

## Description of four new West African forest geckos of the *Hemidactylus fasciatus* Gray, 1842 complex, revealed by coalescent species delimitation

Philipp Wagner<sup>1\*</sup>, Adam D. Leaché<sup>2</sup> & Matthew K. Fujita<sup>3</sup>

<sup>1</sup>Department of Biology, Villanova University, 800 Lancaster Avenue, Villanova, Pennsylvania 19085, USA and Zoologisches Forschungsmuseum A. Koenig, Adenauerallee 160, D53113 Bonn, Germany.

<sup>2</sup>Department of Biology & Burke Museum of Natural History and Culture, University of Washington, Seattle, WA 98195, USA.

<sup>3</sup>Department of Biology, University of Texas at Arlington, 501 S. Nedderman Drive, Box 19498, Arlington, TX 76019-0498, USA.

\*Corresponding Author

**Abstract.** The gecko *Hemidactylus fasciatus* is widespread in rainforest regions of equatorial Africa, from Guinea to Cameroon. Recently, this taxon was identified as a cryptic complex of at least five species, using multilocus genetic data and coalescent models for species delimitation. Here, we provide the formal descriptions of four new species from tropical West and Central Africa. As typical for cryptic species, the new species are genetically distinct, but difficult to distinguish using external morphology. However, coloration, shape of the body crossbands, and body size, are important distinguishing characters for this complex. We provide a new taxonomy for this complex that includes the following forest gecko species: *H. fasciatus* is now restricted to West Africa occurring eastwards to the Dahomey Gap, *H. kyaboboensis* sp. n. is known only from within the Dahomey Gap, *H. eniangii* sp. n. is distributed from the Dahomey Gap to western Cameroon, *H. coalescens* sp. n. occurs from central Cameroon to southern Gabon, *H. biokoensis* sp. n. is restricted to Bioko Island, and *H. ituriensis*, herein recognized as full species, is known from several localities in eastern Africa.

**Key words.** Africa, rainforest, Sauria, Gekkonidae, *Hemidactylus fasciatus* complex, *Hemidactylus ituriensis*.

### INTRODUCTION

An accurate inventory of species diversity forms the foundations for scientific inquiries in biogeography, phylogeography, ecology, conservation, and comparative biology. However, a fundamental problem is that a large proportion of species remain scientifically undocumented, especially those that are not easily distinguishable based on casual examinations of external morphology or coloration. Bickford et al. (2006) defined cryptic species as two or more species that have been recognized as a single nominal species, because they are at least superficially indistinguishable based on external morphology. The uncovering of cryptic species is important for accurate species inventory, and for providing new opportunities to study mechanisms of speciation, biogeography, mate recognition, and conservation management (Bickford et al. 2006). Molecular data and coalescent theory provide useful tools for species delimitation in cryptic species assemblages (Fujita et al. 2012).

The speciation history of *Hemidactylus fasciatus* Gray, 1842 was recently investigated by Leaché and Fujita (2010) using five nuclear loci, and by Leaché et al. (2014) using single nucleotide polymorphism (SNP) data from over 1,000 loci. Both studies used coalescent-based species delimitation methods to statistically test alternative species delimitation models. The species diversity in

*H. fasciatus* was found to be underestimated in both studies, and revealed four new genetically distinct species. Details on the methods are presented by Leaché & Fujita (2010) and Leaché et al. (2014). Bauer et al (2011) identified insufficiencies in the diagnoses according to the International Code of Zoological Nomenclature (ICZN 1999, subsequently named ‘the code’), and argued that the names proposed by Leaché and Fujita (2010) were *nomen nuda*. Here, we follow the recommendations of Bauer et al. (2011) and Fujita & Leaché (2011), and provide formal descriptions for these new species of African forest geckos that meet the criteria of the code (ICZN 1999).

The distributions of the proposed species match the contemporary major blocks of rainforests in equatorial Africa (Wagner et al. 2008; Wagner et al. 2009), suggesting that allopatric divergence, as a result of habitat fragmentation, can explain the formation of these lineages (Leaché & Fujita 2010; Wagner et al. 2009; Wagner 2010; Leaché et al. 2014).

### SPECIES ACCOUNT

The *Hemidactylus fasciatus* species group is distinct by its characteristic coloration to all other African *Hemidactylus*



**Fig. 1.** [A] Living specimen of *Hemidactylus fasciatus* (not collected) from Liberia; [B] Living specimen of *Hemidactylus kyaboboensis* sp. n. from the type locality.

*lus* species, and is therefore not compared to them in the present study.

Specimens, including type specimens, from the following institutions were examined for the present study: Academy of Natural Sciences at Drexel University (ANSP), Philadelphia, PA, USA. American Museum of Natural His-

tory (AMNH), New York, NY, USA. Natural History Museum (BMNH), England, UK. California Academy of Sciences (CAS), San Francisco, CA, USA. Museum of Vertebrate Zoology (MVZ), Berkeley, CA, USA. Zoologisches Forschungsmuseum Alexander Koenig (ZFMK), Bonn, Germany.

***Hemidactylus fasciatus* Gray, 1842**

1842 *Hemidactylus fasciatus* Gray, Description of some new species of Reptiles, chiefly from the British Museum collection. The Zoological Miscellany: 57–59.

1845 *Leiurus ornatus* Gray (*vide* Loveridge 1947), Catalogue of the specimens of lizards in the collection of the British Museum. Trustees of the British Museum/Edward Newman, London: xxvii + 289 pp. [Holotype in BMNH, from “W. Africa”].

1857 *Hemidactylus formosus* Hallowell, (*vide* Loveridge 1947) Notes on the reptiles in the collection of the museum of the Academy of Natural Sciences. Proc. Acad. Nat. Sci. Philadelphia, 8 (4): 146–153 [Syntypes: ANSP 7451-53; Liberia].

*Holotype*. BMNH XXI.24.a, from an unknown locality (*vide* Gray 1842).

