DER ZOOLOGISCHE GARTEN
THE ZOOLOGICAL GARDEN

doi:10.53188/zg0030

Zool. Garten N.F. 92 (2024) 147-158

Taxonomy Goes Zoos: the Inevitable Relevance of Species Delimitation and Conservation Unit Recognition for Adequate *ex situ* Conservation Measures

Taxonomy goes Zoos: die unvermeidliche Bedeutung von Artabgrenzungen und der Anerkennung von Schutzeinheiten für angemessene *Ex-situ*-Erhaltungsmaßnahmen

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Abstract

The One Plan Approach to Conservation by the IUCN Conservation Planning Specialist Group (CPSG) proposes to combine in situ and *ex situ* conservation actions. However, the value of *ex situ* conservation programs run by respective zoos relies on sound scientific evidence of selected conservation units. Only when species and their geographic ranges are adequately defined, they can be properly protected. Accurate taxonomic information, based in particular on integrative analyses that combine several lines of evidence with the molecular assessments being among the most insightful, is not only important for proper identification of species or conservation units in zoo holdings but also for exclusion of hybrids from breeding programs. Molecular analyses, including phyloforensic research, are crucial for conservation units' delimitation and appropriate animal pairing and to prepare suitable restocking measures, to avoid artificial hybridization in conservation breeding facilities, releases in unsuitable regions, and genetic pollution. In this review, some topical vertebrate examples are provided to highlight the significance of sound taxonomy for subsequent conservation measures, including molecular diagnoses of independently evolving lineages for adequate One Plan Approach conservation practice.

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Keywords: conservation units, integrative taxonomy, molecular screening, One Plan Approach to Conservation, phyloforensics, restocking, zoo population planning

There is an underground conflict within the discipline of conservation biology between those interested to prevent populations from becoming too small to retain genetic diversity by adopting a more inclusive Evolutionary Significant Unit (ESU) definition and those that continue to highlight the need for an objective and evolutionary approach to ESU‘s delimitation even if this means having a greater number of conservation units with inevitably smaller ranges and a lower number of individuals (Zachos et al., 2013; Senn et al., 2014; Gippoliti et al., 2018; Gippoliti & Groves, 2020) and thus more prone to extinction. This is an ill-conceived scientific dilemma, as the study of biodiversity and delimitation of species are complex autonomous scientific issues that should be left unaffected from extra-scientific practical management problems (Dubois, 2003). At present there is also an extensive scientific debate around the species‘ concept which shall be applied, of which some conservationists and biologists seem unaware (cf. Zachos, 2016). The aforementioned visions collide when a distinct ESU established by a population geneticist is considered a distinct species by a taxonomist following an evolutionary species concept (Goldstein et al., 2000), the latter move being perceived as ‚anarchic‘ by some biologists (Garnett & Christidis, 2017). Therefore, conservation biologists and zoo managers should be prepared to coexist with taxonomic conflicts and scientific debates. Yet this seems not always the case at present.

This conflict may appear far and mostly ‚academic‘ in several fields of conservation biology, and specifically for in situ conservation as the apparent value of a protected area may not be changed if it protects a population labelled as *Ursus arctos* Linnaeus, 1758, *Ursus arctos isabellinus* Horsfield, 1826 or *Ursus isabellinus*, (but see Hazevoet, 1996; Gippoliti & Amori, 2012). However, the same certainly cannot be said when we are dealing with *ex situ* conservation in zoos and other dedicated facilities (van Bemmel, 1971; Dathe, 1978; Ziegler et al., 2015; Gippoliti, 2019). The following case examples reinforce that exchange and networking with taxonomists positively pave the way for improved One Plan Approach conservation.

A classical recent example originated from the IUCN/SSC Felid Specialist Group attempt to develop a consistent felid taxonomy as a basis for conservation efforts. The results presented by Kitchener et al. (2017) led to a severe contraction of the recognised tiger *Panthera tigris* (Linnaeus, 1758) subspecies. If this taxonomic contraction had been immediately accepted by the zoo community, it would have led to the dismissal of several coordinated *ex situ* breeding programs for tiger subspecies (Luo et al., 2010) if a subsequent study had not contradicted these results (Liu et al., 2018), confirming the validity (‚reality‘) of the classically accepted tiger subspecies. The same problem arises with the lumping of North China and Amur subspecies of leopards, *Panthera pardus japonensis* (Gray, 1862) and *P. pardus orientalis* (Schlegel, 1857) respectively, that could result in terminating the *ex situ* breeding program for the most threatened leopard taxon on Earth, the Amur leopard (Uphyrkina & O’Brien, 2003).

