Co-occurring cryptic species pose challenges for conservation: a case study of the African dwarf crocodile (*Osteolaemus* spp.) in Cameroon

Nicole L. Smolensky

Abstract The conservation status of threatened taxa may be obfuscated by the detection of cryptic species complexes, in both vertebrate and invertebrate species. African dwarf crocodiles (*Osteolaemus* spp.) are hunted throughout their range but their conservation status is unknown. Few population assessments have been carried out and there has been a taxonomic revision of the number of species in the genus. The similar morphologies of *Osteolaemus tetraspis* and *Osteolaemus osborni* pose a challenge for conservation in Cameroon, where they are still managed as a single species. Nocturnal spotlight surveys were conducted in three regions during August–November 2010 and December 2011–February 2012 to provide population assessments of *O. tetraspis* and *O. osborni* and raise awareness of the two species in Cameroon. The mean encounter rates of *O. tetraspis* and *O. osborni* were $1.02 \pm$ SD 1.34 (65 individuals in 39 surveys) and $0.61 \pm$ SD 0.38 (three in four surveys) crocodiles per km, respectively. The *O. tetraspis* population comprised juveniles predominantly and had a male-biased sex ratio. The few *O. osborni* detected comprised both adults and juveniles. Both species are threatened in Cameroon, based on low encounter rates, young population structures and the threats of habitat loss and hunting pressure. This study provides distribution maps and serves as a baseline to quantify population trends and inform conservation strategies.

Keywords Cameroon, crocodile, cryptic species, hunting pressure, *Osteolaemus*, population status

Introduction

The conservation status of a species is determined by its distribution, population size, demographic structure, and associated threats (IUCN, 2012a). This information is also used as a basis for management and conservation strategies (Meffe & Carroll, 1997; Mills, 2007). However, these data are lacking for 24% of species categorized on the IUCN Red List (IUCN, 2012b). Molecular evidence indicates that several species on the Red List may actually be complexes of cryptic species (Pfenninger & Schwenk, 2007; Murray et al., 2008). This taxonomic challenge can have significant ramifications for our understanding of the distribution, population status, management and legislative protection of these threatened cryptic species (Bell et al., 1998; Mace, 2004; Sattler et al., 2007). For example, two species of woolly spider monkeys, the Endangered *Brachyteles arachnoides* and the Critically Endangered *Brachyteles hypoxanthus*, were previously thought to be a single species. Captive-breeding programmes intended to augment *B. arachnoides* populations included hybrids of the two species, which, if introduced into the small population of *B. hypoxanthus* could have resulted in its genetic extinction (Brito, 2004). The status and management of threatened taxa must be assessed on an ongoing basis as taxonomies are refined.

The African dwarf crocodiles (*Osteolaemus* spp.) provide an example of the heuristic approach needed to manage and conserve biodiversity effectively as species' taxonomies change. *Osteolaemus* was formerly a monotypic genus containing two subspecies, *Osteolaemus tetraspis tetraspis* and *Osteolaemus tetraspis osborni*, which were widely distributed in equatorial lowland rainforests of West and Central Africa. They were managed as a single species, listed in Appendix I of CITES (CITES, 2014) and categorized as Vulnerable on the IUCN Red List (IUCN, 2012b) because of the threats of habitat loss and hunting pressure (Eaton, 2010). However, studies have shown the genus comprises three species: *Osteolaemus* sp. nov., *O. tetraspis* and *O. osborni* (Eaton et al., 2009; Franke et al., 2013; Shirley et al., 2014; Smolensky et al., 2014). Efforts are underway to characterize the distribution and population status and develop captive-breeding programmes for all three species (Eaton et al., 2009; Eaton, 2010; Franke et al., 2013; Shirley et al., 2014; Smolensky et al., 2014; Schmidt et al., in press).

Osteolaemus sp. nov. occurs in the upper Guinean rainforests (Fig. 1). It has been extirpated from the extreme western part of its range. The southern coasts of Ghana and Côte d'Ivoire may be the last remaining strongholds for this species (Waitkuwait, 1989; Kofron, 1992; Shirley et al., 2009; Eaton, 2010). *Osteolaemus tetraspis* and *O. osborni* occur in the lower Guinean and Congo rainforests, respectively (Fig. 1). Population assessments of *O. tetraspis* and *O. osborni* are few, mostly outdated, and indicate low densities where they are exploited for bushmeat (Riley & Huchzermeyer,

Nicole L. Smolensky Department of Wildlife and Fisheries Sciences, 210 Nagle Hall, Texas A&M University, College Station, Texas 77843-2258, USA
E-mail nsmo@tamu.edu