*Description*. A fairly large species of *Hemidactylus*, with a maximum SVL of 95 mm, and a maximum total length of 172 mm. Like in the other species of the group, the body and limbs are moderate; the snout is slightly longer than the distance between the eye and the ear opening, the ear-opening is suboval and oblique; the upper surface of the body is covered with small granules, which are intermixed with small, round, and convex tubercle scales, forming more than 20 less regular longitudinal rows; digits are distinctly webbed at the base, and have six to eight lamellae under the inner digits, and nine to ten under the median ones. Like other species of the group, excluding *H. ituriensis*, it is morphologically characterized by a long row of femoral pores in males, which are interrupted in the middle, resulting in a high number of femoral pores (16–20, vs. 8 in *H. ituriensis*) on each side. In coloration it is distinct from its close relative *H. kyaboboensis* sp. n., by lacking the various pale tubercle spots and the broad pale framing of the dark body crossbands, and by having the dark body crossbands more distinct to the pale interspaces (see Fig. 1). It is distinct from other species of the group by having a broad dark band between the eyes and the neck (vs. a narrow stripe in *H. coalescens* sp. n. and vs. lacking in *H. ituriensis*), and by having a pale upper lip (vs. dark in *H. eniangii* sp. n.).

*Distribution*. We herein recognize the distribution of *H. fasciatus* as restricted to the Guinean rainforest system west of the Dahomey Gap. Therefore, it is known from localities in Guinea, Liberia, Côte d’Ivoire, and Ghana.

*Relationships*. Genetic data was presented by Leaché & Fujita (2010), who showed that this species includes all populations that cluster with those from the western Guinean rainforest with strong support in the Bayesian species delimitation model. This species is closely relat-

ed to the other West African species described herein (*H. kyaboboensis* sp. n.), which is so far only known from forests within the Dahomey Gap.

***Hemidactylus kyaboboensis* sp. n.**

2010 *Hemidactylus kyaboboensis* Leaché & Fujita (nom. nud. *vide* Bauer et al. 2010), Bayesian species delimitation in West African forest geckos (*Hemidactylus fasciatus*). Proc Roy Soc B 277: 3071–3077.

*Holotype*. MVZ 245291 (Fig. 2), adult male from Ghana, Volta Region, Togo Hills, Kyabobo National Park, Waterfall, 08.33019° N, 00.59411° E, 515 m, collected by Adam D. Leaché, Raul Diaz and Matthew K. Fujita on 16 June 2004.

*Paratypes*. MVZ 245292–245299, same data as the holotype. ZFMK 93689, subadult from Togo, Missahöhe [=Missahoe or Missahohé], near Kpalimé. ZFMK 19922, adult female from Faille de Bafilo [=fault proper near Bafilo (9.282399, 1.216621)], Togo.

*Diagnosis*. A large species of *Hemidactylus*, with a maximum SVL of 80 mm, and a maximum total length of 160 mm, a broad head (vs. slender in *H. coalescens*), and three enlarged internasal scales (vs. two in *H. eniangii*). Characteristic is the dorsal scalation of irregular arranged smooth and convex tubercle scales, each circumdated by a ring of small granular scales. In coloration, it is unique by having indistinct dark body crossbands, and more prominent whitish stripes and dots. This new species is distinct in coloration in detail to *H. fasciatus* by having a band on the side of the head as broad as the crossband on the neck, and reaching the lower tip of the ear hole (vs. not reaching the lower tip). It is distinct from *H. coalescens* by having the broad band on the side of the head (extension of the crossband on the neck) as broad as the band on the neck (vs. a crossband on the neck becoming a narrow stripe on the side of the head); by having the last indistinct body crossband in contact with the hindlimbs (vs. a distinct crossband not in contact); by having the first indistinct body crossband reaching the head skull (vs. a distinct first body crossband restricted to the neck). It is distinct from *H. eniangii* by having a band on the side of the head as broad as the crossband on the neck (vs. a crossband becoming narrower on the side of the head).

*Description of the holotype*. Habitus stout, head elongated. SVL length 79.2 mm, tail length 77.4 mm (posterior 60 % regenerated). Snout elongate, distance from anterior margin of the tympanum to hind margin of the eye 4.6 mm, from anterior margin of the eye to tip of snout 9.3 mm; eye diameter 4.5 mm. Rostral broad, with a notch on



Fig. 2. The holotype of (MVZ 245291) *Hemidactylus kyaboboensis* sp. n.

its anterior midline, which continues as a vertical suture, but does not separate the rostral scale. Nostril bordered by the rostral, the 1<sup>st</sup> labial and two to three postnasal scales, three enlarged internasal scales present. Granular scales on the snout small, smooth and convex, larger as the scales on top of the head of the frontal and parietal region. Head scales become intermixed with tubercle scales at the posterior part of the neck. Temple covered with convex scales, with only few intermixed enlarged tubercle scales. Mouthline straight, but uplifted at its hindpart. Supralabials (left/right) 10/12, sublabials 10/10. Mental scale triangular, followed by a single pair of postmental scales. Gulars small, smooth, passing posteriorly gradually into the rhombic shaped, imbricate and smooth chest and belly scales. The convex and smooth dorsal tubercles are arranged irregularly, and are circumdated by a ring of granular scales. There is no or only one row of granular scales between these rings. Limbs covered with coarse granular scales, and intermixed with flat and smooth larger tubercle scales. Palmar scales smooth. All fingers and toes with distinct claws and with divided adhesive lamellae beneath, except the terminal subdigital scales, which are undivided like the basal ones.

*Coloration in preservation.* Upper side uniform grey, with darker crossbands from neck to tail. One band on the neck, three between the limbs with the middle band broken into two smaller bands, one on the tail base and two on the unregenerated portion of the tail. Tubercle scale pale whitish possessing a spotted pattern. Underside uniform dirty white.

*Distribution.* This species is distributed in the Togo Hills in Ghana, and in the forests of Missahöhe in Togo.

*Habitat.* At Togo Hills, specimens were collected in moist semi-deciduous rainforest, while the specimen at Missahöhe was found in an old stone building within moist semi-deciduous rainforest.

*Relationships.* This species includes all populations that cluster with those presented by Leaché & Fujita (2010) from the Togo Hills with strong support in the Bayesian species delimitation model. It is the sister taxon of *H. fasciatus* from the Guinean rainforest system in West Africa (Leaché & Fujita 2010; Leaché et al., 2014).

*Etymology.* This species is named after its type locality, the Kyabobo National Park, Togo Hills, Volta Region, Ghana.

### *Hemidactylus eniangii* sp. n.

2010 *Hemidactylus eniangii* Leaché & Fujita (nom. nud. *vide* Bauer et al. 2010), Bayesian species delimitation in West African forest geckos (*Hemidactylus fasciatus*). Proc Roy Soc B 277: 3071–3077.

