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## Review of Crocodiles in Zoological Gardens with a focus on Europe

### Eine Übersicht über in Zoologischen Gärten gehaltene Krokodile, mit einem Schwerpunkt auf Europa

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### Abstract

To gain an overview of crocodile species held in zoos, the number of individuals kept, and the number of keeping institutions, we analyzed collection information from the Zoological Information Management System (ZIMS) database. Our analysis performed from June to July 2016 revealed that there were 24 species of crocodiles kept globally in 451 zoos, with 22 species kept in 185 European zoos. Two globally-kept species were lacking in European zoo holdings according to ZIMS. Of the 27 currently recognized species of crocodiles, one (*Mecistops* sp.) is not held in zoos at present. In addition we have opposed ZIMS data with information available from European studbooks and, based on literature evaluation, analyzed the development of crocodile collections in Europe during the last 40 years. Although ZIMS data is not complete, there is a trend discernible that only a few species are widely kept by the zoo community, whereas most species are represented in smaller numbers. We further discuss the importance of “Regional Collection Plans”, viz. long-term crocodile collection planning, and provide recommendations for population management such as considering a shift from very commonly kept species towards species that are in greater need of conservation support through zoo husbandry efforts.

**Keywords:** Crocodylidae; Zoos; *Ex situ* populations; Husbandry; Conservation breeding; ZIMS analysis

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## Introduction

Recently, Ziegler, Rauhaus, and Gill (2016) published a preliminary review of monitor lizards in zoological gardens, yielding useful results for future conservation breeding measures and improved zoo collection planning, respectively. As crocodiles are the reptiles in zoo holdings with the highest demands for required space, and comprise a considerable number of threatened taxa, we herein intended to provide an equivalent overview of crocodile species held in zoos, the number of individuals kept, and the number of keeping institutions, to uncover the relationship between commonness in zoological gardens, protection status, and necessity of (conservation) breeding. To obtain a global overview, we have compiled collection information from the Zoological Information Management System (ZIMS) database, an international record keeping database for zoological institutions. In addition we have opposed ZIMS data with information from European studbooks and analyzed the development of crocodile collections in Europe during the last 40 years based on data available from Honegger (1975), and Honegger and Zeigler (1991). We further discuss the importance of Regional Collection Plans, viz. long-term collection planning, and provide recommendations for crocodile population management.

## Methods

For this study we have analyzed: (1) the species of crocodiles held in zoos, (2) their individual numbers, and (3) the number of keeping institutions based on available data on living individuals from ZIMS. Many zoos subscribe to, and enter their collection data into ZIMS; however, the completeness of these data cannot be guaranteed, as some data may be obsolete or have not (yet) been entered, and some zoos do not participate in ZIMS. Thus, some data, also from institutions with comprehensive crocodile collections (e.g., Guangzhou Crocodile Zoo, Samutprakran Crocodile Farm) could not be included in this study, which is the reason that actual counts may be higher. This is also indicated, for example, by checking species holdings for further institutions in Germany and Europe using the website “Zootierliste” (<http://www.zootierliste.de/>). Here, further holding institutions can be found (see Fig. 1), but this website also includes private zoos and rescue stations. As far as available we also cross-checked numbers received from ZIMS with the individuals registered in the European studbooks. However, as there are only data available from four studbooks, ZIMS data were the only base for a comprehensive comparison between all species in a world wide scale. Our ZIMS analysis examined the current status of crocodiles maintained in zoos both in Europe and abroad, and was performed from June to July 2016. The updated number of *Crocodylus palustris* held at Madras Crocodile Bank Trust were not taken from ZIMS but received directly from the Madras Crocodile Bank Trust. Species from polytypic genera, which were not specifically identified in ZIMS, were not considered in this analysis: *Alligator* sp. (13 individuals: 0.0.13), *Caiman* sp. (10 individuals: 0.3.7), and *Crocodylus* sp. (20 individuals: 1.0.19). We also have analyzed the development of crocodile collections in Europe during the last 40 years based on data available from Honegger (1975), and Honegger and Zeigler (1991), who conducted surveys by sending questionnaires to the largest zoos.

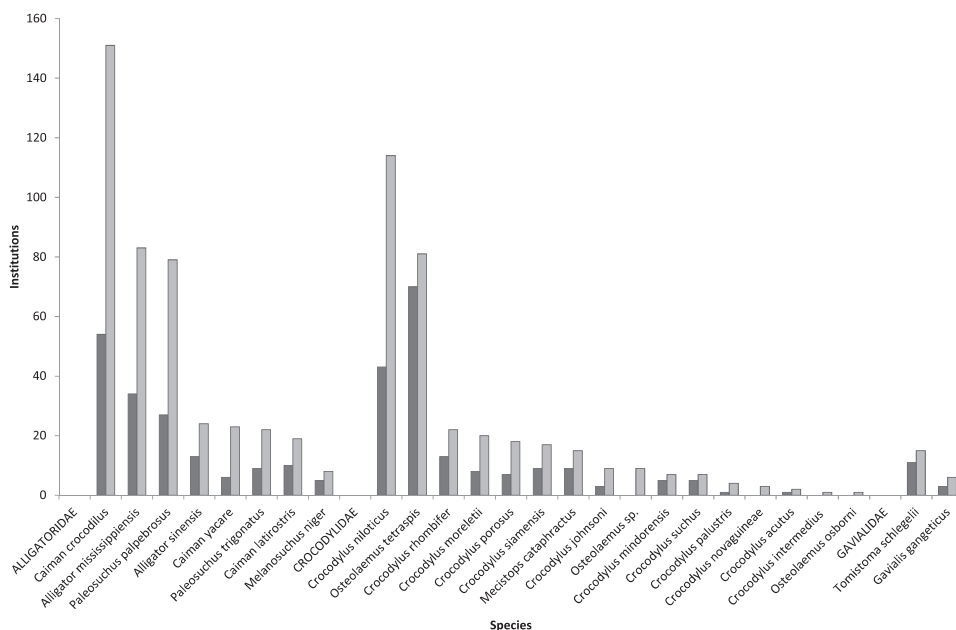


Fig. 1. Total numbers of crocodile keeping institutions in Europe after ZIMS (dark grey columns) versus data from "Zootierliste" (light grey columns).

Table 1. Crocodile species after Uetz & Hošek (2016) and Ziegler (2016); Uetz & Hošek (2016) list *Crocodylus raninus* as valid species, but with unclear status (it has been considered as a synonym of *C. porosus*), wherefore it is not included in the table.

