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The anuran fauna of a West African urban area

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***Abstract.*—Reported are the results of an amphibian survey in the district of Daloa and surroundings, in central-western Ivory Coast. Spanning a three year period, we investigated two general areas, each during the rainy and dry seasons. During 62 days of field work 30 anuran species were recorded. The urban environment mainly contained widespread anuran species with preferences for savannah-dominated landscapes and farmbush habitats. The recorded total anuran species richness in the urban area exceeded the diversity in the savannah islands/forest mosaic bordering the Daloa district. This indicates many savannah species may do well in urban situations. However, this higher species richness was only due to one site that possessed particularly diverse amphibian breeding sites, thus illustrating the necessity of maintaining suitable habitats for a wide-range of species. One of the most surprising findings was *Kassina schioetzi*, a species usually difficult to find in its natural habitat. In Daloa it seems to have successfully adapted to the urban conditions. Although the anuran richness in the Daloa area was relatively low compared to other Ivorian humid savannah areas, it supported an important part of the countries amphibian diversity. Nevertheless the forest habitats, and specifically the forest islands bordering the Daloa district, should be considered sensitive conservation areas.**

Key words. Amphibians, conservation status, Côte d'Ivoire, Upper Guinea, urban ecology

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West Africa has been experiencing intensive urbanization to such a point that human modified landscapes are gradually taking over the majority of natural landscapes, in particular native forests (Deikumah and Kudom 2010; Bible 2013). Whereas various Ghanaian forests are protected and/or sustainably managed (Adum et al. 2013; Ofori-Boateng et al. 2013), only very few Ivorian forest remnants receive sufficient protection and sustainable management (e.g., see Mayaux et al. 2004). The Ivorian population has exploded over the past four decades, tripling from 6.7 million in the early 1970s to approximately 22 million people today (Bible 2013), has largely accelerated an urbanization process causing massive environmental damage. The gradual disruption of forests, has worsened in several forested areas of the Ivory Coast during the prolonged political crisis in the first decade of the 21st century, has mainly stemmed from increase land demand for agriculture and urbanization (Bible 2013; Hansen et al. 2013).

The Haut-Sassandra region is traditionally an important trading center, particularly for cocoa production in the Ivory Coast, has attracted 44.8% of national and 23.4% of foreign farmers (Assiri et al. 2009). During the country's 2010–2011 post election violence, Daloa, the third largest city of the country and the regional capital of the Haut-Sassandra region, became a refuge for people from the northern, central, and western Ivory Coast, resulting in a rapid urbanization process. As one result, forests surrounding the city are increasingly fragmented. To enhance the protection of biological diversity, the Ivorian Ministry of Scientific Research has therefore recently recommended the collection of scientific information to update the biodiversity data of the Haut-Sassandra region. As data for amphibians were still lacking, we sur-

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veyed the amphibian fauna within the district of Daloa and its surroundings, and herein report for the first time an assessment of the species richness and composition of the anuran fauna in a West African urban area.

Methods

Study area. Daloa is the third largest city in the Ivory Coast and the regional capital of the Haut-Sassandra region. It is situated in central-western Ivory Coast (06°53'01.8"–06°94'97.8" N; 006°25'65.3"–006°68′89.0" W), in the transition zone between semi-deciduous forest and humid Guinea savannah. The town is an important trading center, particularly for cocoa. The region has a mean annual temperature of 26.3 °C; the annual precipitation ranges from 1,200 to 1,700 mm. The climate includes a long rainy season (April to June) with the highest precipitation peak in June, a short dry season (July to August) alternating with a short rainy season (September to October), and a long dry season (November to March). The relative mean humidity is 75% (Eldin 1971).

Description of the survey areas (Fig. 1). Our definition of an urban area follows McDonnell and Pickett (1993) and Demographia (2008), i.e., taking into consideration a minimum density of 400 humans/km^2 and other factors such as density of buildings, roads and other infrastructure. We surveyed two general areas: 1) the district of Daloa (urban area), and 2) the savannah islands/forest mosaic bordering the Daloa district (non-urban aspect). Our surveys were covering a three year period (see Appendix 1 for further details). We investigated four sites inside the urban area namely: Balouzon (Bal: 45 ha), Eveché (Eve: 50 ha), Gbokora (Gbo: 80 ha), and Tazibouo (Taz: 100 ha). As a comparison, we surveyed Sapia (Sap: 150 ha) and Zaibo (Zai: 190 ha), two non-urban sites in the savannah islands/forest mosaic adjacent to urban Daloa (see Appendix 1). The Balouzon and Eveché areas were mainly characterized by unpaved roads, a swampy area used for vegetable cultivation, and a concentration of buildings. A large stream, bordered by coconut trees and grasses, was used for fishing activities. The vegetation in Gbokora was dominated by grasses and a semi-deciduous forest interspersed by a highway. Some swampy areas surveyed in this site were being used for vegetable cultivation. This area was noisy due to heavy traffic. A concentration of buildings and streetlights were characteristic of the Gbokora site. The Tazibouo site mainly consisted of unpaved roads, buildings, semi-deciduous forest adjacent the Daloa Jean Lorougnon Guédé University, and some construction sites. This site also comprised the Theological and Pastoral Institute of Daloa whose garden was dominated by bamboo, other grasses, and several stands of different or-