*Holotype.* MVZ 253215 (Fig. 3), adult male from Nigeria, Cross River State, Cross River National Park, Oban Hills Sector, Southern Portion, Erokut Park entry gate, 05.3639° N, 08.43341° E, 143 m, collected by Adam D. Leaché, Anne M. Leaché, and Edem A. Eniang on 6 April 2006.

*Paratypes.* MVZ 253213, 253214, same data as the holotype.

*Diagnosis.* A medium sized species of *Hemidactylus*, with a maximum SVL of 60 mm, a maximum total length of about 140 mm, and a broad head (vs. slender in *H. coalescens* sp. n.). Characteristic is the dorsal scalation of irregular arranged smooth and convex tubercle scales, each encircled by a ring of small granular scales, and having two enlarged internasal scales (vs. three in all other species). In coloration, it is distinct from *H. fasciatus* by having a dark upper lip (vs. a pale one), and in having the band on the side of the head narrower than the crossband on the neck (vs. as broad as the crossband); from *H. coalescens* sp. n. by having the last body crossband in contact with the hindlimbs (vs. not in contact), having the first body crossband starting on the hind part of the head skull (vs. restricted to the neck), and by having a narrow band (vs. a stripe as extension of the neck crossband on the side of the head); and from *H. kyaboboensis* sp. n. by having distinct body crossbands (vs. indistinct bands) and stripes, and by having the extension band on the side of the head narrower than the crossband on the neck (vs. as broad as the crossband).

*Description of the holotype.* Habitus stout, head elongated. SVL length 61.5 mm, tail length 71 mm (posterior 20 % regenerated). Snout elongate, distance from anterior margin of the tympanum to hindmost margin of the eye 4.8 mm, from anterior margin of the eye to tip of snout 6.7 mm; eye diameter 3.7 mm. Rostral broad, with a notch on its anterior midline which continues as a vertical suture but does not separate the rostral scale. Nostril bordered by the rostral, the 1<sup>st</sup> labial and two to three postnasal scales, two enlarged internasal scales present. Granular scales on the snout small, smooth and convex, larger as the scales on top of the head of the frontal and parietal region. Head scales become intermixed with tuber-



Fig. 3. The holotype (MVZ 253215) of *Hemidactylus eniangii* sp. n.

cle scales at the posterior part of the neck. Temple covered with convex scales, with only few intermixed enlarged tubercle scales. Mouthline straight, but uplifted at its hindpart. Supralabials (left/right) 12/12, sublabials 10/10. Mental scale triangular, followed by a single pair of postmental scales. Gulars small, smooth, passing posteriorly gradually into the rhombic shaped, imbricate and smooth chest and belly scales. The convex and smooth dorsal tubercles are arranged irregularly, and are encircled by a ring of granular scales. There is no or only one row of granular scales between these rings. Limbs covered with coarse granular scales and intermixed with flat and smooth larger tubercle scales. Palmar scales smooth. All fingers and toes with distinct claws and with divided adhesive lamellae beneath, except the terminal subdigital scales which are undivided like the basal ones.

*Coloration in preservation.* Upper side uniform grey, with darker crossbands from neck to tail. One band on the neck, three between the limbs, one on the tail base and three on the unregenerated portion of the tail. Tubercle scale pale whitish possessing a spotted pattern. Underside uniform dirty white.

*Distribution.* This species is distributed in the northern portion of the Congolian rainforest north of the Sanaga River, including northern Cameroon, and Nigeria.

*Habitat.* This is a nocturnal species. Mertens (1938) mentioned the gecko as very common in rainforests of lower elevations (400–550m) at Mount Cameroon, but also found one specimen in a small hut outside the forest.

*Relationships.* This species includes all populations that cluster with those presented by Leaché & Fujita (2010) from the northern portion of the Congolian rainforest (eastern Nigeria and northern Cameroon) with strong support in the Bayesian species delimitation model. The SNP loci used by Leaché et al. (2014) provide strong support placing this taxon sister to *H. coalescens* sp. n. and *H. biokoensis* sp. n. This topology contradicts the Leaché and Fujita (2010) study, which suggests a close relationship between *H. eniangii* sp. n. and *H. biokoensis* sp. n.

*Etymology.* This species is named in honor of the Nigerian conservation biologist and herpetologist Dr. Edem A. Eniang for his studies on the Nigerian herpetofauna.

### ***Hemidactylus coalescens* sp. n.**

2010 *Hemidactylus coalescens* Leaché & Fujita (nom. nud. *vide* Bauer et al. 2010), Bayesian species delimitation in West African forest geckos (*Hemidactylus fasciatus*). Proc Roy Soc B 277: 3071–3077.

*Holotype.* ZFMK 87679 (Fig. 4), adult male from Cameroon, Campo Region, Nkoelon, 2.3972° N, 10.04515° E, 85 m, collected by Michael F. Barej and Julia Wurstner on 27 October 2007.

*Paratypes.* ZFMK 87680–82, same data as the holotype.

*Diagnosis.* A medium sized species of *Hemidactylus*, with a max. SVL of 78 mm, a maximum total length of 174 mm, a more elongated head than the other species of the *H. fasciatus* group, and three enlarged internasal scales present in most specimens. It is unique in coloration by possessing body crossbands which are more narrow than the pale interspaces; the interspaces contain indistinct dark bands which are not connected at the vertebrate; by having the first body crossband restricted to the neck (vs. reaching the cranium as in the other species); by having the last crossband on the body between the legs not in contact with the hindlimbs (vs. in contact); and by having a distinctly fine narrow dark stripe on the side of the head between eye and ear, as the extension of the crossband on the neck (vs. a band slightly narrower or as broad as the crossband in the other species).

*Description of the holotype.* Habitus stout, head elongated. SVL length 59.2 mm, tail length 76.2 mm. Snout elongate, distance from anterior margin of the tympanum to hindmargin of the eye 4.6 mm, from anterior margin of the eye to tip of snout 5.4 mm; eye diameter 3.3 mm. Rostral broad, with a notch on its anterior midline which continues as a vertical suture but does not separate the rostral scale. Nostril bordered by the rostral, the 1<sup>st</sup> labial and two to three postnasal scales, three enlarged internasal scales present. Granular scales on the snout small, smooth and convex, larger as the scales on top of the head of the frontal and parietal region. Head scales become intermixed with tubercle scales at the posterior part of the neck. Temple covered with convex scales, with only few intermixed enlarged tubercle scales. Mouthline straight, but uplifted at its hindpart. Supralabials (left/right) 12/12, sublabials 10/10. Mental scale triangular, followed by a single pair of postmental scales. Gulars small, smooth, passing posteriorly gradually into the rhombic shaped, imbricate and smooth chest and belly scales. The convex and smooth dorsal tubercles are arranged irregularly and are encircled by a ring of granular scales. There is no or only one row of granular scales between these rings. Limbs covered with coarse granular scales and intermixed with flat and smooth larger tubercle scales. Palmar scales smooth. All fingers and toes with distinct claws and with divided adhesive lamellae beneath, except the terminal subdigital scales which are undivided like the basal ones.