These extreme episodes demonstrate the critical importance of taxonomy, even because one of these subspecies, the Chinese tiger *Panthera tigris amoyensis* (Hilzhemier, 1905), exists only as an *ex situ* population. Although a single paper is often sufficient to terminate the validity of a taxon and thus deleting it from the conservation agenda, this needs extreme caution because synonymizations have frequently been subsequently reversed, for example when new datasets with new evidence were available. An example is the Northwestern African crocodile *Crocodylus suchus* E. Geoffroy, 1807, for long time hidden under the Nile crocodile *C. niloticus* (Laurenti, 1768), also in zoo collection holdings (Ziegler et al., 2015). Best studied species, such as tiger, may also be separated in a number of units for conservation (Hoelzel, 2023) but this extra-taxonomic option is precluded to most organisms at present.

Fig. 1: Amur leopard (*Panthera pardus orientalis*). Photo: S. Gippoliti

Fig. 2: Mhorr gazelle (*Nanger mhorr*). Photo: S. Gippoliti

Fig. 3: West African crocodile (*Crocodylus suchus*). Photo: A. Rauhaus

The simple fact that the number of currently recognised mammal species has grown to 6,495 compared to the 5,416 in 2005 – an increase of 1,079 species in about 13 years (Burgin et al., 2018); and in September 2024 the number raised at 6,753 (mammaldiversity.org) shows that increasing species number is a reality even for the most well-known taxonomic groups.

In general, careful consideration is recommended in the treatment of populations from different geographic lineages under *ex situ* conditions, in particular if different conservation breeding units or even taxa could be involved. Molecular analyses are thus crucial for separating different conservation units, carrying out proper population planning, and preparing suitable restocking measures to strengthen natural populations (Pohlová et al., 2014; Norman et al., 2018). A prominent example from herpetology is the Chinese softshell turtle *Pelodiscus sinensis* (Wiegmann, 1835) complex, a species listed as Vulnerable by the IUCN Red List and previously believed to be widespread, but now consisting of six species with smaller ranges and thus also being more threatened (Gong et al., 2021). Recently, a first conservation breeding program has been established for the taxonomically distinct conservation unit from northern Vietnam (Ziegler et al., 2020a). The black knobby newt *Tylototriton asperrimus* Unterstein, 1930 was also believed to be widespread and kept by both hobbyists and zoos, but now consists of a continuously growing number of micro-endemic species, that have to be dealt with independently (Bernardes et al., 2013).

This is in particular important taking the IUCN CPSG's One Plan Approach to Conservation into account, which combines *in situ* and *ex situ* conservation measures (Byers et al., 2013). In the Four-eyed turtle *Sacalia quadriocellata* (Siebenrock, 1903) several conservation units were identified recently applying a molecular analysis in a phylogeographical context. This is crucial on the one hand for building up adequate conservation breeding groups as suitable assurance colonies for later restocking measures to stabilize diminished natural populations. On the other hand, this knowledge helps to avoid genetic pollution by releasing individuals from confiscations in unsuitable populations and locations. Release in unsuitable regions could also lead to animal losses, if for example individuals from southern populations are transferred into the much cooler north during the winter time (Le et al., 2020). Such phyloforensic research also

Fig. 4: Four-eyed turtle (*Sacalia quadriocellata*). Photo: T. Ziegler

Fig. 5: Vietnamese crocodile lizard (*Shinisaurus crocodilurus vietnamensis*). Photo: T. Ziegler

has recently been performed for the water monitor lizard *Varanus salvator* species complex (Welton et al., 2013) and the crocodile lizard *Shinisaurus crocodilurus* Ahl, 1930, which were revealed to consist respectively of several taxa and conservation units. Genetic screening of zoo stocks was crucial to allocate held individuals to respective lineages (Ngo et al., 2020). Molecular analyses helped to allocate individuals to populations and geographic lineages, to identify hybrids and care for proper species identification and zoogeographical allocation. A recent example from ichthyology is the Malagasy rainbowfish *Bedotia madagascariensis* Regan, 1903, which was previously misidentified in European zoo holdings as *B. geayi* Pellegrin, 1907 until molecular identification took place (Ziegler et al., 2020b).