Fig. 1. Typical aspects of habitats of the urban Daloa; a = concentration of houses in a high population zone; b = degraded forest on the periphery of the urban area; c = highway crossing degraded forest and farmbush; d = amphibian breeding pond in the urban environment.

namental plants. Some water bodies, i.e., two large permanent ponds situated near a roadside and bordered by grasses, were encountered. The ponds served as a water point for cattle. A few termite mounds were also present. A swampy area investigated was used for rice and vegetable cultivations. Some parts of this area were lightened by streetlights at night. The sites Sapia and Zaibo, adjacent to the district of Daloa represented non-urban conditions. However, they had lost the majority of their natural forest cover, resulting in an overall change from a forest to a savannah-dominated landscape. Both sites mainly consisted of farmbush, small farms, coffee, and cocoa plantations. Some swamps that were part of these two sites had been converted to rice fields. Small forest islands were still encountered at Zaibo, but fewer forest islands were left at the Sapia site.

Field work, sampling effort and vouchers. Amphibians were mainly located opportunistically, during visual and acoustic surveys of all available habitats by NGK. Surveys were undertaken daily between 07:00–11:00 and 18:00–22:00 GMT over a total of 62 days (see Appendix 2) at all general survey areas. A hand-held GPS receiver (Garmin 12XL) was used to record the geographical positions of all study sites. The searching techniques used included acoustic surveying, visual scanning of terrain and refuge examination (e.g., lifting logs and rocks, peeling away barks, scraping through leaf litter, looking around or within burrows, and termite mounds). Amphibians encountered were not marked and repeated sightings thus cannot be excluded. As we only include presence/absence data and not abundances in our analyses this seem to be of negligible importance.

Below we comment only on a few species being remarkable concerning their distribution, taxonomy, biology or threats, or being particularly typical for the urban amphibian fauna. The nomenclature used herein follows the taxonomy by Frost (2015). After capture, frogs were identified to species level, measured, sexed, and if not kept as vouchers, released in their respective habitats. Snout-urostyle-length (SUL) was taken with a dial caliper (accuracy ± 0.5 mm). Records of *Xenopus muelleri* were based on visual observations only. For all other species we deposited vouchers at the Jean Lorougnon Guédé University, Daloa, Ivory Coast (see Appendix 3). Frog vouchers were euthanized humanly in a 1,1,1-Trichloro-2-methyl-2-propanol hemihydrate (MS222) solution and thereafter preserved in 70% ethanol.

Statistics. We used the daily species lists to calculate the sampling efficiency. We calculated the estimated species richness with the Chao2 and Jack-knife1 estimators (software: EstimateS, Colwell 2006). These estimators are incidence based, calculating with the presence/absence data of the daily species lists (62 days of survey work) for 30 anuran species. To avoid order effects we accomplished 500 random runs of the daily species lists. The Sørensen's Similarity Index (β) was used to determine the extent of similarity between the two main surveyed areas (herein the district of Daloa and the savannah islands/forest mosaic bordering the Daloa district; β may vary from 0 to 1 (Sørensen 1948; Wolda 1981).

Results

Species richness and faunal similarities

In total we recorded 30 anuran species (Table 1). Acoustics indicated more than one *Arthroleptis* species live in our area. So far, it is not possible to separate taxa from

Table 1. Anuran species recorded in the urban and non-urban areas of Daloa, with sites (see Appendices 1–3), general habitat preference and distribution range. S = savannah, FB = farmbush (degraded forest and farmland), F = forest, A = Africa (occur also outside West Africa), WA = West Africa (defined as the area west of the Cross River in Nigeria), UG = Upper Guinea (forest zone west of the Dahomey Gap), E = endemic to Ivory Coast and eastern Guinea, * = taxon comprise complex of several species, ** = records on this survey comprise several species (according to acoustics).

Family / Species	Site	Habitat			Distribution			
		S	FB	F	A	WA	UG	E
Arthroleptidae								
Arthroleptis spp.**	Bal, Eve, Gbo, Sap, Taz, Zai	—	X	X	—	—	X	(?)
Leptopelis spiritusnoctis	Zai		X	X	—	X	—	—
L. viridis	Bal, Eve, Gbo, Taz	X	—	—	X	—	—	—
Bufonidae								
Amietophrynus maculatus	Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
A. regularis	Taz	X	X	—	X	—	—	—
Dicroglossidae								
Hoplobatrachus occipitalis	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
Hemisotidae								
Hemisus marmoratus	Taz, Zai	X	X	—	X	—	—	—
Hyperoliidae								
Afrixalus dorsalis	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—

Table 1 (continued). Anuran species recorded in the urban and non-urban areas of Daloa, with sites (see Appendices 1–3), general habitat preference and distribution range. S = savannah, FB = farmbush (degraded forest and farmland), F = forest, A = Africa (occur also outside West Africa), WA = West Africa (defined as the area west of the Cross River in Nigeria), UG = Upper Guinea (forest zone west of the Dahomey Gap), E = endemic to Ivory Coast and eastern Guinea, * = taxon comprise complex of several species, ** = records on this survey comprise several species (according to acoustics).