*Coloration in preservation.* Upper side uniform light brownish, with darker crossbands from neck to tail tip.



Fig. 4. The holotype (ZFMK 87679) of *Hemidactylus coalescens* sp. n.



One band on the neck, three between the limbs, one on the tail base and six on the tail. Tubercle scale pale whitish possessing a spotted pattern. Underside uniform dirty white.

*Distribution.* This species is distributed in the southern portion of the Congolian rainforest south of the Sanaga River, including southern Cameroon, Gabon and Congo.

*Relationships.* This species includes all populations that cluster with those from the southern portion of the Congolian rainforest (southern Cameroon, Gabon and Congo) presented by Leaché & Fujita (2010), with strong support in the Bayesian species delimitation model. The SNP loci used by Leaché et al. (2014) provide strong support placing this taxon in a clade with *H. biokoensis* sp. n.

*Etymology.* This species is named after the coalescent process used to delimit the species.

#### ***Hemidactylus biokoensis* sp. n.**

*Holotype.* ZFMK 9342 (Fig. 5), adult female from Ureca on Bioko Island, Equatorial Guinea, collected by Martin Eisentraut between 17.–30. January 1963.

*Paratypes.* CAS 207624, Equatorial Guinea, Bioko Island, near Malabo (03° 42' 39.8" N, 08° 39' 59.9" E), collected by L.G. Henwood and J.V. Vindum on 18 October 1998; CAS 207663-4, Equatorial Guinea, Bioko Island, road S of Luba (03° 28' 06.1" N, 08° 29' 34.2" E), collected by L.G. Henwood and J.V. Vindum on 14 October 1998; CAS 207777-8, Equatorial Guinea, Bioko island, ca 3.6 km N (by road) of Luba (03° 28' 58.9" N, 08° 34' 55.2" E); ZFMK 9339-49, same data as the holotype.

*Diagnosis.* A medium sized, broad headed species of *Hemidactylus*, with a maximum SVL of 80.6 mm and a maximum total length of 166.7 mm. It is overall similar to *H. coalescens* sp. n. in its morphological characters. Characteristic is the dorsal scalation of pale, smooth and convex tubercle scales irregularly arranged in longitudinal rows, and distinct to the dark body crossbands in coloration and the dark bands on the lower side of the tail. In coloration, it is distinct from *H. fasciatus* by having pale dots on the dark body crossbands (vs. uniform dark crossbands), and by lacking fine, dark stripes within the interspaces between the crossbands, and by having the interspaces slightly broader than the crossbands (vs. crossbands slightly broader than the interspaces); it is distinct from *H. kyaboboensis* sp. n. by having distinct body crossbands (vs. indistinct bands and stripes), and by having the extension band on the dorsolateral side of the head narrow-

er than the crossband on the neck (vs. as broad as the crossband); it is distinct from *H. eniangii* sp. n. by having the upper lip dirty white (vs. brownish), and by having the first body crossband broader at the median of the neck than on the lateral parts of the neck (vs. broader on the lateral sides); it is distinct from *H. coalescens* sp. n. by having the band between eye and neck as broad as the crossband on the neck and half the size of the eye height (vs. having a narrow stripe a quarter the size of the eye height), by having the interspaces slightly broader than the crossbands (vs. distinctly broader than the crossbands), by lacking the dark stripe in the center of each interspace between the limbs which is present in *H. coalescens* sp. n., and by having the first body crossband starting on the hind part of the head skull (vs. restricted to the neck); and it is distinct to *H. ituriensis* by having a dark band as extension of the neck crossband between the eye and the neck (vs. lacking this band), by having interspaces which are slightly broader than the body crossbands (vs. body crossbands which are distinctly broader than the interspaces), and by having body crossbands with a median notching (vs. without it).

*Description of the holotype.* Habitus stout, head elongated. SVL length 66.4 mm, tail length 79.9 mm. Snout elongate, distance from anterior margin of the tympanum to hind margin of the eye 5.5 mm, from anterior margin of the eye to tip of snout 7.6 mm; eye diameter 4.5 mm. Rostral broad, with a notch on its anterior midline which continues as a vertical suture but does not separate the rostral scale. Nostril bordered by the rostral, one small and one elongated postnasal scale, in contact with the internasal at its upper tip and with the 1<sup>st</sup> labial scale on its lower tip, three enlarged internasal scales present. Granular scales on the snout small, smooth and strongly convex, larger as the scales on top of the head of the frontal and parietal region. Head scales become intermixed with tubercle scales just behind the eyes. Temple covered with convex scales, with only few intermixed enlarged tubercle scales. Mouthline straight, but uplifted at its hindpart. Supralabials (left/right) 9/10, sublabials 9/9. Mental scale triangular, followed by a single pair of postmental scales. Gulars small, smooth, passing posteriorly gradually into the rhombic shaped, imbricate and smooth chest and belly scales. Dorsal tubercle scales numerous, convex and smooth, arranged in irregular longitudinal rows and circumdated by a ring of granular scales. No or only one row of granular scales between these rings on the upper side of the body. Limbs covered with coarse granular scales, and intermixed with flat and smooth larger tubercle scales. Palmar scales smooth. All fingers and toes with distinct claws and with divided adhesive lamellae beneath, except the terminal subdigital scales which are undivided.