**Crocodylidae**

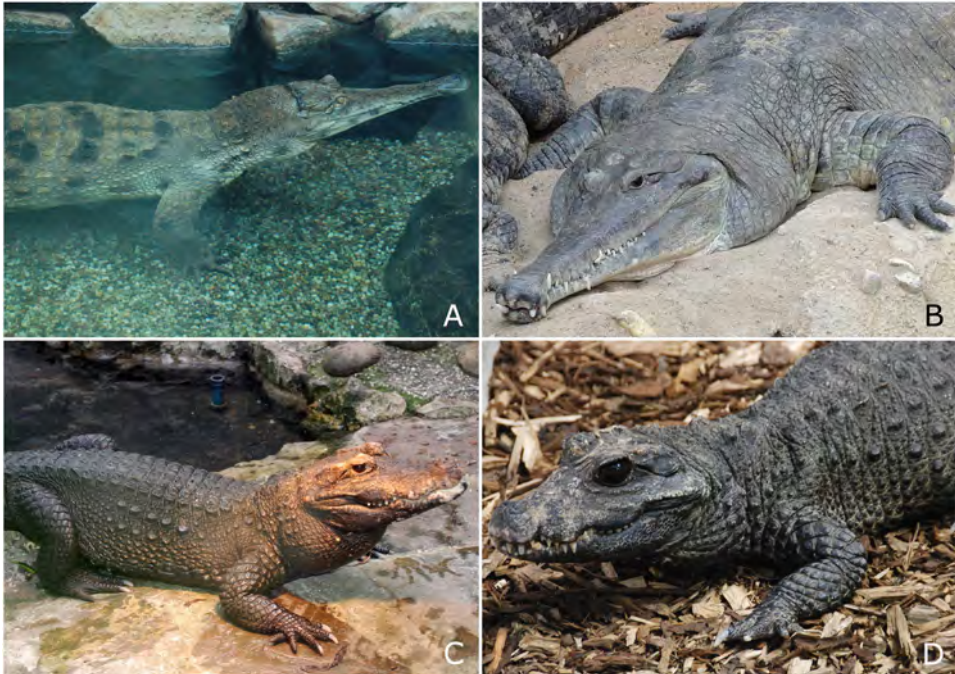
- Crocodylus acutus*
- C. intermedius*
- C. johnsoni*
- C. mindorensis*
- C. moreletii*
- C. niloticus*
- C. novaeguineae*
- C. palustris*
- C. porosus*
- C. rhombifer*
- C. siamensis*
- C. suchus*
- Mecistops cataphractus*
- Mecistops sp.*
- Osteolaemus tetraspis*
- O. osborni*
- Osteolaemus sp.*

**Alligatoridae**

- Alligator mississippiensis*
- A. sinensis*
- Caiman crocodilus*
- C. latirostris*
- C. yacare*
- Melanosuchus niger*
- Paleosuchus palpebrosus*
- P. trigonatus*

**Gavialidae**

- Gavialis gangeticus*
- Tomistoma schlegelii*



**Fig. 2.** Recent taxonomic changes: *Mecistops cataphractus* sensu lato has been split into the (A) nominate form (phot. F. Schmidt) and (B) *Mecistops* sp. (phot. A. Rauhaus), and *Osteolaemus tetraspis* has been split into the nominate form, (C) *O. osborni*, and (D) *Osteolaemus* sp. n. (phot. F. Schmidt).

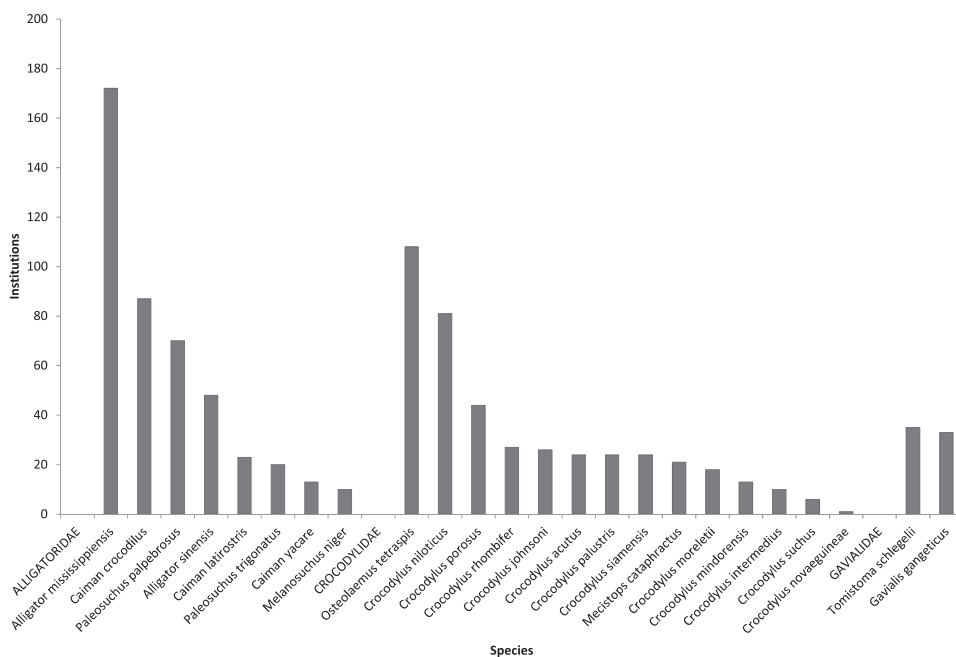
Crocodile systematics followed Uetz and Hošek (2016) and Ziegler (2016) (see Table 1). In ZIMS and “Zootierliste”, there was no differentiation between *Mecistops cataphractus* and *Mecistops* sp. (e.g., Shirley, Villanova, Vliet, & Austin, 2014), and *Osteolaemus osborni*, which we herein treated at full species level, was listed as subspecies of *O. tetraspis* (Fig. 2). In “Zootierliste” and in the European studbook it was differentiated between *Osteolaemus t. tetraspis*, *O. tetraspis osborni* and *O. tetraspis* subsp. nov., which were treated here as *O. tetraspis*, *O. osborni* and *Osteolaemus* sp. (e.g., Schmidt, Franke, Shirley, Vliet, & Villanova, 2015; Shirley, Villanova, et al., 2014; Shirley, Vliet, Carr, & Austin, 2014; Smolensky, Hurtado, & Fitzgerald, 2015). Individuals listed as *Crocodylus cataphractus* in ZIMS herein were included in *Mecistops cataphractus*. *Crocodylus suchus* and *Caiman yacare*, treated as subspecies of *C. niloticus* and *C. crocodilus* in ZIMS, respectively, were considered as distinct species in this review (e.g., Trutnau & Sommerlad, 2006; Ziegler, Hauswaldt, & Vences, 2015).

## Results

According to our ZIMS analyses, 24 species of crocodiles were maintained globally in 5894 individuals in a total of 451 zoos (see Table 2), with 22 species kept in 1230 individuals

**Table 2.** Numbers of crocodile keeping zoos and kept individuals in a world wide scale sorted by genus (after ZIMS).

Genus	Institutions	Individuals
<b>Alligatoridae</b>		
<i>Alligator</i>	220	1845
<i>Caiman</i>	99	483
<i>Melanosuchus</i>	10	50
<i>Paleosuchus</i>	84	272
<b>Crocodyliidae</b>		
<i>Crocodylus</i>	200	2414
<i>Mecistops</i>	21	58
<i>Osteolaemus</i>	108	259
<b>Gavialidae</b>		
<i>Gavialis</i>	31	440
<i>Tomistoma</i>	35	100



**Fig. 3.** Crocodile keeping zoos in a world wide scale (after ZIMS).

in 185 European zoos (see Figs. 3–8). Two globally-kept species were absent from European zoo holdings according to ZIMS: *Crocodylus intermedius*, and *C. novaeguineae*. However, according to the website “Zootierliste” the aforementioned two species are represented among European facilities.

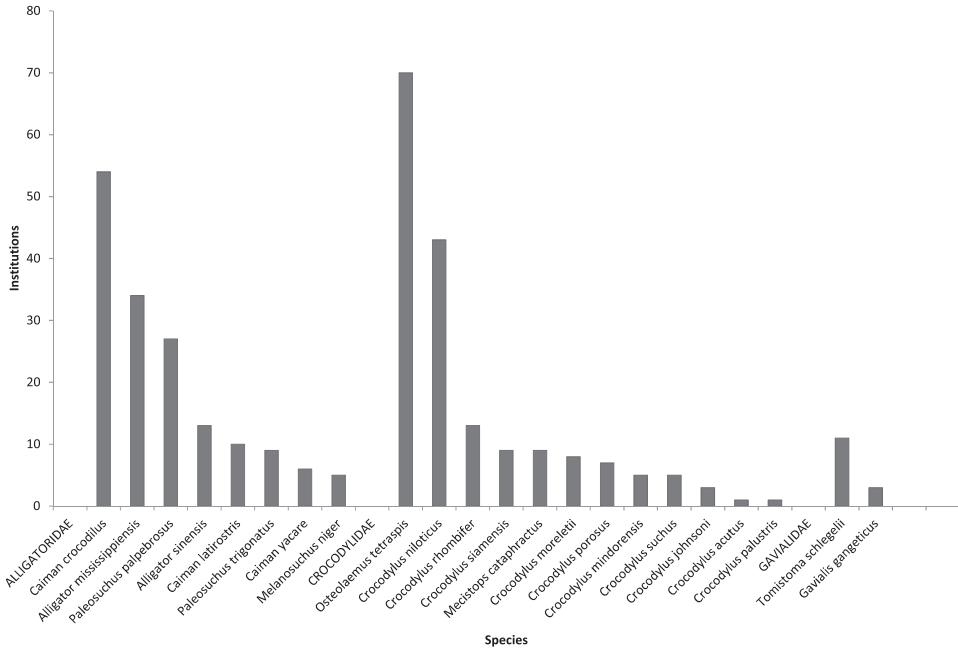


Fig. 4. Crocodile keeping zoos in Europe (after ZIMS).