Family / Species	Site	Habitat			Distribution			
Hyperoliidae (cont.)		S	FB	F	A	WA	UG	E
Hyperolius concolor concolor	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	—	—	X	—
H. fusciventris fusciventris	Sap		X	X	—	—	X	—
H. guttulatus	Zai	X	X	—	X	—	—	—
H. nitidulus	Bal, Eve, Gbo, Sap, Taz	X	—	—	—	X	—	—
H. picturatus	Gbo, Sap, Taz, Zai	—	X	X	—	—	X	—
H. sp.	Taz	—	X	X	—	—	X	—
Kassina schioetzi	Taz	X	X	—	—	—	X	—
K. senegalensis	Sap, Taz	X	—	—	X	—	—	—
Phrynobatrachidae								
*Phrynobatrachus calcaratus**	Sap	—	X	X	X	—	—	—
P. francisci	Bal, Taz	X	—	—	—	X	—	—
*P. gutturosus**	Sap, Taz, Zai	X	X	X	—	—	X	—
P. latifrons	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
Phrynomeridae								
Phrynomantis microps	Taz	X	—	—	X	—	—	—
Pipidae								
Xenopus muelleri	Taz	X	—	—	X	—	—	—
Ptychadenidae								
Ptychadena bibroni	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
*Ptychadena mascareniensis**	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
Ptychadena oxyrhynchus	Sap, Taz, Zai	X	X	—	X	—	—	—
Ptychadena tournieri	Sap, Taz	X	—	—	—	X	—	—
Ptychadena pumilio	Bal, Eve, Gbo, Sap, Taz, Zai	X	X	—	X	—	—	—
Ptychadena tellinii	Taz	X	—	—	X	—	—	—
Ranidae								
Amnirana albolabris	Sap, Zai	—	X	X	X	—	—	—
A. galamensis	Taz	X	—	—	X	—	—	—

the *Arthroleptis poecilonotus*-complex based on morphology. They can be distinguished by advertisement call and genetic characters. However, assigning populations, based on these characters, to available names (indistinguishable museum types without molecular data) is not possible (for a short review of the taxonomic situation in West African *Arthroleptis* spp. see Rödel and Bangoura 2004). We thus provisionally lumped all records of this genus as *Arthroleptis* spp. A list of recorded anurans with site records, known habitat preference and their distribution ranges is given in Table 1.

Based on the daily species lists we calculated our sampling efficiency. The Jack-knife 1 estimator calculated 33 anuran species, the Chao 2 estimator estimated 31 species for the study area. We hence recorded almost the entire (94% and 99%, respectively) estimated species richness. More than one fifth of the encountered species (seven spp., 23%; Table 1) depend on forest but tolerate farmbush habitats (degraded forest). Nine species (30%) are very closely associated with savannah habitats. Thirteen species (43%) exhibit a strong preference for savannah and farmbush habitats and are normally not found in forest. Four species (13%) do not occur outside West Africa [defined as the area west of the Cross River in Nigeria; see Penner et al. (2011)], and are often restricted to smaller parts of West Africa. Seven of all recorded species (23%) occur only in the Upper Guinea forest zone (forests west of the Dahomey Gap). The total number of species recorded in the district of Daloa was 25, while the species richness in the adjacent savannah/forest mosaic was 21. However, the high species number for Daloa was mainly due to one site (Tazibouo). When excluding this

Table 2. Sørensen's similarity values for pairwise comparisons of the anuran community between the six surveyed sites (see text and Appendix 1).

Sites	Eve	Gbo	Taz	Sap	Zai
Bal	0.95	0.87	0.61	0.62	0.59
Eve	–	0.91	0.57	0.64	0.61
Gbo	–	–	0.65	0.67	0.71
Taz	–	–	–	0.65	0.63
Sap	–	–	–	–	0.71

site diversity was higher in the savannah/forest mosaic. The number of species common to both areas was 16 (Sørensen's Similarity Index β: 0.70). Within the district of Daloa we recorded 11 species in Balouzon, 10 species in Eveché, 12 in Gbokora, and 25 in Tazibouo. Within the savannah/forest mosaic we recorded 18 and 16 species in Sapia and Zaibo, respectively.