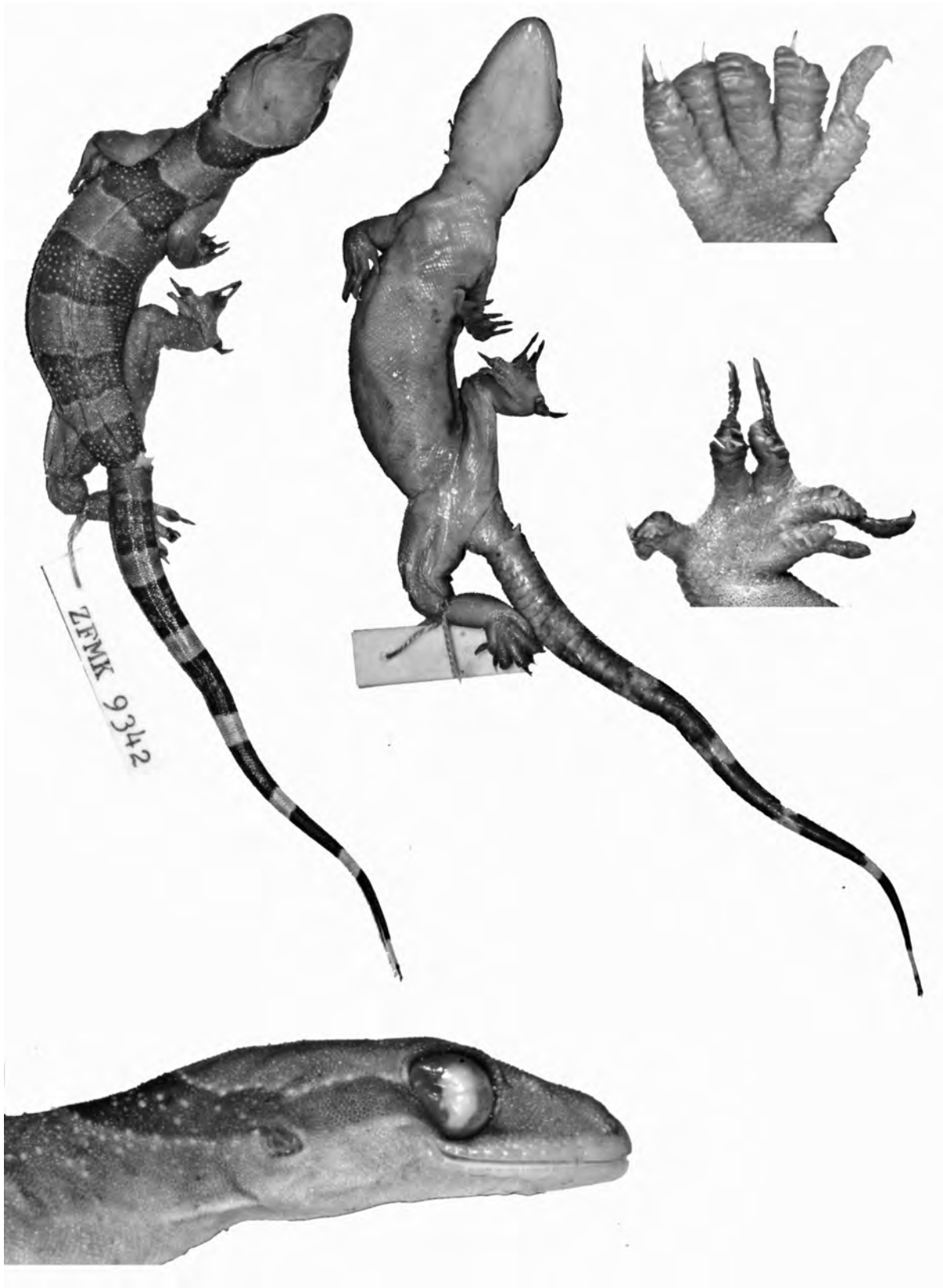
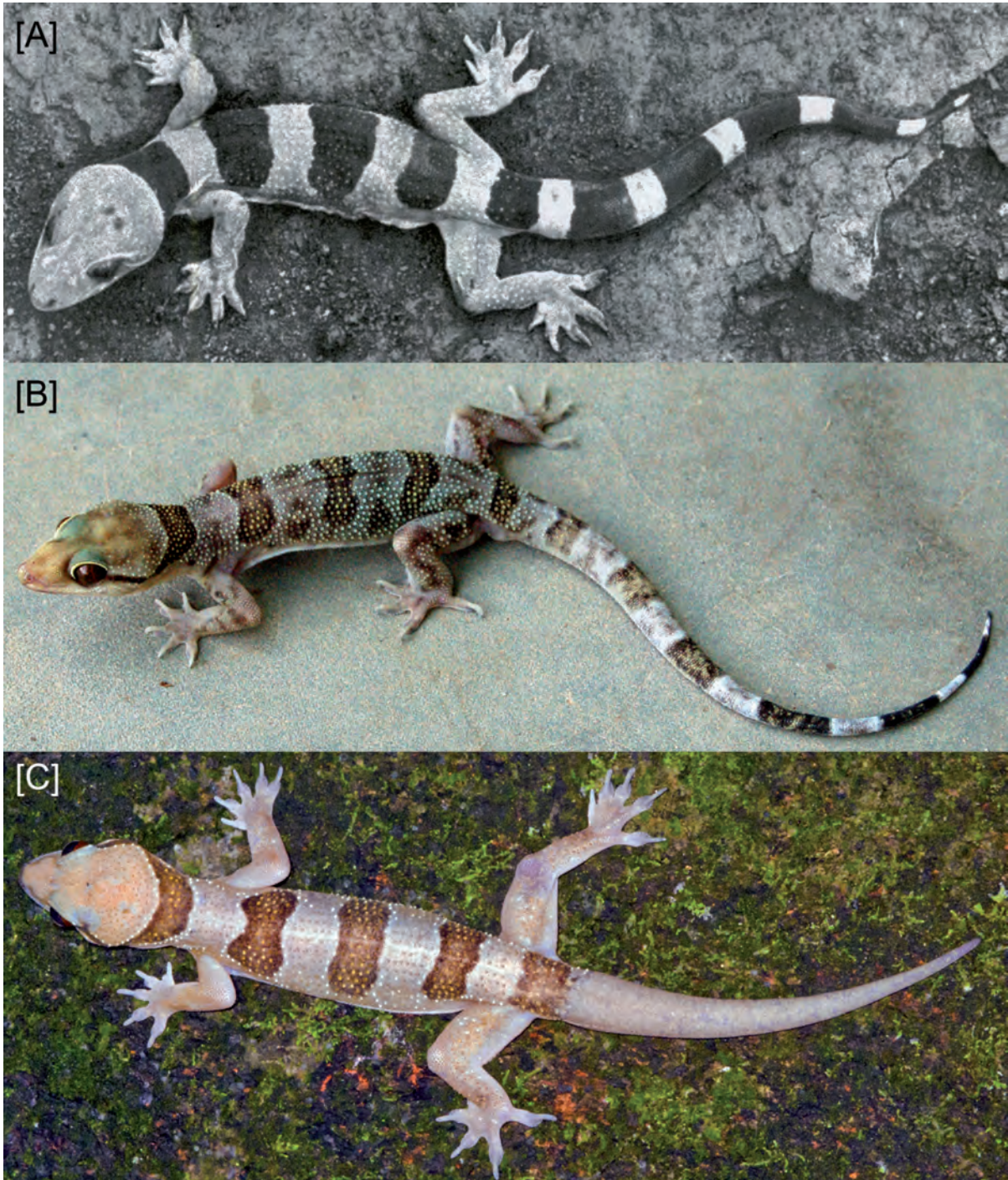