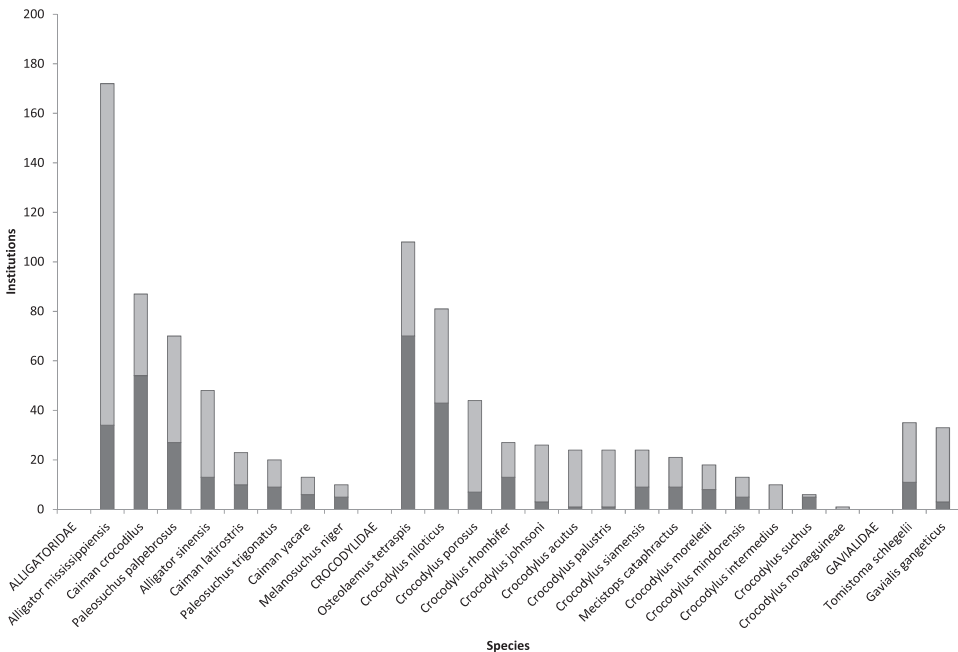


Fig. 5. Total numbers of crocodile keeping zoos in a world wide scale (light grey columns) including crocodile keeping zoos in Europe only (dark grey columns inside grey columns) (after ZIMS).

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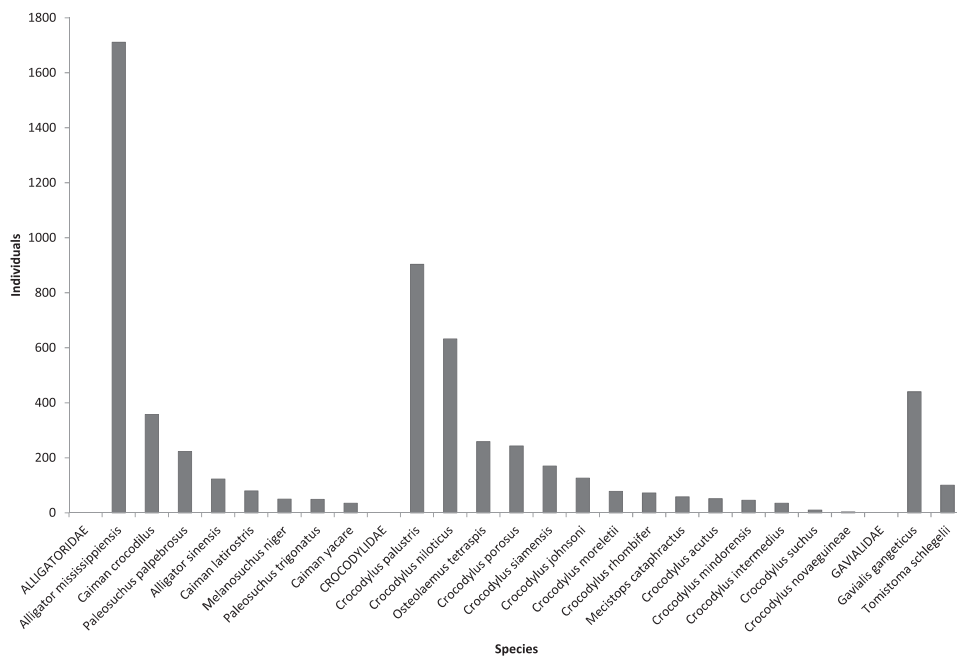


Fig. 6. Individual numbers of crocodiles kept in zoos in a world wide scale (after ZIMS).

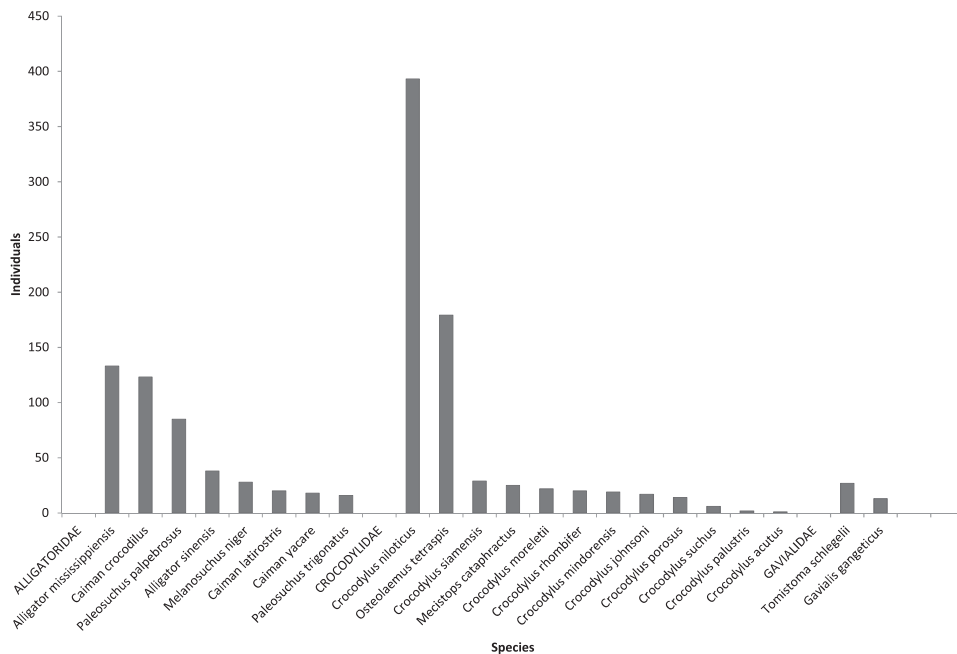
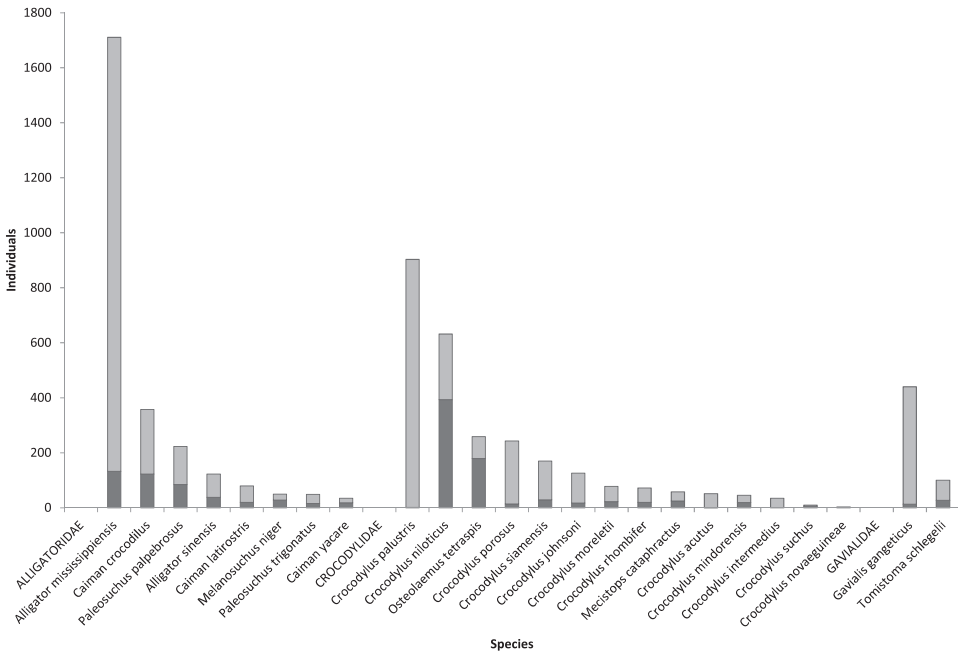