The results of the Sørensen's similarity for pairwise comparisons in the six surveyed sites are presented in Table 2. At least more than 50% of the recorded species were similar between sites. The anuran fauna of Daloa urban area was most similar to that of the Comoé National Park, a savannah area in northern Ivory Coast (β: 0.72). With 68% and 66% faunal similarity the Lamto Faunal Reserve and the Marahoué National Park, which are situated in the same vegetation zone as Daloa, were very similar to the Daloa fauna. Other Ivorian protected areas such as the Mont Péko and Mont Sangbé National Parks comprise savannah and real rainforest zones and thus consequently differed in their faunal composition, compared to Daloa (Table 3).

Species accounts

Amietophrynus regularis (Reuss, 1833) – The genus *Amietophrynus* currently encompasses 40 species of true African toads [Frost 2015; although this list also contains non-vaild taxa such as *Amietophrynus chudeaui* (Chabanaud, 1919) see Rödel (2000)]. *Amietophrynus regularis* has a wide distribution in Africa and inhabits a broad range of habitats from moist and dry savannahs, montane grassland, forest margins, and agricultural habitats, as well as human settlements, often in association with rivers (Rödel 2000; Channing and Howell 2006). In our urban sites *A. regularis* (Fig. 2) seemed to reach its highest abundances directly around human settlements. At night, it was found in gardens, around houses, parking areas, buildings, or below streetlights, preying mostly on insects. During the day, it was found under rocks or logs. The most imminent threat to the toad's survival in the city of Daloa is its exploitation for scientific courses at the university. Every year several hundred individuals are collected by students and subsequently killed and dissected in anatomy courses. This exploitation seems to have reached a point where the species is becoming rare in the city. However, concerning the entire range of the species, it is very common and of Least Concern (IUCN 2015).

Hoplobatrachus occipitalis (Günther, 1859) is the most commonly consumed frog species in West Africa. The frog trade varies regionally from e.g., local scale in Burkina Faso, to intensive cross-border trade in northern Benin and Nigeria (Mohneke et al. 2009, 2010). The consumption of *H. occipitalis* (Fig. 3a) has recently increased to a considerable extent in the Ivory Coast where this species is an important component of animal protein in some local populations (NGK, unpubl. obs.). In Daloa, the trade of *H. occipitalis* mainly took place on a local scale at the different markets of the district. Usually a batch of five adult specimens was sold for 500.00 FCFA (app. 0.84 USD). Frog meat are sold fresh (Figs. 3b, c) or dried (Fig. 3d). It is used in soups, stews, or sauces by the local populations. The local price in Daloa markets was mean to low compared to prices recorded in Burkina Faso and Nigeria, respectively. According to Mohneke et al. (2010), in Burkina Faso, the price for one frog depended on its size and varied between 25.00 FCFA for a small frog, up to 250.00 FCFA (0.05 USD and 0.50 USD) for a large one. In Nigeria, they reported one bag containing at least 1,000 frogs cost 26.94–40.40 USD on purchase and 40.40–67.34 USD at sale. In the urban area of Daloa hard data on harvested frog numbers and respective consequences for the local populations are lacking. The local trade of *H. occipitalis* hence needs more attention and detailed investigation.

Hyperolius concolor concolor (Hallowell, 1844)(Fig. 4) is a typical West African farmbush species living in degraded forest of the forest zone and gallery forests in the savannah zone (Schiøtz 1967; Rödel 2000). It seemed to do very well under urban condition and was hence among the most widespread species recorded in the ur-

Table 3. Sørensen's similarity value (β) between the anuran fauna of the Daloa urban area and other Ivorian areas, and respective species richness; twenty-five species were recorded in urban Daloa (this study); NP= national park; FR= faunal reserve.

Area	Species richness	Number of species common with the Daloa urban area	β-value (Sørensen)	Source
Comoé NP	33	21	0.72	Rödel and Spieler (2000)
Lamto FR	40	22	0.68	Adeba et al. (2010)
Marahoué NP	33	19	0.66	Rödel and Ernst (2003)
Mont Péko NP	33	11	0.38	Rödel and Ernst (2003)
Mont Sangbé NP	45	20	0.57	Rödel (2003)

Fig. 2. *Amietophrynus regularis* female recorded in the garden of the Theological and Pastoral Institute of Daloa.

ban sites of Daloa (Table 1); it was particularly abundant among grasses near ponds. In the rainy season we recorded some, presumably migrating, individuals on windows, balconies, and in houses.

Hyperolius sp. – The genus *Hyperolius* Rapp, 1842 is one of the most diverse African anuran genera with currently approximately 28 species occurring in West Africa (Schiøtz 1967, 1999; Frost 2015). A major taxonomic problem is many species of this genus are highly variable (e.g., Schiøtz 1999). On 15 September 2013, at around 07h00 GMT, we found a *Hyperolius* on humid ground in the Tazibouo site, within the garden of the Theological and Pastoral Institute, after it had rained heavily the night before. Our individual lacked a vocal sac and gland and hence is either female or juvenile (Fig. 5). It resembles either a juvenile *H. picturatus* or a newly metamorphosed individual phase J of *H. sylvaticus ivorensis*, which is normally brownish to green with paired undelimited dorsolateral stripes, and an hourglass pattern (Schiøtz 1999). The size of our reed frog was 20 SUL, thus exceeding the size of freshly metamorphosed *Hyperolius* of most species (compare e.g., Schiøtz 1967; Rödel 2000). Its dorsal surface was beige with a greenish grey hourglass pattern. The iris was golden, the anterior and posterior sides of pupil were red. The ventral surface was whitish. Without having male specimens and advertisement calls available it cannot be decided if this frog represents an undescribed species or only an atypical, but known *Hyperolius* species.