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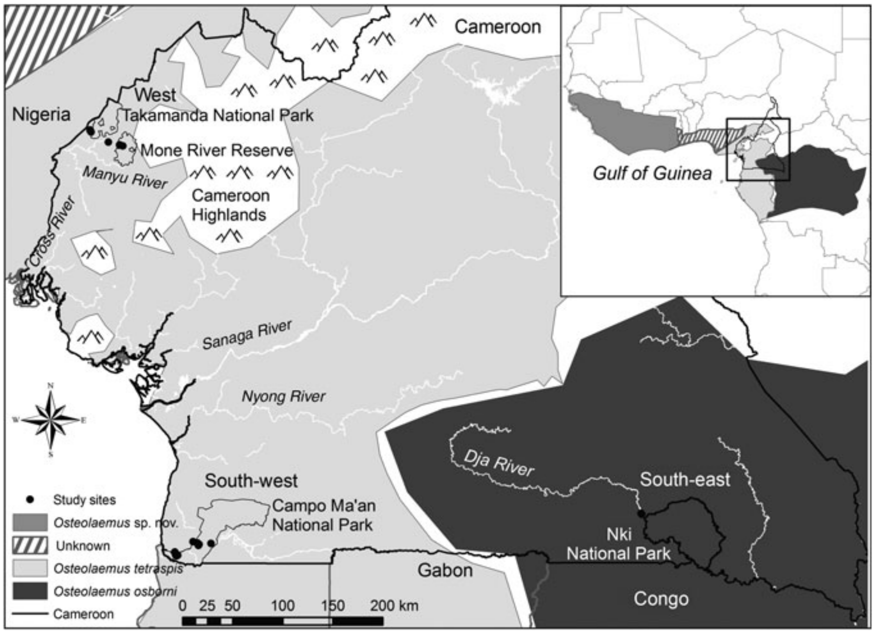

FIG. 1 The West, South-west and South-east study sites in the lowland Congo–Guinean rainforest in Cameroon, where surveys were conducted for the African dwarf crocodiles *Osteolaemus tetraspis* and *Osteolaemus osborni*. The rectangle on the inset shows the location of the main map in Africa.

1999; Wild, 2000; Eaton, 2006, 2010). In light of these taxonomic revisions and current threats to the species, population assessments are needed to update their conservation status and inform appropriate management to conserve their evolutionary diversity.

The co-occurrence of cryptic taxa further complicates conservation status assessments of species. Smolensky et al. (2014) confirmed the co-occurrence of *O. tetraspis* and *O. osborni* in Cameroon. *Osteolaemus tetraspis* is widely distributed there but is threatened by hunting and deforestation (Wild, 2000; Gonwouo & LeBreton, 2010). These latest assessments were conducted during 1990–2004 and were presence/absence surveys, except at one site where population density surveys were conducted (Wild, 2000). There have been no population density assessments of *O. osborni*.

Here I provide information on the population ecology of *O. tetraspis* and *O. osborni* in Cameroon to facilitate independent conservation of these species. I present the first population assessments of *O. osborni* and *O. tetraspis*, a re-assessment of the western population of *O. tetraspis*, and distribution maps for both species.

Study area

During 18 August–21 November 2010 and 17 December 2011–16 February 2012 I conducted population surveys in three study regions (West, South-west and South-east) in the lowland Congo–Guinean rainforest in Cameroon (Fig. 1). The West study region was where Wild (2000) conducted an assessment of *O. tetraspis* in 1998, facilitating a temporal comparison of population estimates with this study, and an assessment of the population trend. I conducted surveys within the Mone River Reserve, on the southern border of the Takamanda National Park, and near the villages of Okpambe and Ebinsi, located between the Reserve and the Park (Fig. 1). The South-west region provided an additional site for a spatial comparison of *O. tetraspis* populations, facilitating assessment of the status of the species at a broad scale. In this region surveys were conducted during 2010–2012 in the Campo Ma'an National Park, specifically in the sections known as Ile Dipikar and Corridor. The Congo Basin in the South-east is the only region known to harbour *O. osborni*, and was chosen to provide the first assessments for this species in Cameroon (Smolensky et al., 2014).

Study sites in each region were selected based on road access, proximity to a protected area, and anecdotal evidence of *Osteolaemus* presence. All sites were at low elevation (< 500 m), with dense canopy cover and gallery forest vegetation. Streams in the West and South-west were 1–10 m wide and had clear, slow-flowing water of depth < 0.25–1 m but typically < 0.5 m. The Dja River, in the South-east study region, is a major tributary of the Congo Basin, with turbid waters, maximum width 120 m, and mean annual discharge 450–500 $m^3 s^{-1}$ (Seyler et al., 1993).