Fig. 7. Individual numbers of crocodiles kept in European zoos (after ZIMS).



**Fig. 8.** Total individual numbers of crocodiles kept in zoos in a world wide scale (light grey columns) including total individual numbers of crocodiles only kept in European zoos (dark grey columns inside grey columns) (after ZIMS).

Of the 27 currently recognized crocodile species (Alligatoridae 8, Crocodylidae 17, Gavialidae 2, see Table 1), three (11%) are presently not held in zoos according to ZIMS: *Mecistops* sp., *Osteolaemus osborni*, and *Osteolaemus* sp. It is possible that some zoos may keep these species but have not yet entered this information into ZIMS, or because the recently resurrected taxa were listed under the collective names (*Mecistops cataphractus*, *Osteolaemus tetraspis*). According to the website “Zootierliste” *O. osborni* and *Osteolaemus* sp. are represented among European facilities. In fact, according to the European studbook (Schmidt, 2016) in total 159 *O. tetraspis* are held in 53 zoos, 20 *Osteolaemus* sp. in 11 zoos, and only one *O. osborni*. Generally, our comparisons of data received through ZIMS with current data available from the European studbooks revealed more details and higher numbers both for individuals and institutions based on the studbooks (see Table 3).

The five most common crocodile species held globally in zoos were *Alligator mississippiensis* (kept in 172 zoos), *Osteolaemus tetraspis* (108 zoos), *Caiman crocodilus* (87 zoos), *Crocodylus niloticus* (81 zoos), and *Paleosuchus palpebrosus* (70 zoos). The greatest numbers of individuals held globally were of *Alligator mississippiensis* ( $n = 1711$ ), *Crocodylus palustris* ( $n = 903$ ), *C. niloticus* ( $n = 632$ ), *Gavialis gangeticus* ( $n = 440$ ), and *Caiman crocodilus* ( $n = 358$ ). The rarest species in zoos on a global scale were *Crocodylus novaeguineae* (kept in only a single zoo), *C. suchus* (kept in six zoos), *C. intermedius* and *Melanosuchus niger* (kept in ten zoos each), as well as *Caiman yacare* and *Crocodylus mindorensis* (kept in 13 zoos each) (Fig. 9). The lowest numbers of individuals held



**Table 3.** Crocodile numbers and number of keeping institutions for crocodiles for which up-to-date data from European studbooks exist (currently not available for *Alligator sinensis* and *Crocodylus siamensis*): ZIMS data versus information from most recent studbook editions (Bungard, 2015; Fernández-Hoyo, 2012; Schmidt, 2016; Ziegler & Rauhaus, 2016).

Genus	ZIMS		Studbook	
	Individuals	Institutions	Individuals	Institutions
<i>Crocodylus mindorensis</i>	19	5	54	7
<i>C. rhombifer</i>	20	13	38	17
<i>Osteolaemus</i> (all taxa)	179	70	239	83
<i>Tomistoma schlegelii</i>	27	11	49	15

globally were of *Crocodylus novaeguineae* ( $n = 3$ ), *C. suchus* ( $n = 10$ ), *Caiman yacare* and *Crocodylus intermedius* ( $n = 35$  each), as well as *C. mindorensis* ( $n = 49$ ).

The most common species kept among European zoos were *Osteolaemus tetraspis* (kept in 70 zoos), *Caiman crocodilus* (54 zoos), *Crocodylus niloticus* (43 zoos), *Alligator mississippiensis* (34 zoos), and *Paleosuchus palpebrosus* (27 zoos) (Fig. 10). Among European zoos the greatest numbers of individuals held were of *Crocodylus niloticus* ( $n = 393$ ), *Osteolaemus tetraspis* ( $n = 179$ ), *Alligator mississippiensis* ( $n = 133$ ), *Caiman crocodilus* ( $n = 123$ ), and *Paleosuchus palpebrosus* ( $n = 85$ ). The rarest species kept among European zoo holdings were *Crocodylus acutus* and *C. palustris* (each kept in only a single zoo), *C. johnsoni* and *Gavialis gangeticus* (kept in three zoos each), as well as *Crocodylus mindorensis*, *C. suchus* and *Melanosuchus niger* (kept in five zoos each). Among European zoos, the lowest numbers of individuals held were of *Crocodylus acutus* ( $n = 1$ ), *C. palustris* ( $n = 2$ ), *C. suchus* ( $n = 6$ ), *Gavialis gangeticus* ( $n = 13$ ), and *Crocodylus porosus* ( $n = 14$ ).

In a world wide scale, Alligatoridae are most often represented (kept in 443 institutions) compared to Crocodylidae (427 institutions) and Gavialidae (kept in 68 institutions). Individual numbers of Alligatoridae and Crocodylidae were almost equal (2629 versus 2686), with Gavialidae bearing the lowest individual number (540). In Europe, most zoos (174) keep members of the Crocodylidae, with 158 zoos keeping Alligatoridae and only 14 zoos keeping Gavialidae. Further, in Europe members of the Crocodylidae represent the highest individual numbers (727), followed by Alligatoridae (461), and Gavialidae (40).

During our ZIMS analyses, in the framework of our comparison between European and global crocodile zoo populations we also found some regional differences and preferences, respectively. For example the preference of North American zoos to keep *Alligator mississippiensis* (117 of in total 172 institutions) and *Crocodylus acutus* (16 of 24 institutions); the preference of Asian zoos to keep *Gavialis gangeticus* (21 of in total 31 institutions) and *Crocodylus palustris* (20 of 22 institutions); the preference of Australian zoos to keep *Crocodylus johnsoni* (18 of in total 26 institutions); and the preference of European zoos to keep *Osteolaemus tetraspis* (70 of in total 108 institutions), *Crocodylus niloticus* (43 of 81 institutions), and representatives of the *Caiman crocodilus* complex (54 of 87 institutions).

