the ENNR, one within the Blei Community Forest on the southern edge of the ENNR, six at and around Mount Gangra to the west of the ENNR and a single site at the base of Mount Tokadeh (see Figure 5). The altitudes at which these animals were captured ranged between 449 and 651 m above sea level.

The best model for occupancy separated detections for the first night from the other nights. Detection (p) on the first night was zero, and on subsequent nights was 0.233 (C.I. = 0.1020–0.4482). The best model to explain ψ across all 76 sites included one additional covariate, TDS (Table 1). Based on this model, the probability of occupancy ranged from 0.024 to 0.472. There were no other competing models that outperformed the null model (Table 1).

Comparing mined and unmined sites, we captured five individuals at four different sites at Mount Gangra (the unmined area), and one at Mount Tokadeh (the mining area). As for the previous analysis, the best model for evaluating detection was a model that separated the first night from the other nights, with detection (p) on the first night being zero, and on subsequent nights being 0.121 (C.I. = 0.0552–0.2444). The best model included a single covariate, whether the area was under mining or not (Table 2). Based on this model, occupancy was 1.0 at Mount Gangra (the unmined area), and 0.138 at Mount Tokadeh (the mining area). The two next best models were 1.79 AICs of the top model and included stream width and depth (Table 2). Both stream depth and width had their 95% CI crossing zero [estimates = 0.00161 and 0.00337, standard errors (SEs) = 0.002356 and 0.078302, respectively], and therefore, were not deemed relevant predictors of the Nimba otter-shrew occupancy.

The environmental and stream variables measured at the mined and unmined sites did not differ statistically except for TDS and water temperature, which were higher at the mined area compared with the unmined area (Table 3). In fact, the TDS was more than twice as high in the mined area.

Of the 11 Nimba otter-shrews that were fitted with transmitters, only seven were tracked for more than one night, and just four provided sufficient data for estimating home range movements. These four animals were tracked for between six and ten nights, with a total of between 219 and 420 fixes per animal. The mean total linear distance moved along streams was 518.3 m (SE ± 88.43 m; range: 388–690 m). The mean distance moved per night was 373.2 m (SE ± 130.02; range: 113–649 m) and the mean speed of movement was 32.8 m/h (SE ± 10.6; range: 12.2–55.1 m/h).

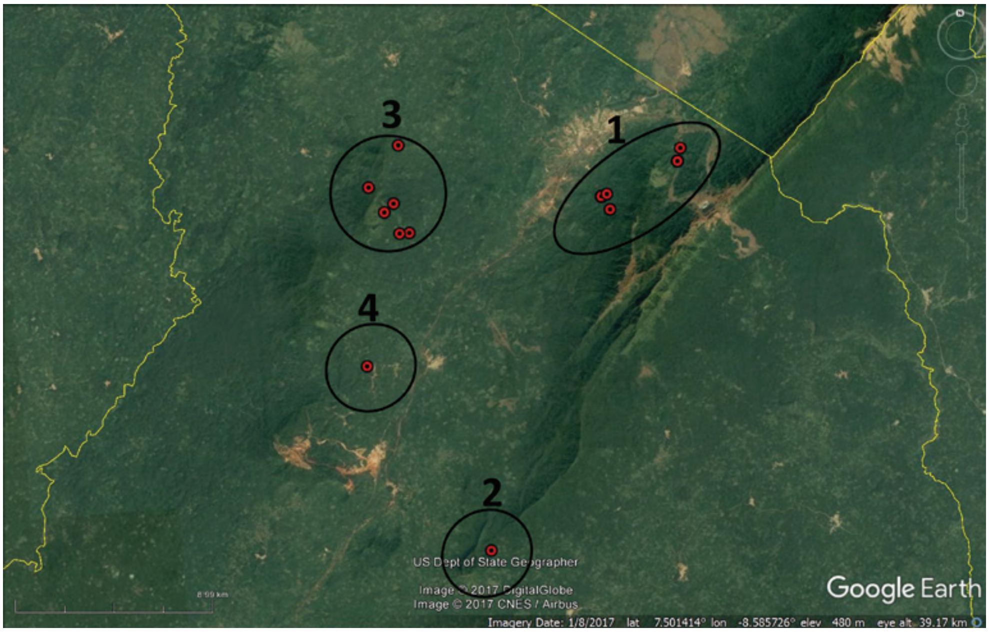

Figure 5: Map of the 13 sites in Liberia where Nimba otter-shrews were captured during this survey, overlaid on a Google Earth image. The yellow lines show international boundaries. The circles refer to the four areas within which otter-shrews were captured: at East Nimba Nature Reserve (1); at Blei Community Forest (2); on and at the base of Mount Gangra (3); and at the base of Mount Tokadeh (4).