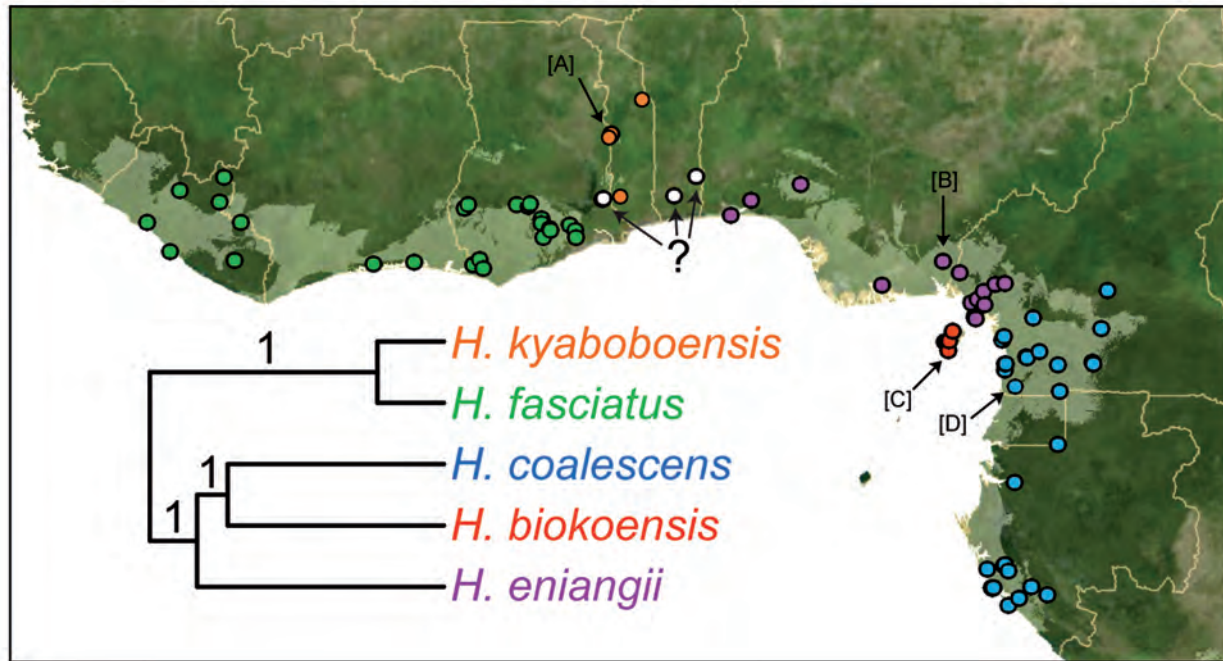
Fig. 5. The holotype (ZFMK 9342) of *Hemidactylus biokoensis* sp. n.



**Fig. 6.** [A] Living specimen of *Hemidactylus ituriensis* (AMNH 10273) from Akenge (obtained from Schmidt 1919, plate XVI); [B] living specimen of *Hemidactylus coalescens* sp. n. (ZFMK 87679, holotype) from the type locality; and [C] uncollected living specimen of *Hemidactylus biokoensis* from Bioko Island (Reserva científica de la Caldera de San Carlos, 3°14'2.39"N, 8°37'38.60"E.).

*Coloration in preservation.* Upper lip white. Upper side of the body uniform grey, with darker, white framed, crossbands from neck to tail. One band on the neck, three between the limbs, one on the tail base and seven on the tail.

Tubercle scale pale whitish possessing a spotted pattern. Underside uniform dirty white, except the tail where the crossbands are also obvious on the lower side.



**Fig. 7.** Species tree for the *Hemidactylus fasciatus* species group based on a coalescent-based Bayesian analysis of 1,087 single nucleotide polymorphisms (Leaché et al. 2014). Posterior probabilities are shown on branches. Museum specimen records were downloaded from the HerpNet database, and geographic distribution was predicted using Maxent. Populations with uncertain taxonomic placement are indicated with “?”. Type localities are: [A]= *H. kyaboboensis* sp. n.; [B]= *H. eniangii* sp. n.; [C]= *H. biokoensis* sp. n.; and [D]= *H. coalescens* sp. n.

**Distribution.** Endemic to Bioko Island (former Fernando Poo, Equatorial Guinea) and only known from some localities on the island like e.g., Luba, Malabo, San Carlos, and Ureca.

**Habitat.** Only known from coastal areas on Bioko Island where it does not avoid cultural areas (Mertens 1964). Within the Reserva científica de la Caldera de San Carlos is was found in a forest almost immediately adjacent to the beach.

**Relationships.** This species includes all populations that cluster with those from the Bioko Island with strong support in the Bayesian species delimitation model (Leaché and Fujita, 2010). It is the sister species to *H. coalescens*, which together form the sister group to *H. eniangii* sp. n. (Leaché et al. 2014).

**Etymology.** This species is named after Bioko Island, Equatorial Guinea, where it is endemic.

### ***Hemidactylus ituriensis* Schmidt, 1919**

1919 *Hemidactylus fasciatus ituriensis* Schmidt, Contributions to the Herpetology of the Belgian Congo based on the Collection of the American Congo Expedition,

1909–1915. Part I: turtles, crocodiles, lizards, and chamaeleons. Bull Amer Mus Nat Hist 39 (2): 385-624

**Holotype.** AMNH 10272, from “Avakubi,” Democratic Republic of the Congo.

**Description.** A fairly large species of *Hemidactylus* with a maximum SVL of 89mm and a maximum total length of 162mm. The species is morphologically characterized by a high number of subdigital lamellae (9–11 on 4<sup>th</sup> finger; 11–13 on 4<sup>th</sup> toe); by having the enlarged subcaudal scales about one-third of the tail width; and by having a low number of femoral pores in males (8 vs. 16–20 in the West African species). In coloration the species is distinct from all other taxa of the *H. fasciatus* group by lacking the sharply defined band between neck and eye on the side of the head and by having the body crossbands, which are wider than the interspaces, without a median notching (see Fig. 6).