Regarding sex ratios, we observed a rather balanced situation (see Fig. 11). Generally, the numbers of females were slightly higher than numbers of males. Females were more abundant than males in 21 species, and in 8 species (single individuals excluded),



**Fig. 9.** The rarest species in zoos on a global scale were (A) *Crocodylus novaeguineae* (phot. F. Schmidt), (B) *C. suchus*, (C) *C. intermedius* (phot. A. Rauhaus) and (D) *Melanosuchus niger* (phot. F. Schmidt), as well as (E) *Caiman yacare* and (F) *Crocodylus mindorensis* (phot. T. Ziegler).

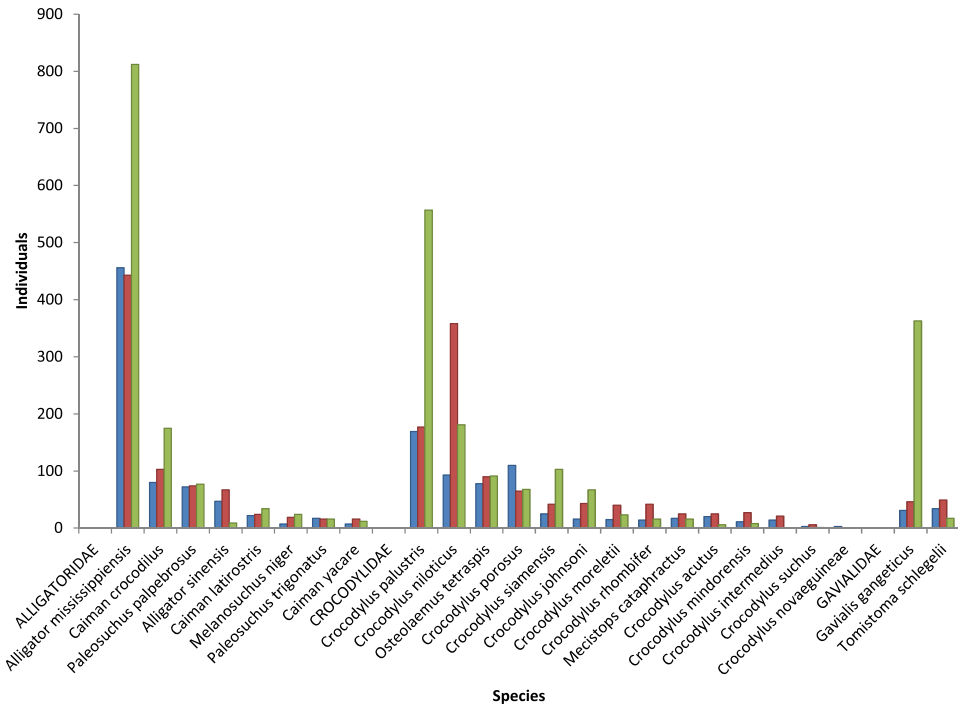
the number of females was at least twice the number of males (sex ratios expressed as male.female.undetermined): *Crocodylus johnsoni* (16.43.67), *C. mindorensis* (11.27.8), *C. moreletii* (15.40.23), *C. niloticus* (93.358.181), *C. suchus* (3.6.1), *C. rhombifer* (14.42.16), *Caiman yacare* (7.16.12), and *Melanosuchus niger* (7.19.24). For four species there were (slightly) more males than females: *Crocodylus novaeguineae*, *C. porosus*, *Alligator mississippiensis*, and *Paleosuchus trigonatus*. Our analysis further revealed a high number of individuals with undetermined sex ( $n = 2676$ : Alligatoridae 1159, Crocodylidae 1137,



**Fig. 10.** The most common species kept among European zoos were (A) *Osteolaemus tetraspis*, (B) *Caiman crocodilus* (phot. F. Schmidt), (C) *Crocodylus niloticus* (phot. A. Rauhaus), (D) *Alligator mississippiensis* (phot. F. Schmidt), and (E) *Paleosuchus palpebrosus* (phot. T. Ziegler).

Gavialidae 380), which represented either unsexed mature individuals or juveniles which were too young for proper sex identification.

Most zoos having entered their data into ZIMS were from Europe (185 institutions), North America (161), Asia (58), and Australia (Oceania) (24); apparently few zoos use ZIMS in South America (15) and Africa (8). Nevertheless, a trend is clearly discernible from the data, viz. that few species are widely-kept in the zoo community. Most species are represented in smaller numbers in zoo holdings and for few species zoo populations



**Fig. 11.** Total individual numbers of crocodiles kept in zoos in a world wide scale (after ZIMS), sorted by sex (blue = males, red = females, green = juveniles/unsexed).

are very small. For one species (*Mecistops* sp.) a zoo population is virtually not existing at time.

Concerning the development of crocodile collections in Europe during the last 40 years, Honegger (1975) collected data from 28 European zoos for the year 1973, and Honegger and Zeigler (1991) included data from 58 European zoos for the year 1990. Although more institutions were included in the survey of Honegger and Zeigler (1991), for nearly all crocodile species the number of holding institutions actually dropped in between 1973 and 1990 (see Fig. 12), with the exception of the two small-sized species *Osteolaemus tetraspis* and *Paleosuchus palpebrosus*. Also the individual numbers for these two species increased between 1973 and 1990, as well as for *Alligator sinensis* and among the larger growing species for *Crocodylus niloticus* sensu lato and *C. rhombifer* (see Fig. 13). In particular the populations of *C. acutus* and *C. palustris* distinctly and constantly decreased over time. In contrast, the five species *Melanosuchus niger*, *Paleosuchus trigonatus*, *Crocodylus intermedius*, *C. mindorensis* and *C. moreletii*, which were among the seven rarest species in 1973 (Fig. 14), vanished completely by 1990. However, with the exception of *C. intermedius*, aforementioned species are kept again in European zoos nowadays, with growing populations (e.g., 54 individuals within the European Studbook for *C. mindorensis* after Ziegler & Rauhaus, 2016). In terms of species numbers per institution in Europe, in 1973 one institution kept on average seven species (Honegger, 1975), but only two in 1990 (Honegger &

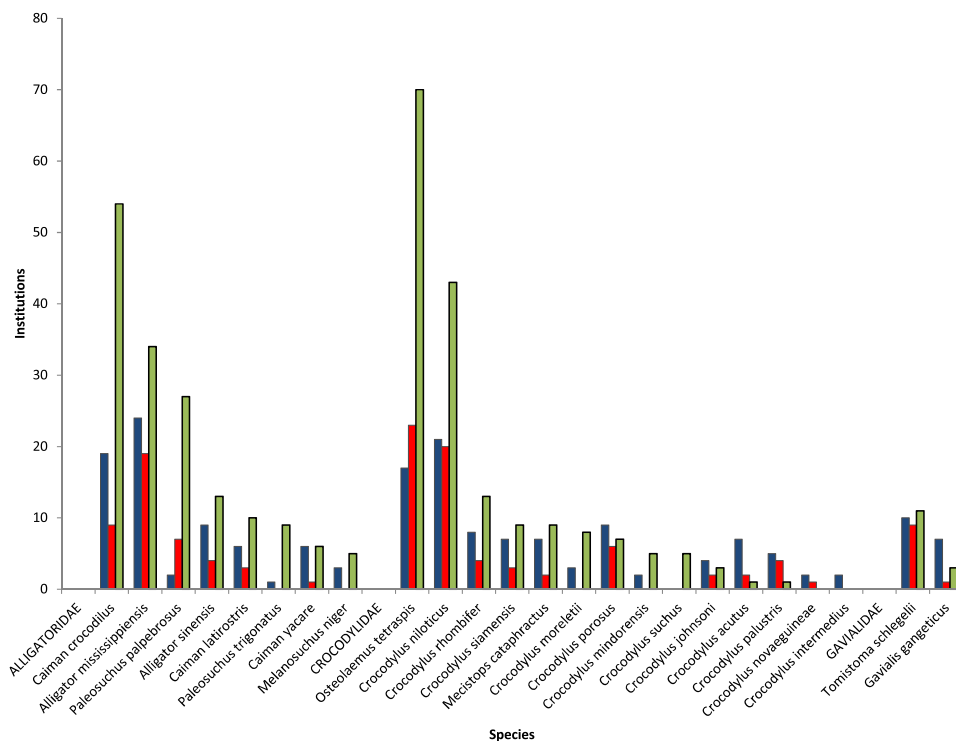


Fig. 12. Development of crocodile keeping zoo numbers in Europe from 1973 (Honegger, 1975, blue), 1990 (Honegger & Zeigler, 1991, red) to 2016 (this study, green).