Methods

Nocturnal spotlight surveys were conducted to obtain a census of crocodile populations (Chabreck, 1966). The number of surveys was reduced at sites where initial surveys yielded few encounters. Surveys entailed wading, walking or canoeing along the edges of the Dja River. I surveyed the edges of the river, where flow was reduced and canopy cover was dense.

TABLE 1 Mean encounter rates for the African dwarf crocodiles *Osteolaemus tetraspis* in the South-west and West and *Osteolaemus osborni* in the South-east study sites of the lowland Congo–Guinean rainforest in Cameroon (Fig. 1).

Study region	Site	No. of surveys	Survey distance (km)	No. detected	No. captured	Mean encounter rate ± SD (individuals per km)
Osteolaemus tetraspis						
South-west	Ile Dipikar	16	40.54	35	25	1.01 ± 0.98
	Corridor	11	26.20	10	7	0.48 ± 0.58
Total		27	66.70	45	32	0.79 ± 0.88
West	Mone river	5	3.38	9	6	2.16 ± 2.75
	Okpambe	2	3.70	2	1	0.56 ± 0.11
	Ebinsi	1	1.30	0	0	0.00
	Kekukesem*	3	3.91	9	5	2.17 ± 0.84
	Takamanda*	1	1.70	0	0	0.00
Total		12	13.99	20	12	1.54 ± 2.04
Total for both regions		39	80.69	65	44	1.02 ± 1.34
Osteolaemus osborni						
South-east	Nki	4	24.71	13	3	0.61 ± 0.38

* In the Takamanda National Park (c.f. Wild, 2000)

Each survey began 2 hours after dusk and ended 2–4 hours before dawn. Each stream was searched during 1–3 nights, covering different sections of the stream each night. Start and end points were recorded using a global positioning system, to map the location and length of each survey. A white LED headlamp (200 lumens) was used to detect crocodiles, which typically were solitary. The waters were clear and shallow, which facilitated detection of submerged crocodiles. I attempted to capture all crocodiles to obtain morphometric measurements and tissue samples for species identification via genetic analyses. Smaller individuals were grabbed by hand and larger individuals were captured using a snare-pole (Hutton et al., 1987). For each crocodile, I recorded its location, snout-vent length, total length and sex. Crocodiles were given unique identifying marks by removal of caudal scutes (Webb & Messel, 1977), and released at the site of capture.

Sex was determined for individuals of total length > 40 cm. Crocodiles were categorized according to life-stage, based on studies of captive and wild *Osteolaemus* populations (Beck, 1978; Teichner, 1978; Tryon, 1980; Eaton, 2009): hatchlings (< 24 cm), juveniles (24–99 cm) and adults (> 100 cm). Crocodiles that evaded capture were not categorized.

Encounter rates and population structure were used to assess the population status of *O. tetraspis* and of *O. osborni*. Encounter rates were recorded as the number of crocodiles detected per km of river habitat, and served as relative population density indices. Population structure was the relative proportions of captured individuals in each size category. Encounter rates and population structures in the three study regions were compared using Kruskal–Wallis and Fisher's exact tests, respectively. For the South-west, where surveys were conducted for 2 years, a Wilcoxon signed-rank test was used to compare encounter rates and population structure between years.

Results

Forty-three nocturnal spotlight surveys were conducted (27 in the South-west, 12 in the West and four in the South-east), covering a total of 105.4 km of stream and river habitat across the three study regions. Sixty-five *O. tetraspis* and 13 *O. osborni* were encountered. Crocodiles were detected in all regions and at 75% of the eight survey sites (Table 1), although in general the encounter rate at individual sites was low (Table 1). The mean encounter rates for *O. tetraspis* and *O. osborni* were 1.02 ± SD 1.34 (65 individuals in 39 surveys) and 0.61 ± SD 0.38 34 crocodiles per km (three in four surveys), respectively. Encounter rates did not differ among regions ($H = 0.06$, $P = 0.80$) or among sites ($H = 6.25$, $P = 0.51$).

The mean encounter rate of *O. tetraspis* populations from Takamanda and Kekukesem, sites previously surveyed in 1998 (Wild, 2000), declined from three to 1.01 crocodiles per km. Encounter rates in the South-west also declined, from 1.31 ± SD 1.13 (n = 11 surveys) in 2010 to 0.44 ± SD 0.46 crocodiles per km (n = 16) in 2012 but the decrease was not significant ($W = -1.94$, $P = 0.053$). No crocodiles marked in 2010 were re-captured in 2012.