Table 1: Comparison of the top models for occupancy (ψ) and detection probability (p) of the Nimba otter-shrew in relation to stream variables obtained from all 76 sites surveyed during this study at Mount Nimba, Liberia.

Model	AIC	ΔAIC	AIC weight	Number of parameters
ψ (TDS), p (night)	122.50	0	0.1802	4
ψ (.), p (night)	123.10	0.60	0.1335	3
ψ (TDS, Width), p (night)	123.50	1.00	0.1093	5
ψ (Width), p (night)	123.98	1.48	0.0860	4
ψ (Temp), p (night)	124.21	1.71	0.0766	4
ψ (Flow), p (night)	125.04	2.54	0.0506	4
ψ (pH), p (night)	125.06	2.56	0.0501	4
ψ (Depth), p (night)	125.09	2.59	0.0494	4
ψ (All six covariates), p (night)	130.92	8.42	0.0027	10

All models were parameterized for detection of the first night vs. the remaining nights, presented as “p (night)”. Models are ranked by Akaike’s information criterion (AIC) score. The ΔAIC value is the difference between the current model and the best (top) model. Also shown are the AIC weight and the numbers of parameters entered into the model.

Table 2: Comparison of the top models for occupancy (ψ) and detection probability (p) of the Nimba otter-shrew at 30 mined and unmined sites surveyed during this study at Mount Nimba, Liberia.

Model	AIC	ΔAIC	AIC weight	Number of parameters
ψ (Mined), p (night)	55.08	0	0.2912	4
ψ (Depth), p (night)	56.87	1.79	0.1190	4
ψ (Width), p (night)	56.87	1.79	0.1190	4
ψ (Temp), p (night)	57.79	2.71	0.0751	4
ψ (TDS), p (night)	57.85	2.77	0.0729	4
ψ (.), p (night)	59.03	3.95	0.0404	3
ψ (pH), p (night)	59.84	4.76	0.0270	4
ψ (All six covariates), p (night)	60.42	5.34	0.0202	8

All models were parameterized for detection of the first night vs. the remaining nights, presented as “p (night)”.

Discussion

In this study, we demonstrate that the Nimba otter-shrew has a relatively small known EOO for a mammal of its size (Kingdon et al. 2013), and that the threats to its persistence include ongoing mining activities in the core of its known range that involves widespread disruption to its freshwater habitat. In addition, our very low capture rates (18 animals in 19,455 trap-nights), coupled with relatively high detection (0.23 per night after the first night), suggest that this species occurs at relatively low densities, even in the core of its global distribution. Its current conservation status of “Near Threatened”, therefore, seems to underestimate the dangers facing this elusive species. We suggest that, based on the information provided in this study, the Nimba otter-shrew meets the IUCN criteria for listing as “Vulnerable” under the specific criteria of B1a and B1b

Table 3: Comparison of environmental variables recorded at streams in the unmined (Mount Gangra) and mined (Mount Tokadeh) areas within the ArcelorMittal Liberia mining concession, Mount Nimba.

Environmental variable	Unmined (Gangra)	Mined (Tokadeh)
Stream width (cm)	104.9 ± 5.44	96.8 ± 5.33
Stream depth (cm)	10.2 ± 0.65	9.6 ± 1.06
Water temperature (°C)	**23.2 ± 0.29**	**25.1 ± 0.54**
Water TDS	**11.3 ± 2.21**	**25.5 ± 4.06**
Water pH	6.69 ± 0.16	6.28 ± 0.24
Water flow rate (m/s)	0.27 ± 0.02	0.24 ± 0.03

Values are presented as mean ± SE. Statistically significant differences are highlighted in bold ($p < 0.05$).