Zeigler, 1991) until nowadays according to our ZIMS analysis. Also the individual numbers per institution dropped from on average 16 in 1973 over eight in 1990 to seven nowadays.

## Discussion

Zoo populations were usually considered for public display and education purposes, but they can also serve as assurance populations under human care. Due to the increasing threats in the wild, assurance colonies will become more and more important. In general, the majority of the crocodile species are represented in zoo collections, distributed among different institutions and regions. In comparison with other reptile groups, e.g., in monitor lizards, the ratio of 49:30 between species kept and not yet kept in zoos is distinctly worse and most monitor lizard species kept in zoos are characterized by small-sized populations only (Ziegler et al., 2016). All 27 currently recognized crocodile species are represented within zoos with the exception of one species (*Mecistops* sp.). A large male of this species was kept in Rotterdam Zoo until its death in 2014 (Shirley & Vliet, 2014; pers. comm.). However genetic screening of the *Mecistops* population in human care, which is currently undertaken, may reveal representatives of this cryptic sister species of *M. cataphractus*, which could be

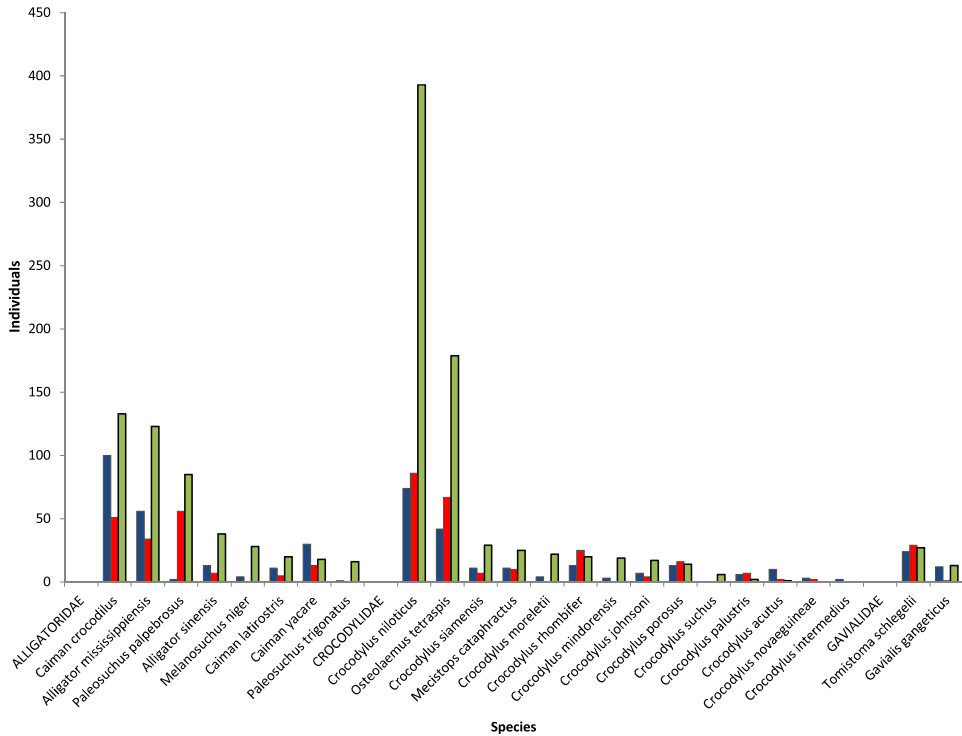


Fig. 13. Development of individual numbers of crocodiles kept in Zoos in Europe from 1973 (Honegger, 1975, blue), 1990 (Honegger & Ziegler, 1991, red) to 2016 (this study, green).

already kept but not yet correctly identified. A similar study on the European population of Nile crocodiles enabled the identification of specimens of the cryptic, recently resurrected Northwest African crocodile (*Crocodylus suchus*) before kept as *C. niloticus* in several zoos (Hauswaldt, Vences, Louis, Brennemann, & Ziegler, 2013; Ziegler et al., 2015). Following proposed changes in the taxonomy of the African dwarf crocodiles in the wild (Eaton, Martin, Thorbjarnarson, & Amato, 2009), the European collection also was screened within the framework of the European studbook, resulting in the proper identification of more than 95% of the individuals within the studbook (Franke et al., 2013; Schmidt et al., 2015). Most crocodile species are kept in medium-sized populations distributed among several zoos. There are only few species which appear in too low numbers held in only few zoos, among them also Critically Endangered species such as *Crocodylus intermedius* and *C. mindorensis*. For such species we propose to consider to replace not threatened crocodiles by these endangered species whenever there is an opportunity, e.g., when planning and constructing new exhibits.

Further, our results show remarkable differences between different regions with preferences for certain species (Figs. 15 and 16). This may be due to the availability of certain species and regional influences (preferences): There is a preference for *Alligator mississippiensis* and *Crocodylus acutus* in North America, for *C. johnsoni* in Australia and for *C.*



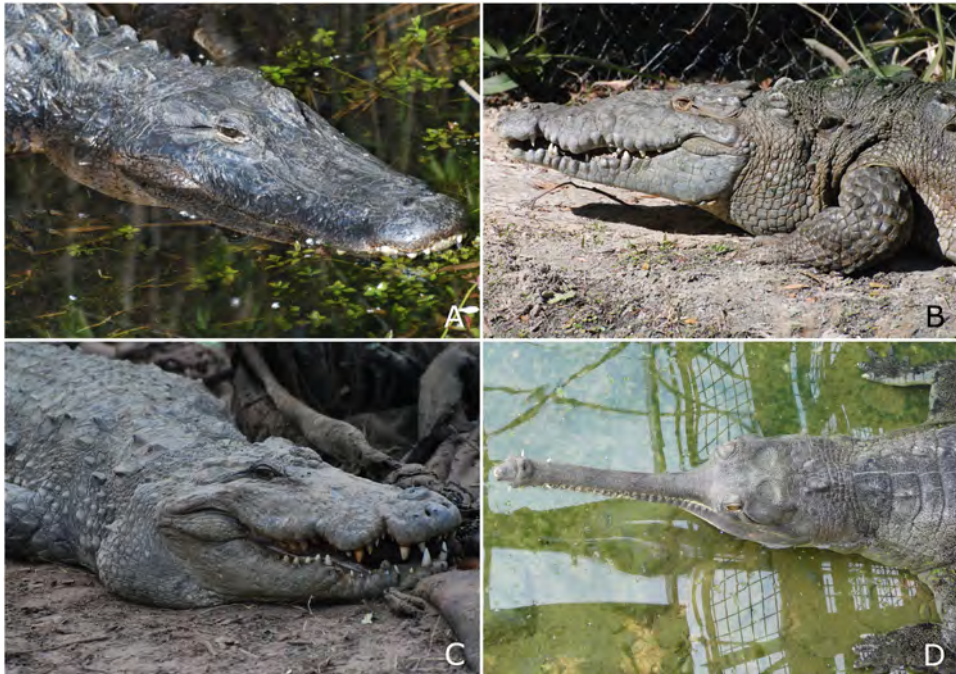
**Fig. 14.** (A) *Paleosuchus trigonatus* and (B) *Crocodylus moreletii* were among the seven rarest species in European zoos in 1973, which vanished completely by 1990 but are kept again in Europe nowadays, with growing zoo populations (phot. F. Schmidt).