O. tetraspis populations were composed predominantly of juveniles (Fig. 2). In the South-west juveniles comprised 75% (n = 24) of the population, and adults 25% (n = 8). No hatchlings were detected although 22% of the juveniles had recently entered this size category and were 30–35 cm in total length (Fig. 2). The population structure was unchanged between 2010 and 2012. In the West, juveniles comprised 83.3% (n = 10) of the population, and adults 16.7%

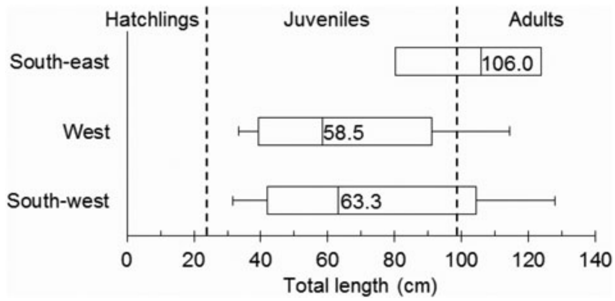

Fig. 2 Population structure of *O. tetraspis* at study sites in the west (n = 12) and south-west (n = 32) of the lowland Congo–Guinean rainforest in Cameroon (Fig. 1), and of *O. osborni* in the south-east (n = 3). Dashed vertical lines represent the divisions between hatchlings (< 24 cm total length), juveniles (< 100 cm total length) and adults, based on Beck (1978), Teichner (1978), Tryon (1980) and Eaton (2009). The numbers to the right of the median are mean encounter rates, and error bars represent minimum and maximum sizes of captured crocodiles.

(n = 2). Two of the juveniles were 30–35 cm in total length. There was no significant difference in the population structure between regions (F = 2.89, P = 0.19). The sex ratio was male-biased (1.75 : 1, n = 22) in the South-west and female-biased in the West (0.67 : 1, n = 5) and South-east (1 : 2, n = 3).

Two adult and one juvenile *O. osborni* were captured in the South-east study region. *O. osborni* detected but not captured also fell within these size categories.

Discussion

These results provide information on the population status of *O. tetraspis* throughout its range in Cameroon, and the first estimate of *O. osborni* population densities in Cameroon. Encounter rates of both species were low. They were comparable to exploited populations of these species in similar habitats in the Republic of the Congo, and 4.5 times lower than encounter rates of unexploited *O. tetraspis* populations in Gabon (Eaton, 2009). Both species are hunted throughout Cameroon but the intensity of hunting pressure is unknown (Wild, 2000). The low encounter rates of both species, and the juvenile-biased population structure of *O. tetraspis*, may be indicative of unsustainable exploitation (Webb et al., 2000). Additional factors not associated with hunting that may have influenced observed encounter rates are discussed below. The wide distribution of *O. tetraspis* throughout Cameroon may be critical for its persistence in the country (Smolensky et al., 2014). *Osteolaemus osborni* has a much narrower distribution and the low encounter rate implies a tenuous status in Cameroon.

Encounter rates of *O. tetraspis* were similar across its range. In many of the surveys in the South-west and West one or no individuals were encountered in 2.5 km of river habitat, with encounter rates of two or more crocodiles per km being more common in the West. The habitats were similar in their physical and vegetation characteristics but differed in levels of anthropogenic disturbance. The sites adjacent to or in the protected areas of the West were remote, with lower human population densities and fewer logging concessions and roads in the surrounding area compared to sites in the South-west. Sites far from protected areas (e.g. Ebinsi) had even lower encounter rates, which may be attributable to degraded habitats, lack of enforcement of hunting regulations, and fishing methods involving the use of poisonous organo-chloride insecticides (Gonwouo & LeBreton, 2010). Cameroon's human population density, infrastructure development and agriculture sector have doubled since 2000 (de Wasseige, 2012; World Bank, 2014). Thus the decline in encounter rates, from three (Wild 2000) to 1.01 crocodiles per km in the West, may be a result of increased exploitation. Alternatively, lower encounter rates may be associated with edge effects around protected areas (Woodroffe & Ginsberg, 1998), as my surveys were conducted on the edge of the Takamanda National Park whereas those of Wild (2000) were conducted in the interior of the Park.