The mixing of different lineages or subspecies, as in the case of *Nanger dama* (Pallas, 1766), the dama gazelle (Senn et al., 2014), with the subspecies *Nanger dama mhorr* (Bennett, 1833) having a very small number of founders, must be carefully considered. It only seems to be justified, when total extinction of a taxon has to be prevented. Scientific evidence about the original genetic population structure, its origin and adaptive significance is crucial here, but often lacking (Thakur et al., 2018; Schreiber et al., 2018; Schreiber, 2022). For comparison, it is interesting to note that despite a long history of scientific debate whether the red wolf *Canis rufus* Audubon et Bachman, 1851, viz. was a true species or rather hybrids between coyotes and wolves (National Academies of Sciences, Engineering, and Medicine, 2019), the US Fish and Wildlife Service continues to support *ex situ* efforts and new reintroduction has recently taken place (Hinton et al., 2013; Gese et al., 2015).

Maintaining viable *ex situ* populations is at present one of the most important goal of modern zoological gardens (Robovský et al., 2020). Although greater emphasis is directed toward genetic and demographic goals, the value of these *ex situ* programs relies on the soundness of selected conservation units. As the recent case of the Chinese giant salamanders (genus *Andrias* Tschudi, 1837) highlights, breeding and releasing individuals without the due care of the taxonomic reality may exacerbate problems rather than being a solution (Yan et al., 2018). Formerly believed monotypic with a unique species, *Andrias davidianus* (Blanchard, 1871), Chinese authorities supported breeding and reintroduction programs that de facto mixed the four species currently recognised based on molecular analyses (Turvey et al., 2019). The *Andrias* case demonstrates that the arguments for a due attention to solid taxonomic evaluation before performing *ex situ* conservation and translocations (Dubois, 2006; Gippoliti et al., 2021) were well-founded. Another similar example concerns the genus *Tupinambis* Daudin, 1802, for which taxonomic revisions revealed the presence of multiple species in this once monotypic genus. However, individuals held in zoos continued to be associated to only one species, *T. teguixin* (Linnaeus, 1758), which was described more than 260 years ago. Thus, it was not surprising that first molecular analyses revealed more than one tegu species being held among zoos (Ziegler et al., 2019a). It should be noted that zoo support to taxonomic-phylogenetic research should always be positive if, as in the case of the Ethiopian endemic primate *Theropithecus gelada* (Ruppell, 1835), it helps to identify distinct ESUs that should be the target of in situ conservation programs (Zinner et al., 2018).

These examples reinforce the idea that zoo stocks should be carefully checked regarding both taxonomic affiliation and purity of breeding, because only properly identified and pure-bred zoo stocks are of conservation value in the sense of IUCN's One Plan Approach to Conservation. For example, if crocodiles with farm origin should be included in conservation breeding and restocking projects, genetic testing of purity of breeding is crucial, as hybrids were reported, e.g. among held Siamese crocodiles *Crocodylus siamensis* (Schneider, 1801) and Philippine crocodiles *C. mindorensis* Schmidt, 1935 (Ziegler et al., 2015). The case of another charismatic zoo animal, the giraffe, is emblematic here, as holdings of animals of different provenances were encouraged by a general lack of credibility that surrounded taxonomy and the subspecies concept in biological circles (Geist, 2007; Vinarski 2015a; 2015b) during most of the twentieth

Fig. 6: Cryptic golden tegu (*Tupinambis cryptus*). Photo: T. Ziegler

Fig. 7: Philippine crocodile (*Crocodylus mindorensis*). Photo: T. Ziegler

century. Giraffes now are recognised as belonging to a still unstable number of species and subspecies (Groves & Grubb, 2011; Fennesy et al., 2016; Petzold et al., 2020) with obvious hybrid *ex situ* subpopulations without any conservation significance having to be excluded from zoo breeding programs.

While debates about the taxonomic status of hidden or overlooked populations among higher vertebrates have been relatively common in recent years (Gippoliti & Groves, 2018; Taylor et al., 2019), true discoveries happen still regularly and scientific descriptions are continuously released among lower vertebrates. An impressive example is the megadiverse gecko genus *Cyrtodactylus* Gray, 1827 from Southeast Asia, with far more than 300 nominal species and thus representing the most diverse genus of the Gekkonidae. The species number of bent-toed geckos reported from Laos and Vietnam has remarkably increased from five in 1997 to 71 species in 2021 (Ngo et al., 2022). Only when species and their ranges are defined, they can be properly protected, because we can only protect what we know.