**Distribution.** The species is recently only known from northeastern parts of the DR Congo. Wagner (2010) suggests a wider distribution along the Albertine Rift and probably eastwards to Uganda and probably Kenya, similar to the distribution pattern of forest species in this area (Wagner et al. 2008, 2009).

*Relationships.* So far genetic information of this taxon are lacking, but we expect, due to morphological characters and the distribution pattern, a close, probably sister taxon, relationship to the clade including *H. eniangii* sp. n., *H. coalescens* sp. n., and *H. biokoensis* sp. n.

## DISCUSSION

Speciation in the *Hemidactylus fasciatus* species group (including *H. biokoensis* sp. n., *H. coalescens* sp. n., *H. eniangii* sp. n., *H. fasciatus*, and *H. kyaboboensis* sp. n.) illustrates some of the common patterns of geographic divergence observed across the reptile and amphibian forest fauna of West and Central Africa. The current levels of West African rainforest fragmentation are due to an expansion of dry forest and savannah into the rainforest blocks during the last glacial maximum of the Pleistocene (Hamilton & Taylor 1991). Within these different fragments, many species diverged in spatial separation (Wagner et al. 2008; Wagner et al. 2009; Wagner 2010). The Dahomey Gap, a stretch of dry savannah extending from central Ghana through western Nigeria (Salzmann & Hoelzmann 2005), separates many West and Central African forest species (e.g., *Amietophrynus superciliaris*, *Lepidothyris fernandi*). The formation of this arid barrier, which was frequently opened and closed over time (Salzmann & Hoelzmann 2005), corresponds with the initial divergence in the *H. fasciatus* species group (Fig. 7). The Togo Hills as well as nearby forests, like the Missahöhe, are situated within the Dahomey Gap. These mountainous areas contain moist semi-deciduous rainforests, which are isolated from the more expansive rainforest blocks to the west and east (Leaché et al. 2006, Wagner 2010). Therefore, these rainforest ‘islands’ harbor many specialists, including *H. kyaboboensis* sp. n., which were isolated over time from other populations. Likewise geographically isolated, *H. biokoensis* sp. n. is endemic to Bioko Island in the Gulf of Guinea, separated from the mainland by about 40 km and sea depths of less than 60 m. Bioko was probably connected to the mainland during the last glaciation (Lee et al. 1994). Finally, the Sanaga River in Cameroon appears the likely barrier, separating *H. eniangii* sp. n. from *H. coalescens* sp. n. However, fine-scale population sampling is necessary for investigating the geographic limits of these new species.

The taxonomy within the *H. fasciatus* species complex is hampered by the lack of a specific type locality in the original description of *H. fasciatus* by Gray (1842); the collection locality of the name bearing type (BMNH xxi.24.a) is also not given in the BMNH catalogue. The first available synonym of the species also has an unspecific type locality (*Leiurus ornatus* Gray, 1845 from “W. Africa”), but the second synonym is more specific (*Hemidactylus formosus* Hallowell, 1857 from “Liberia”). Fol-

lowing article 76 of the Code, the type locality is the collecting locality of the name bearing type, but despite recommendations set forth in 76A.1 of the Code, it is not possible to specify the type locality any further. However, following recommendation 76.A.1.4 of the Code, localities within the known range of the taxon can be used as the type locality, but without prejudice to other clarifications. Given that one of the synonyms of the species has a relatively specific type locality (Liberia), we restrict the distribution of *H. fasciatus* to the western Guinean rainforest system from Sierra Leone to the Dahomey Gap in Ghana, excluding the Togo Hills and other forests within the Dahomey Gap e.g. the nearby Missahöhe, which is not in conflict with the herein described new species. Following Leaché and Fujita (2010), *H. fasciatus* includes populations from the western and central Guinean rainforest (all west of the Dahomey Gap) and whose evolutionary history has been independent from other lineages.

Two other large-bodied, forest-dwelling taxa of *Hemidactylus* occur in equatorial Central Africa: *H. ituriensis* Schmidt, 1919 and *H. makolowodei* Bauer, LeBreton, Chirio, Ineich & Talla Kouete, 2006. However, the latter is clearly distinct from the *H. fasciatus* complex (Bauer et al. 2006), and although the phylogenetic relationships among these species are currently unknown, we predict that these large-bodied, forest-dwelling species of *Hemidactylus* are closely related to the *Hemidactylus fasciatus* complex. Schmidt (1919) considered the non-overlapping morphological characters (e.g., larger head, higher number of subdigital lamellae [10–10 vs. 12–12], enlarged subcaudals about one-third the width of the tail [vs. more than half of the width], lower number of femoral pores [8 vs. 16–20 on each side]) of *H. fasciatus* and *H. ituriensis* sufficient for species differentiation. Loveridge (1936) also regarded *H. ituriensis* as distinct from *H. fasciatus* at the species level, but later recognized the taxon *ituriensis* as a subspecies of *H. fasciatus* (Loveridge 1947). The characters reported by Schmidt (1919) are sufficient for recognizing *H. ituriensis* as a full species. Currently, the characters diagnosing the *H. fasciatus* group refer to color pattern, which was already used by Schmidt (1919) to distinguish *H. ituriensis*. An evaluation of other possible morphological characters including body proportions and scale counts is needed.

**Acknowledgements.** The authors are thankful to the Ghanaian Wildlife Division, the Nigerian Biodiversity Research Center, Conservation International, the Nature Conservation Research Center and IUCN for assistance with fieldwork. For the use of their images we are grateful to Jessica Weinberg (Bioko Biodiversity Protection Program) and Michael Barej. For useful comments we thank Michael Barej (ZMB) and two anonymous reviewers.