Kassina schioetzi Rödel, Grafe, Rudolf, and Ernst, 2002 was known so far from the Mont Péko National Park, the Marahoué and Comoé National Parks, and the Lamto Faunal Reserve, all situated in the Ivory Coast (Rödel et al. 2002; Rödel and Ernst 2003; Adeba et al. 2010). It lives along the savannah forest edge, reaching into the savannah zone along rivers. The species may also occur in Bia National Park, western Ghana, but a voucher from there exhibited a mixture of characters with *K. cochranae* (Hillers et al. 2009). *Kassina schioetzi* is usually hard to find in all localities so far investigated (see above and own experience of the authors). In the district of Daloa (Tazibouo), some males were observed calling at night from more exposed sites (Fig. 6). We also encountered a small number of other males calling in a bamboo patch within the Theological and Pastoral Institute, and at a grassy roadside in the vicinity of a large pond. Our recorded males measured 32.1 ± 1.6 (SUL, n = 4), thus being within the known range of *K. schioetzi* (Rödel et al. 2002).

Leptopelis viridis (Günther, 1868) (Fig. 7) is one of the most characteristic species inhabiting the West African savannahs and the degraded areas of the former rainforest belt. As a synanthropic species, it also lives in villages (Schiøtz 1967; Rödel 2000). It is one of the most widespread anurans in the urban sites of Daloa. *Leptopelis viridis* was found around houses, and in gardens. The majority of the recorded males were found at night calling exposed on the ground between short grasses, which is in contrast to the calling sites in natural habitats. There the species calls, often from high perch sites, in bushes and trees (Grafe et al. 2000; Rödel 2000).

Phrynomantis microps Peters, 1875 is a medium-sized microhylid frog inhabiting the savannah regions of West Africa (Hirschfeld and Rödel 2011) where it hides in burrows or empty termite mounds during the day and the dry season. The frog was also observed to occupy and

live essentially unharmed in the nest of the highly aggressive ant species – *Paltothyreus tarsatus* (e.g., Rödel and Braun 1999; Rödel et al. 2013). In Daloa, *P. microps* was heard calling at night in tufts of grass around houses after heavy rainfalls. In the garden of the Theological and Pastoral Institute, a calling male was observed in association with an Emperor Scorpion (*Pandinus imperator*) in a hole behind the wall of a building. The association of *P. microps* with scorpions has also been reported by Rödel and Braun (1999) and Rödel (2000). We captured another male (Fig. 8) on 08 September 2013 around 22h00 GMT at the edges of a wide roadside pond beside the Theological and Pastoral Institute.

Xenopus muelleri (Peters, 1844) is an aquatic species inhabiting the West African savannah ponds of highly variable size during the rainy season and the edges of rivers during the dry season (Rödel 2000). In the urban site Tazibouo, the frog was observed to live in holes drilled in the ground by the national company of water distribution. The depths of these holes varied from 0.7–1.20 m.

Discussion

Despite their importance to ecosystem functions (Mohneke and Rödel 2009; Hocking and Babbitt 2014), amphibians are still among the least studied vertebrates particularly in urban and suburban areas in the tropics (Hamer and McDonnell 2008; Pickett et al. 2001). Almost 85% of amphibian species threatened by urbanization are encountered in the tropics (IUCN, Conservation International and NatureServe 2006). Many factors are known to negatively influence the herpetofauna inhabiting big cities. Among these factors are habitat loss, habitat fragmentation, isolation, pollution, over harvesting, and road traffic (Hammer and McDonnell 2008; Perry et al. 2008; Stuart et al. 2008; Deikumah and Kudom 2010; Tonini et al. 2011). However, many species are able to adapt to urban conditions and sometimes urban areas may even surprise with the discovery of scientifically new species (Newman et al. 2012; Feinberg et al. 2014; Howlader et al. 2015). This also concerns the Ivorian city of Abidjan where a monotypic genus *Morerella cyanophthalma* and a night-frog *Astylosternus laticephalus* have recently been discovered and described (Rödel et al. 2009, 2012).