*palustris* and *Gavialis gangeticus* in Asia. In these cases this can be explained by the availability through local endemism and in the case of *Crocodylus acutus* and the Asian species by their conservation status. However, the high presence of African species (*Crocodylus niloticus* and *Osteolaemus tetraspis*) in Europe must have different reasons, which are probably caused by the short geographic distance and by the history of European countries in colonial times. In addition, representatives of the *Caiman crocodilus* complex are not only kept in large numbers in European zoos, but also by private keepers in Europe. Similar to the dwarf caimans of the genus *Paleosuchus* and the African dwarf crocodiles of the genus *Osteolaemus*, members of the *Caiman crocodilus* complex are relatively small-growing, can be kept in comparatively small enclosures and are widely available in the pet trade. Regularly caimans are brought to the zoo community either directly by private holders, who are no longer able or willing to keep them, or by local authorities searching space

for confiscated animals. As hybridization can occur, genetic screening is the appropriate method to properly identify individuals of unknown origin (Sommerlad et al., 2014; Ziegler et al., 2015).

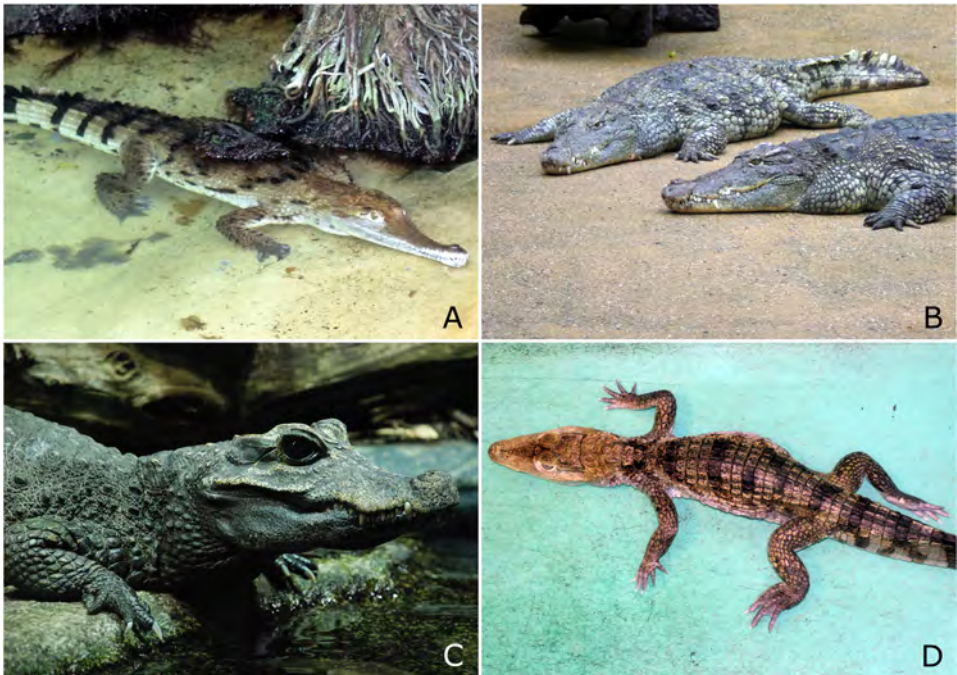
Regarding the development of crocodile collections in Europe during the last 40 years based on data available from Honegger (1975) and Honegger and Zeigler (1991), the general decrease of holding institutions and also of the number of species per institution can be explained by the fact, that especially the traditional, large zoos used to keep several large crocodile species represented by just one or only few individuals together in mixed exhibits. This husbandry system began to change in the 1980s, when most of these zoos focused on single taxa per enclosure (e.g., Brazaitis & Abene, 2008; Niekisch, 2010). In addition, a trend to keep smaller-growing taxa is discernible. However, it must be mentioned that historical data from afore mentioned studies have to be treated with caution, because, for example, older records of Philippine crocodiles in European zoos may be doubtful (see Hauswaldt et al., 2013; Sommerlad, Schmidt, & Ziegler, 2011) and recent taxonomical changes had not yet been considered in previous works.

As highlighted at the beginning of the discussion, in terms of conservation, zoo populations should be considered as assurance colonies under human care. If necessary, they can be used for restocking and/or reintroduction projects in the wild. This has already been done in several species such as *Alligator sinensis* or *Crocodylus intermedius* (e.g., Jiang et al.,



**Fig. 15.** There is a preference for (A) *Alligator mississippiensis* and (B) *Crocodylus acutus* in North America, and for (C) *C. palustris* (phot. F. Schmidt) and (D) *Gavialis gangeticus* in Asia (phot. A. Rauhaus).





**Fig. 16.** There is a preference for (A) *C. johnsoni* in Australia, and for African species – (B) *Crocodylus niloticus* (phot. T. Ziegler) and (C) *Osteolaemus tetraspis* (phot. F. Schmidt) – and representatives of the (D) *Caiman crocodilus* complex in Europe (phot. T. Ziegler).

2006; Rossi Lafferriere et al., 2016; Wang, Yao, Ding, Thorbjarnarson, & Wang, 2011). Therefore it is very important that zoo breeding programmes are based on pure-bred animals which exclude possible hybrids (Schmidt et al., 2015). Furthermore within such pure populations, the collections should be large enough to represent a healthy genetic diversity and avoid loss of genes (Schmidt & Ziegler, 2014). In general, space and resources in zoos are limited, both at individual institutions and on a global scale. Species selection for zoo collections should therefore be well-planned, particularly in terms of building up *ex situ* conservation breeding programs.

For proper zoo collection planning, it is crucial to consider the conservation status of the different crocodile taxa (see Table 4). CITES Appendix I includes 16 species and an additional subspecies. Certain populations of six of these species are listed in Appendix II. The remaining eleven species are listed in CITES Appendix II. The IUCN Red List of Threatened Species lists only 23 of the currently recognized 27 crocodile species. This is mainly due to the fact that especially in African crocodiles taxonomical changes arose quite recently, and the Red List status has not yet been evaluated. However, the IUCN SSC Crocodile Specialist Group (CSG), of which the authors are members, is currently dealing with respective assessments. Comparing the current conservation status of crocodiles (see Table 4) with the numbers kept in zoos, there are some obvious discrepancies that need to be addressed. Considering alligatorids, *Alligator mississippiensis*, *Caiman crocodilus*

**Table 4.** Crocodile species listed in the IUCN Red List of Threatened Species including status. CITES Appendices are marked as follows: non bold – CITES Appendix II (except for *Caiman crocodylus apaporiensis*, which is listed under CITES Appendix I); bold – CITES Appendix I; bold with asterisk – CITES Appendix I except for given populations which are listed under CITES Appendix II.