In the South-west encounter rates also decreased during 2010–2012 although not significantly. Although it may take several years to detect changes in population structures of crocodiles (Webb et al., 2000), the observed differences may reflect a change in activity rates. In 2010 surveys were conducted at the end of the rainy season, which probably coincides with the end of the mating season and the beginning of the nesting period (Waitkuwait, 1989; Kofron & Steiner, 1994; Eaton, 2009), whereas in 2012 surveys were conducted at the end of the dry season, when the availability of aquatic prey is low, and therefore more individuals may be inactive, remaining in burrows until the onset of the rainy season (Brummett & Teugels, 2004).

The lowest encounter rates were recorded for the *O. osborni* population, which may be attributed to the combined threats of hunting pressure and drowning in gillnets. The turbidity of the waters of the Dja River, compared with the clear-water streams surveyed for *O. tetraspis*, may also have resulted in lower detection rates (Bayliss, 1987; Hutton & Woolhouse, 1989). It is unlikely that low encounter rates were a result of poor habitat, as *Osteolaemus* species use a variety of aquatic habitats, including rivers (Eaton, 2009).

Population structure may be influenced by the type of aquatic habitat. Although few *O. osborni* individuals were caught they were adults and large juveniles detected at the edges of a large river, whereas small and large *O. tetraspis* were detected in small tributaries in the West and South-west. These findings may be a result of ontogenetic shifts in habitat use, whereby small crocodiles are less common in larger rivers because of the higher predation risk (Subalusky et al., 2009). In the South-west and West the population structure was skewed towards juveniles, a situation that is often attributed to size-selective hunting pressure (Montague, 1983; Webb et al., 2000). However, the population structures were similar to those of populations in Gabon not subject to hunting pressure (Eaton, 2009). Thus, proportionally higher numbers of juveniles in the population may be typical of *O. tetraspis* populations surveyed during the dry season. Females are nesting during this period and may be located several metres away from water, which may account for the male-biased sex ratio observed in the South-west population (Waitkuwait, 1989).

Cameroon provides an important case study for *Osteolaemus* species and cryptic taxa in general, as it is one of two countries known to harbour two *Osteolaemus* species, the other being the Republic of the Congo (Eaton, 2010; Smolensky et al., 2014). Separate population assessments were conducted and distribution maps provided to raise awareness of the two cryptic species in Cameroon, providing a baseline to determine the stability of the density and structure of the country's *O. tetraspis* and *O. osborni* populations. The low encounter rates of both species, the young population structure of *O. tetraspis*, and the increasing threats of habitat loss and hunting pressure indicate that both species are threatened in Cameroon, and both merit categorization as Vulnerable there. The conservation status of *O. osborni* may worsen if national and international policy and management are not revised to protect this unique species.

The similar morphologies of *O. tetraspis* and *O. osborni* pose a hybridization risk for both in situ and ex situ management programmes. Hybridization has been detected in captive-breeding programmes in European zoos, and efforts are underway to mitigate this and curtail translocations or reintroductions of hybrids into wild populations (Franke et al., 2013; Schmidt et al., in press). In Cameroon, management authorities and conservation organizations confiscate live crocodiles from the bushmeat trade and release them back into the wild but not necessarily into their original populations (NLS, pers. obs.), creating the potential for hybridization. The distribution maps provided here and elsewhere (Smolensky et al., 2014) should mitigate some of these hybridization risks. I recommend that confiscated crocodiles be released back to their original populations. Regional and national reports of these findings are being distributed to governmental ministries and non-governmental agencies. Plans for continued monitoring are underway, in addition to further delineation of *O. tetraspis* and *O. osborni* distributions, particularly where contact zones may occur.

As species' taxonomies are revised, population assessments and reassessments are important in conserving their evolutionary diversity. Continued monitoring of *O. tetraspis* and *O. osborni* populations would elucidate whether the observed juvenile-biased population structures are typical of *Osteolaemus* populations or are indicators of overexploitation. Further studies on reproductive phenology and seasonal activity patterns would facilitate our understanding of the spatial and temporal variability of *O. tetraspis* populations. Although crocodile ranching and farming has been a successful conservation strategy for exploited crocodile species (Crocodile Specialist Group, 2014), preliminary assessments indicate this would not be an economically viable strategy for *Osteolaemus* species in Cameroon (Behra, 1993). My results suggest that protected areas are important havens for populations of *O. tetraspis* and that they should be extensive, with enforcement of wildlife laws and limited access to their interiors. Sustainable livelihood opportunities must be created for local communities to offset the costs of reduced hunting.

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Biographical sketch

Nicole Smolensky's research interests lie in the population ecology and conservation of reptiles. She uses a combination of field methods and molecular and biochemical techniques to study the status, sustainable use, distribution, and trophic ecology of reptiles in the USA and Cameroon.