With its geographic position in a transition zone between the semi-deciduous forest and humid savannah, we expected the urban landscape of Daloa region to promote a diverse amphibian fauna. However, the overall species richness (30 spp.) was lower compared to the species richness recorded in western, central, and northern Ivorian savannah areas, for instance the Mont Sangbé National Park (45 species, Rödel 2003), Lamto Faunal Reserve (40 species, Adeba et al. 2010), Marahoué and Mont Péko National Parks (33 species for each park, Rödel and Ernst 2003), or the Comoé National Park (33

Fig. 3. *Hoplobatrachus occipitalis* from the district of Daloa (a) and a woman trading this species on a local market (b); batches of five adult specimens, fresh (b and c) or dried (d), were sold for 500.00 FCFA (app. 0.84 USD).

Fig. 4. A calling *Hyperolius concolor concolor* male recorded at the garden of the Theological and Pastoral Institute of Daloa.

Fig. 5. Dorsolateral view of a juvenile *Hyperolius* sp. with uncertain taxonomic status from the urban Daloa.

species, Rödel and Spieler 2000). Compared to these and other West African savannah areas with known amphibian assemblages such as north-western Benin (Nago et al. 2006), east-central Guinea (Greenbaum and Carr 2005), central-northern Guinea (Hillers et al. 2008a), or eastern Ghana (Leaché et al. 2006), the urban landscape of Daloa ranks among the West African areas of medium to low amphibian species richness. While we recorded few forest related species e.g., *Amnirana albolabris*, *Leptopelis spiritusnoctis*, *Phrynobatrachus calcaratus*, and *P. gutturosus* (Rödel and Branch 2002; Assemian et al. 2006; Kouamé et al. 2014; Kpan et al. 2014; the latter two species comprising out of cryptic species with savannah and forest specialists), most of the recorded frogs were widespread species with preferences for savannah-dominated landscape and farmbush habitats. The six surveyed sites all shared at least half of their species with all other sites. We observed the highest species richness at the Tazibouo site (25 spp.) which was the only urban site comprising various suitable breeding habitats. For instance in the

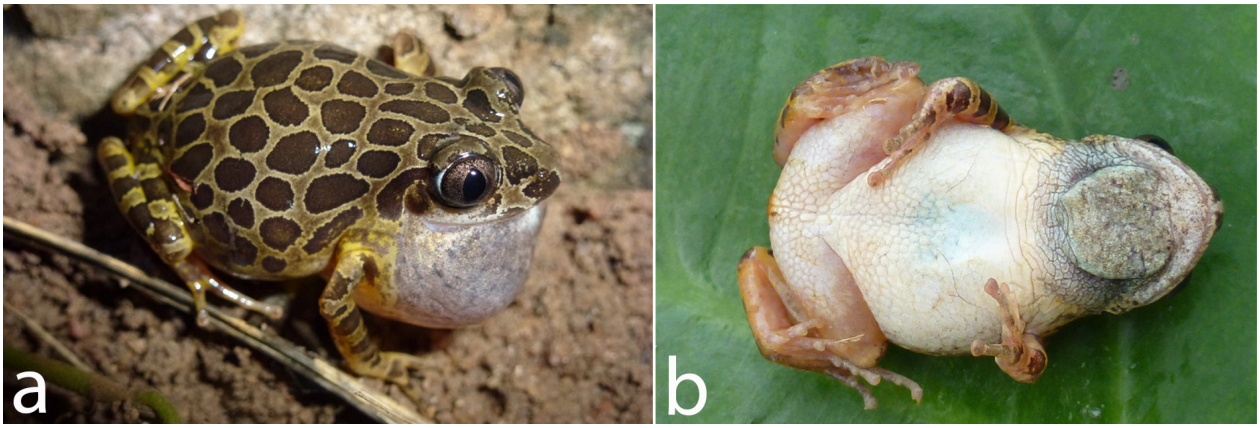

Fig. 6. *Kassina schioetzi* from Daloa urban area; shown is a male calling from the ground (a), and its whitish venter and almost circular gular gland (b) characteristic for the species.

garden of the Theological and Pastoral Institute, ephemeral and perennial wetlands, well-suited for the co-existence of species with different reproductive strategies were present: e.g., very small temporary breeding sites (*Phrynobatrachus* spp.), larger, almost permanent breeding sites (*Afrixalus dorsalis*, *Hyperolius concolor*, *Kassina schioetzi*, *K. senegalensis*, *Phrynomantis microps*), and humid places for species with terrestrial direct development (*Arthroleptis poecilonotus*-group). This garden also played an important role in providing refuge for several other species in particular during the heat of the day and the dry season.

In addition to the fact that many amphibian species depend on different but complementary habitats (e.g., aquatic sites for the tadpoles, terrestrial site of the metamorphosed individuals), their populations are usually structured as meta-populations (Pope et al. 2000; Marsh and Trenham 2001). Urbanization and in particular fragmentation and isolation of habitats by roads and other urban infrastructure is reducing the connectivity of population networks (Vos and Chardon 1998). Hence, we expected to record lower amphibian diversity in the district of Daloa than in the savannah-forest mosaic adjacent to this district. Surprisingly, the total anuran richness in the urban environment was higher than in the adjacent savannah-forest mosaic. This result indicates many amphibian species may survive under urban situations, such as in the district of Daloa. However, this high total species richness was due to only one of four urban sites, i.e., the Theological and Pastoral Institute, comprising many different habitat types and particularly diverse breeding sites. The other urban sites actually had slightly lower species richness than the non-urban sites. This illustrates a high amphibian diversity in urban areas may be maintained and even exceed such as of nearby non-urban areas; however, this can only be achieved by offering a wide range of different habitats suitable for various amphibian species.