(IUCN 2012). Principally, its EOO is less than 20,000 km^2, the population is very fragmented and there is a projected decline in the EOO and the population of mature adults due to ongoing mining activities and slash-and-burn agriculture.

This is the first study to show that mining may directly and negatively impact on a semi-aquatic mammal in tropical Africa, although this has already been assumed to be the case for otter-shrews (Vogel 2013a). This is all the more worrisome for the Nimba otter-shrew as most records of this species are from outside of protected areas (Decher et al. 2016, Stephenson 2016). Our study has shown that this species was relatively abundant at an unmined site (Mount Gangra), but had largely disappeared from a nearby site (Mount Tokadeh) in identical habitat, where it had been recorded less than a decade previously (Decher et al. 2016). We were able to detect significant differences in two aquatic variables between these two sites, which were TDS and water temperature, both of which are known to increase with mining activities (Banks et al. 1997). We are not sure of how an increase in these two variables would affect populations of Nimba otter-shrews, but hypothesize that it may be driven by reduction in prey densities and reduced ability to capture prey in murky water. As much of this species' range falls within mining concessions (Decher et al. 2016, AM and WYC, personal observation), this is of particular concern.

By radio tracking Nimba otter-shrews, we have been able to corroborate the anecdotal observations of previous workers (Vogel 2013a, Decher et al. 2016). Our results clearly show that the range of this species is linear in nature and is centered along rivers and streams. Our sample sizes are too small to make any generalizations about the spatial ecology of this species, except to note that this animal utilizes relatively large lengths of riparian habitat along streams. A single animal occupies around half a kilometer of river or stream, and there is no evidence to suggest that animals have overlapping home ranges. Furthermore, all our tracked animals stayed within forested habitats, not moving out into agricultural landscapes. This means that long lengths of riparian habitat need to be protected to conserve a viable population of Nimba otter-shrews. Based on two radio-tracked individuals of the aquatic tenrec (*Limnogale mergulus* Major 1896), a semi-aquatic small mammal endemic to Madagascar and of similar size to the Nimba otter-shrew, mean nightly distances moved were 860 and 1067 m (Benstead et al. 2001), which is roughly double that of the Nimba otter-shrew. The slightly smaller Pyrenean desman [*Galemys pyrenaicus* (E. Geoffroy St. Hilaire 1811)], a semi-aquatic small mammal endemic to Europe, has linear home ranges along streams typically ranging from 350 to 670 m (Melero et al. 2012), which is similar to that of the Nimba otter-shrew.

Based on the Maxent model, we recommend further surveys of this species in northern Liberia. In particular, the North Lorma National Forest, situated near the town of Luyema, and the nearby Wonegizi range are worth investigating for the presence of this species. This area has been surveyed before (Koopman et al. 1995, Hoke et al. 2007); however, these surveys were primarily or exclusively for bats and the Nimba otter-shrew may have been easily overlooked or was not targeted with specialized aquatic traps. In parallel with trapping studies, we suggest interviewing local farmers and fishermen, as this species is well known by local communities where it occurs (Decher et al. 2016). Interestingly, the Maxent model does not include the southernmost locality at Putu, Liberia (see Figure 4). We do not know the reasons for this, but we suggest that this supports the contention that Putu is an isolated outlying population with potentially no suitable habitat connecting it to Mount Nimba. However, this contention should be supported by additional field surveys in the Putu region. This also highlights the limitations of a niche modeling approach, a subject that has received much attention (Elith et al. 2011, Merow et al. 2013). However, we note that the choice of explanatory variables entered into the Maxent model will obviously be of paramount importance. We suggest that by incorporating forest and stream covers (two important habitat features of the Nimba otter-shrew), future studies may be able to obtain more accurate models. In addition, we suggest that future studies investigate the ecology of its prey which includes crabs, invertebrates and frogs (Vogel 2013b), as this could possibly explain the close association between the Nimba otter-shrew and hilly or mountainous terrain.

In conclusion, our study has clarified the EOO of this range-restricted and threatened species, and shown that mining negatively impacts on its persistence along forested mountain rivers and streams. We suggest that the Nimba otter-shrew is an important near-endemic to Mount Nimba that requires urgent conservation attention to ensure its long-term persistence. Furthermore, this study corroborates the view that small mammals are neglected by researchers and conservationists although they may face the threat of extinction.

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