## REFERENCES

- Bauer AM, Parham JF, Brown RM, Stuart BL, Grismer L, Papenfuss TJ, Böhme W, Savage JM, Carranza S, Grismer JL, Wagner P, Ananjeva NB, Inger RB (2011) On the availability of new Bayesian-delimited gecko names and the importance of character-based species descriptions. *Proceedings of the Royal Society B: Biological Sciences* 278: 490–492
- Bauer AM, LeBreton M, Chirio L, Ineich I, Kouete MT (2006) New species of *Hemidactylus* (Squamata: Gekkonidae) from Cameroon. *African Journal of Herpetology* 55: 83–93
- Bickford D, Lohmann DJ, Sodhi NS, Ng PKL, Meier R, Winker K, Ingram KK, Das I (2006): Cryptic species as a window on diversity and conservation. *Trends in Ecology and Evolution* 22: 148–155
- Fujita MK, Leaché AD (2011) A coalescent perspective on delimiting and naming species: a reply to Bauer et al. *Proceedings of the Royal Society B: Biological Sciences* 278: 493–495
- Fujita MK, Leaché AD, Burbrink FT, McGuire JA, Moritz C (2012) Coalescent-based species delimitation in an integrative taxonomy. *Trends in Ecology and Evolution* DOI: 10.1016/j.tree.2012.04.012
- Gray JE (1842) Description of some new species of Reptiles, chiefly from the British Museum collection. *The Zoological Miscellany*: 57–59
- Hamilton AC, Taylor D (1991) History of climate and forests in tropical Africa during the last 8 million years. *Climatic Change* 19: 65–78
- ICZN [International Commission of Zoological Nomenclature] (1999) International Code of Zoological Nomenclature. International Trust for Zoological Nomenclature, 4<sup>th</sup> edition, 106 pp.
- Leaché AD, Fujita MK (2010) Bayesian species delimitation in West African forest geckos (*Hemidactylus fasciatus*). *Proceedings of the Royal Society B: Biological Sciences* 277: 3071–3077
- Leaché AD, Rödel MO, Linkem CW, Diaz RE, Hillers A, Fujita MK (2006) Biodiversity in a forest island: reptiles and amphibians of the West African Togo Hills. *Amphibian & Reptile Conservation* 41: 22–45
- Leaché AD, Fujita MK, Minin V, Bouckaert R. (2014) Species delimitation using genome-wide SNP data. *Systematic Biology*. doi:10.1093/sysbio/syu018
- Lee D-C, Halliday AN, Fittion JG, Poli G (1994) Isotopic variations with distance and time in the volcanic islands of the Cameroon line: evidence for a mantle plume origin. *Earth and Planetary Science Letters* 123:119–138
- Loveridge A (1936) African reptiles and amphibians in the Field Museum of Natural History. *Zoological Series of the Field Museum of Natural History* Chicago 22: 1–122
- Loveridge A (1947) Revision of the African lizards of the family Gekkonidae. *Bulletin of the Museum of Comparative Zoology* 98: 1–469
- Mertens R (1938) Herpetologische Ergebnisse einer Reise nach Kamerun. *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft* 442: 1–52
- Mertens R (1964) Die Reptilien von Fernando Poo. *Bonner zoologische Beiträge* 15: 211–238
- Salzmann U, Hoelzmann P (2005) The Dahomey gap: an abrupt climatically induced rain forest fragmentation in West Africa during the late Holocene. *Holocene* 15: 190–199
- Schmidt KP (1919) Contributions to the herpetology of the Belgian Congo based on the collection of the American Museum Congo Expedition 1909–1915. Part I. Turtles, crocodiles, lizards and chameleons. *Bulletin of the American Museum of Natural History* 39: 385–624
- Wagner P (2010) Diversity and distributions of African reptiles. Unpublished PhD-thesis, University of Bonn, 374 pp.
- Wagner P, Köhler J, Schmitz A, Böhme W. (2008) The biogeographical assignment of a west Kenyan rain forest remnant: further evidence from analysis of its reptile fauna. *Journal of Biogeography* 35: 1349–1361
- Wagner P, Schmitz A, Pauwels OSG, Böhme W (2009) A review of the African red-flanked skinks of the *Lygosoma fernandi* (Burton, 1836) species group (Squamata: Scincidae) and the role of climate change in their speciation. *Zootaxa* 2050: 1–30
- Yang Z, Rannala B (2010) Bayesian species delimitation using multilocus sequence data. *Proceedings of the National Academy of Sciences, USA* 107: 9264–9269

## APPENDIX

## Material examined

*Hemidactylus biokoensis* sp. n. Equatorial Guinea. CAS 207624, 207663-4, 207777-8 from Bioko Island; ZFMK 9339-49 from Bioko Island (Ureca); ZFMK 9350-52 from Bioko Island (San Carlos).

*Hemidactylus coalescens* sp. n. Cameroon. ZFMK 87679-82 from Nkoelon. Gabon. ZFMK 73188 from Mokabane; ZFMK 20698 from Kama River. PR Congo. USNM FS246343 from Impfondo; ZFMK 65482 from between Oyo and Bokouélé.

*Hemidactylus entiangii* sp. n. Cameroon. AMNH 45332 from Koupé-Manengouba Division; ZFMK 59514 from MT Kupe; ZFMK 61356 from Mt. Yuhan; ZFMK 61398-99 from Bonjongo; ZFMK 69603 from Nyasoso; ZFMK 77893 from Ekomtolo. Nigeria. MVZ 253213-15 from Erokut Park entry gate, Cross River National Park.

*Hemidactylus fasciatus* BMNH XXI.24.a, from an unknown locality. BMNH (unknown) from “W. Africa” [holotype of *Leiurus ornatus* Gray, 1845]. Ghana. LSUMNS 86983, 87027, 87037 from Asumura; MVZ 252492-6 from Birim North District; MVZ 245300-7, 245437 from Ankasa National Park. Liberia. ANSP 7451-53 from Liberia [syntypes of *Hemidactylus formosus* Hallowell, 1857].

*Hemidactylus ituriensis* DR Congo. AMNH 10270 from Batama; AMNH 10271-72 from Avakubi; AMNH 10273 from Akenge; AMNH 10274 from Medje; AMNH 10275 from Panga.

*Hemidactylus kyaboboensis* sp.n. Ghana. MVZ 245291-7, 245299, 245436, 249695-704 from Kyabobo National Park. Togo. ZFMK 19922, from Faille de Bafilo [=fault proper near Bafilo (9.282399, 1.216621)]; ZFMK 93689, from Missahöhe, near Kpalimé.