Apart from roads potentially reducing or ceasing gene flow, amphibians further face direct threats in urban areas, in the form of the collection of anurans for anatomy and food consumption. Compared to European towns (e.g., Mollov 2005), however, there are still plenty of habitats available to amphibians, the traffic is usually less intense as many of the roads remain unpaved allowing frogs to cross. In fact our non-urban sites were all within a matrix of agricultural land and thus most likely prone to a variety of pesticides which could be a higher threat than the threats experienced in towns. The adaptability of amphibians within the urban development seemed to be species-specific and was highly variable even between sites. For example some species such as *Hyperolius guttulatus*, *H. fusciventris fusciventris*, *Amnirana albolabris*, *Leptopelis spiritusnoctis*, and *Phrynobatrachus calcaratus*, encountered in the savannah-forest mosaic outside of Daloa were never found in the urban sites. This is most likely due to the fact that their specific habitats are no longer present. For instance *Hyperolius guttulatus* breeds almost exclusively in very large and deeper ponds (Rödel 2000; Schiøtz 1967, 1999); and *Phrynobatrachus calcaratus* typically lives at rain forest edges or in gallery forests in the savannah zone (Rödel 2000). Respective habitat types for both latter species were not found in the urban environment. It is known that in forested areas the alteration of the microclimate, due to degradation of the vegetation structure, causes a shift in species composition (Ernst and Rödel 2005, 2006; Hillers et al. 2008b; Ofori-Boateng et al. 2013). Such effects might be even worse in the usually more open habitats of urban areas.

Conclusion

The study is indicating that an unexpected high number of anuran species seem to be able to survive in a current African city. However, this is not the case for all species. For those species the protection of natural forest and savannah ecosystems is very important. The forest habitats, and specifically the forest ‘‘islands” bordering the Daloa district, should thus be considered sensitive areas and dispersal corridors need to be maintained. Within the

Fig. 7. Dorsolateral view of *Leptopelis viridis*, one of the most widespread anurans from the Daloa urban area.

Fig. 8. Dorsolateral view of a male *Phrynomantis microps* from Daloa urban area.

urban areas, the availability of a diverse set of habitats is a prerequisite for the maintenance of high amphibian species richness.

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Appendix 1. Geographic position and short description of study sites in the Daloa study area.

Site	Latitude (N)	Longitude (W)	Elevation (m a.s.l.)	Habitat description
Bal	N06°53'64.5"	W006°25'65.3"	259	Highway; grassy habitats; heavy traffic; dense human population
Eve	N06°53'01.8"	W006°26'05.9"	261	Large stream bordered by coconut trees and grass; unpaved roads; concentration of buildings; swampy area used for vegetable cultivation; dense human population
Gbo 1	N06°54'15.8"	W006°27'15.3"	265	Semi-deciduous forest patch; swampy area dominated by grassy vegetation; buildings; highway, heavy traffic; streetlight; swampy area partly used for vegetable cultivation; dense human population
Gbo 2	N06°54'03.4"	W006°27'09.6"	275	Buildings; shrubby vegetation; unpaved roads; highway; dense human population
Sap 1	N06°87'20.8"	W006°37'83.8"	239	Subsistence farming; rice field in a swampy area; high grassy vegetation
Sap 2	N06°87'22.8"	W006°37'93.7"	260	Forests islands; cocoa plantation at edge of a rice field; high grassy vegetation
Sap3	N06°87'37.1"	W006°38'09.7"	276	Stream crossing cocoa plantation; palm tree at edge of the water body; plantain and coffee plantations
Sap 4	N06°86'83.8"	W006°38'99.3"	244	Swampy area; high grassy vegetation; rice field; humid savanna; tracks
Sap 5	N06°86'83.8"	W006°37'61.5"	229	Rice field in a swampy area; coconut trees at edge
Taz 1	N06°90'42.8"	W006°43'97.4"	274	Semi deciduous forest patch close to the Jean Lorougnon Guédé University; garden of the Theological and Pastoral Institute, dominated by bamboo, grasses and stands of different ornamental plants; two large wide ponds surrounded by vegetation (Asteraceae); streetlight; unpaved roads, concentration of buildings; dense human population
Taz 2	N06°90'33.7"	W006°43'78.9"	268	Swampy area; buildings; rice field; vegetable cultivation; many constructions of houses underway
Zai 1	N06°94'97.8"	W006°67'35.7"	223	Swamps within a semi deciduous forest; stream; ponds; grassy vegetation; clearing; rice field; cocoa plantation
Zai 2	N06°94'33.6"	W006°68'89.0"	222	Very large rice field; high grasses; edge of coffee and cocoa plantations; forest patch
Zai 3	N06°94'65.9"	W006°66'58.7"	209	Rice field crossed by a stream: coffee plantation; tracks; forest patch

Appendix 2. Amphibian survey periods in the urban and non-urban areas of Daloa (compare Appendix 1).