IUCN Red List status	Species
Critically Endangered	<b><i>Alligator sinensis</i></b> <b><i>Crocodylus intermedius</i></b> <b><i>C. mindorensis</i></b> <b><i>C. rhombifer</i></b> <b><i>C. siamensis</i></b> <b><i>Mecistops cataphractus</i></b> <b><i>Gavialis gangeticus</i></b>
Vulnerable	<b><i>Crocodylus acutus</i></b> * <b><i>C. palustris</i></b> <b><i>Osteolaemus tetraspis</i></b> <b><i>Tomistoma schlegelii</i></b>
Lower Risk/Conservation Dependent	<b><i>Melanosuchus niger</i></b> *
Lower Risk/Least Concern	<i>Alligator mississippiensis</i> <i>Caiman crocodylus</i> <b><i>C. latirostris</i></b> * <i>C. yacare</i> <i>Paleosuchus palpebrosus</i> <i>P. trigonatus</i> <i>Crocodylus johnsoni</i> <b><i>C. niloticus</i></b> * <i>C. novaeguineae</i> <b><i>C. porosus</i></b> *
Least Concern	<b><i>Crocodylus moreletii</i></b> *

and *Paleosuchus palpebrosus* are among the species with the lowest IUCN Red List status (Lower Risk/Least Concern), but at the same time the three alligatorid species which are represented in most zoos and in highest individual numbers. Considering crocodylids, three out of the five globally most endangered species, which are listed as Critically Endangered and registered in CITES Appendix I, are among the rarest species kept in zoos according to ZIMS: *Crocodylus intermedius* (35 specimens in 10 zoos globally), *C. mindorensis* (46 specimens in 13 zoos globally) and *Mecistops cataphractus* (58 specimens in 21 zoos globally). For the latter species, the real number might be lower, as genetic screening still must be conducted to check how many individuals in fact represent *Mecistops cataphractus* and whether *Mecistops* sp. or even hybrids are among the captive population.

The crocodile species which were considered by the CSG to merit priority action and major initiatives conformed with most species listed by the IUCN as Critically Endangered (*Alligator sinensis*, *Crocodylus intermedius*, *C. mindorensis*, *C. siamensis*, and *Gavialis gangeticus*). *Crocodylus rhombifer* and *Mecistops cataphractus*, likewise listed by the IUCN as Critically Endangered, were not considered but in addition *Tomistoma schlegelii* and *Caiman crocodylus apaporiensis*.

To coordinate keeping, conservation breeding and further conservation efforts of threatened taxa, the regional zoo associations have established Taxon Advisory Groups (TAG's); these are expert committees who deal with certain animal groups. TAG's also develop Regional Collection Plans (RCP's) for the different regions. While in Europe the crocodiles are covered by the Reptile TAG of the European Association of Zoos and Aquaria (EAZA), there is a special Crocodylian Advisory Group (CAG) in the Association of Zoos & Aquariums (AZA) in North America. In 2007, the CAG published a first comprehensive RCP (Vliet, Groves, Brueggen, & Odum, 2007), followed by a second edition five years later (Vliet, Groves, Brueggen, & Odum, 2012). The goals of these documents include serving as resource for information concerning crocodile species management, education and research and facilitate cooperation and collaboration between zoos, the scientific community, government agencies and the private sector (Vliet et al., 2012). But the main task of an RCP is to develop, conduct and support programmes for further crocodile conservation. RCP's may include space analyses within the region, define population size in order to be self-sustaining, and define the criteria after which species are selected and prioritized. These criteria usually include conservation status, existing collections, and possibilities to run successful programmes, education, research and display values as well as taxonomic uniqueness. For example, the CAG recommends eight species for breeding programmes (Species Survival Plans, SSP's), which include two yellow SSP's (viz. programs managing populations that are potentially sustainable but require additional attention and effort to increase their sustainability) for *Alligator sinensis* and *Crocodylus rhombifer*, and six red SSP's (programs managing populations that are currently unsustainable and in critical need of start-up efforts to help them increase their sustainability) for *C. intermedius*, *C. mindorensis*, *C. siamensis*, *Mecistops cataphractus*, *Gavialis gangeticus* and *Tomistoma schlegelii*. In contrast, five species are recommended for phasing out, which include *Caiman crocodilus*, *C. yacare*, *Crocodylus moreletii*, *C. novaeguineae* and *C. palustris*. The remaining species are recommended to be kept for display, education or research purposes with current non-breeding policies for *Alligator mississippiensis*, *Crocodylus acutus*, *C. niloticus* and *C. porosus*.

In Europe, the EAZA follows a relatively short RCP from 2009 (Gibson, 2009) and now has established six breeding programmes (Fig. 17), one European Endangered Species Programme (EEP: for *Alligator sinensis*) and five European Studbooks (ESB: for *Crocodylus mindorensis*, *C. rhombifer*, *C. siamensis*, *Osteolaemus tetraspis*, and *Tomistoma schlegelii*). Additionally, there is a monitor programme currently underway for *Mecistops cataphractus*, which may lead into another breeding programme being established soon. It will be important that existing programmes develop further and establish genetically pure and diverse crocodile populations as assurance colonies, develop or link with conservation projects for these species in the wild and educate the zoo visitors about their conservation needs. A good example is the aforementioned establishment of a European breeding programme for the more endangered West African *Mecistops* form (*M. cataphractus*), on which also AZA's SSP is focussing and for which a conservation project in Ivory Coast has started (Lovich, Shirley, Eschenbrenner, & Groves, 2014).

The importance of establishing breeding programmes is also demonstrated by the fact that none of the managed species in Europe has decreased in population since establishing the programme, and all except *Tomistoma schlegelii* actually did increase both in institution as



**Fig. 17.** In Europe, the European Association of Zoos and Aquaria (EAZA) has established six breeding programmes, one European Endangered Species Programme (EEP: for (A) *Alligator sinensis* (phot. A. Rauhaus)) and five European Studbooks (ESB: for (B) *Crocodylus mindorensis* (phot. T. Ziegler), (C) *C. rhombifer* (phot. F. Schmidt), (D) *C. siamensis* (phot. T. Ziegler), (E) *Osteolaemus tetraspis* (phot. F. Schmidt), and (F) *Tomistoma schlegelii*) (phot. T. Ziegler).

well as in individual numbers in the last 25 years. In contrast, species that were not managed (either not threatened or, when classified as Vulnerable, managed in different regions) did not increase in population (*Crocodylus porosus*), decreased (*C. acutus*, *C. palustris*) or even disappeared among European zoos (*Crocodylus novaeguineae*).

Theoretically, there is still a lot of space in zoos available for Critically Endangered crocodile species, which is currently occupied by Least Concern species. But that certainly

can only be dealt with in the long term, for example when planning and building new crocodile exhibits. As aforementioned the relatively large size of crocodiles may negatively impact conservation breeding under human care because crocodiles require a lot of space, which is usually scarce in the zoo community. Also not every zoo is in the position to keep crocodiles. Most crocodiles need warm tropical houses which are lacking especially in small zoos in temperate regions. However, such zoos could concentrate on Chinese alligators, which can be kept outside for most time of the year. Other species, like the Philippine crocodile, have special husbandry requirements, as they need specially designed enclosures with sliding gates for being able to separate individuals due to their high intra-specific aggressive behaviour (e.g., [Rauhaus & Ziegler, 2016](#)). Crocodile enclosures must be planned for the long term as well, as crocodiles have high longevity ([Weigl, 2014](#)) and it is usually difficult to find new institutions taking over surplus individuals. Compared to other reptiles and other animals anyway, the temperature-dependent sex determination can be of advantage for the population management, because due to the temperature gradient in the nest usually both sexes develop and, if a certain sex is required, this also can be acquired by adjusting the incubation temperatures during artificial incubation. Apart from *in situ* conservation measures in the wild and the *ex situ* conservation measures in zoos, a third aspect has to be considered for crocodiles, which is the sustainable management in crocodile farms. They can positively influence crocodile conservation ([Daltry et al., 2016](#)), but then it is crucial that species are professionally managed and kept in genetically pure farm populations.

## Outlook

In general, we herein recommend considering a shift from very commonly kept species such as *Alligator mississippiensis*, *Caiman crocodilus*, and *Crocodylus niloticus* towards species that are in greater need of support through zoo husbandry efforts. Genetic screenings are required in cryptic species complexes to build up fitting and genetically pure breeding groups. The IUCN Red List status should be updated for certain species. The building up and development of conservation breeding programs could be beneficial for selected, endangered species, as well as improved international network between zoos, *in situ* projects, crocodile experts (such as CSG members), and crocodile farms.

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