Site	Surveyed periods						
	10–21 Aug. 2011	27 Aug.–1 Sep. 2011	27 Sep.–1 Nov. 2012	16–25 Aug. 2013	18–27 Oct. 2013	18–27 Jun. 2014	16–24 Aug. 2014
Urban area	**6 days**	**2 days**	**1 day**	**6 days**	**2 days**	**6 days**	**3 days**
Bal	6	2	1	6	2	6	3
Eve	6	2	1	6	2	6	3
Gbo	6	2	1	6	2	6	3
Taz	6	2	1	6	2	6	3
Non-urban area	**6 days**	**4 days**	**4 days**	**4 days**	**8 days**	**4 days**	**6 days**
Sap	3	2	2	2	4	2	3
Zai	3	2	2	2	4	2	3
Total days	**12**	**6**	**5**	**10**	**10**	**10**	**9**

Appendix 3. List of amphibian voucher specimens from the district of Daloa and surroundings. Given are field and collection numbers (NG), collection site (compare Appendix 1) and collection date.

Arthroleptidae: *Arthroleptis* spp.: NG001 (Taz, 08 Nov. 2011); NG002 (Sap, 16 Oct. 2013); NG003 (Zai, 23 Oct. 2013); *Leptopelis spiritusnoctis*: NG004 (Zai, 23 Oct. 2013); *L. viridis*: NG005 (Taz, 24 Oct. 2011); NG006 (Taz, 30 Oct. 2013); **Bufonidae**: *Amietophrynus maculatus*: NG007 (Zai, 25 Oct. 2013); *A. regularis*: NG008 (Taz, 19 Oct. 2011); **Dicroglossidae**: *Hoplobatrachus occipitalis*: NG009 (Taz, 25 Oct. 2011); **Hemisotidae**: *Hemisus marmoratus*: NG010 (Taz, 08 Sep. 2010); NG011 (Sap, 25 Oct. 2013); **Hyperoliidae**: *Afrixalus dorsalis*: NG012 (Taz, 18 Aug. 2011); *Hyperolius concolor concolor*: NG013 (Taz, 18 Aug. 2011); NG014 (Sap, 18 Oct. 2013); *H. fusciventris fusciventris*: NG015 (Sap, 19 Oct. 2013); *H. guttulatus*: NG016 (Zai, 23 Oct. 2013); NG017 (Zai, 25 Oct. 2013); *H. nitidilus*: NG018 (Taz, 25 Aug. 2011); NG019 (Sap, 16 Oct. 2013); *H. picturatus*: NG020 (Taz, 01 Sep. 2011); NG021 (Sap, 18 Oct. 2013); NG022 (Taz, 23 Oct. 2013); *H.* sp.: NG023 (Taz, 15 Sep. 2013); *Kassina schioetzi*: NG024–027 (Taz, 08 Sep. 2013); *K. senegalensis*: NG028 (Taz, 17 Aug. 2011); NG029 (Taz, 30 Aug. 2013); **Microhylidae**: *Phrynomantis microps*: NG030 (Taz, 08 Sep. 2013); **Phrynobatrachidae**: *Phrynobatrachus calcaratus*: NG031–036 (Sap, 19–20 Oct. 2013); *P. francisci*: NG037–038 (Taz, 01 Sep. 2011); NG039 (Taz, 17 Aug. 2013); *P. gutturosus*: NG040 (Taz, 19 Aug. 2013); NG041 (Sap, 20 Oct. 2013); *P. latifrons*: NG042 (Taz, 20 Aug. 2011); NG043 (Taz, 25 Aug. 2011); NG044 (Sap, 19 Oct. 2010); NG045 (Zai, 23 Oct. 2013); **Ptychadenidae**: *Ptychadena bibroni*: NG046 (Taz, 09 Sep. 2012); NG047 (Zai, 24 Oct. 2013); *P. tellinii*: NG048 (Taz, 01 Sep. 2013); *P. mascareniensis*: NG049 (Taz, 16 Sep. 2013); NG050 (Zai, 24 Oct. 2013); *P. oxyrhynchus*: NG051–052 (Taz, 06 Sep. 2012); NG053 (Zai, 24 Oct. 2013); *P. pumilio*: NG054 (Taz, 16 Sep. 2013); NG055 (Sap, 19 Oct. 2013); *P. tournieri*: NG056 (Taz, 10 Sep. 2012); **Ranidae**: *Amnirana albolabris*: NG057 (Sap, 19 Oct. 2013); *A. galamensis*: NG058 (Taz, 24 Aug. 2014).