This is not where research ends, it is rather beginning with the adequate taxonomy. Next, habitat requirements and ecological adaptations must be determined to better understand the species' niche occupancy but also for the proper set up of keeping conditions for the build-up of conservation breeding programs in zoos (Ziegler et al., 2019b). To reach an official or increased legal protection status (i.e. IUCN Red List, CITES, new protected areas) population and threat analyses must follow, as they were performed recently for crocodile and warty newts, for genera such as *Tylototriton* Anderson, 1871, and *Paramesotriton* Chang, 1935, the Psychedelic Rock Gecko *Cnemaspis psychedelica* Grismer, Ngo & Grismer, 2010, tiger geckos *Goniurosaurus* Barbour, 1908, and the Green Water Dragon *Physignathus cocincinus* (G. Cuvier, 1829) (Bernardes et al., 2020; Nguyen et al. 2018, Ngo et al. 2016; Ngo et al., 2019, Gewiss et al. 2020). Several higher taxa, such as amphibians, constitute a diverse yet still incompletely characterised clade of vertebrates, in which new species are still being discovered and described at a high rate (Vietes et al., 2009; Streicher et al., 2020). Regardless of whether divergent lineages should or should not be recognized and described as distinct species, even conspecific divergence is important in *ex situ* conservation programmes. Nominally conspecific yet divergent lineages represent allopatric populations that may have genetic variants that represent incompatibilities or local adaptations and perhaps cannot or should not be interbred in human hands (Crawford et al., 2013). This highlights the significance of sound taxonomy for subsequent research and adequate One Plan Approach conservation measures.

Fig. 8: Cryptic bent-toed gecko (*Cyrtodactylus cryptus*). Photo: T. Ziegler

Fig. 9: Vietnamese crocodile newt (*Tylototriton vietnamensis*). Photo: A. Rauhaus

For the impact on biodiversity conservation worldwide, an increased attention to taxonomy and a stronger collaboration with the taxonomic community may prove highly beneficializing to both *ex situ* and *in situ* conservation. In the end, continuing discoveries of Earth biodiversity may prove a further force to increase awareness of the need to maintain its ecological properties among new generations of humans.

Acknowledgements

We thank Prof. Dr Minh D. Le (Vietnam National University, Hanoi), Prof. Theo B. Pagel and Dr A. Sliwa (Cologne Zoo, Cologne) for kindly commenting on a previous version of the manuscript. Dario Fraschetti (Paignton) kindly revised the final draft.

References

Backhaus, D., & Frädrich, H. (1965). Experiences keeping various species of *Ungulates* together at Frankfurt Zoo. International Zoo Yearbook, 5, 14-24.

Bernardes, M., Le, M.D., Nguyen, T.Q., Pham, C.T., Pham, A.V., Nguyen, T.T., Rödder, D., Bonkowski, M., & Ziegler T. (2020). Integrative taxonomy reveals three new taxa within the *Tylototriton asperrimus* complex (Caudata, Salamandridae) from Vietnam. ZooKeys, 935, 121-164.

Bernardes, M., Rödder, D., Nguyen, T.T., Pham, C.T., Nguyen T.Q., & Ziegler T. (2013). Habitat chracterization and potential distribution of *Tylototriton vietnamensis* in northern Vietnam. Journal of Natural History, 47,1161-1175.

Burgin, C.J., Colella, J.P., Kahn, P.L. & Upham, N.S. (2018) How many species are there? Journal of Mammalogy, 99(1), 1-14.
Byers, O. Lees, C. Wilcken, J.; Schwitzer, C. (2013) The One Plan approach: The philosophy and implementation of CBSG's approach to integrated species conservation planning. WAZA Magazine, 14, 2-5.
Crawford, A.J., Cruz, C., Griffith, E., Ross, H., Ibanez R., LIPS K.R., Driskell A.C., Bermingham, E. & Crump, P. (2013). DNA barcoding applied to *ex situ* tropical amphibian conservation programme reveals cryptic diversity in captive populations. Molecular Ecology Resources, 13, 1005-1018 doi: 10.1111/1755-0998.12054
Dathe, H. (1978). The meaning and value of breeds representing pure subspecies in zoological gardens. Zoologische Garten NF, 48, 164-166.
Dubois A. (2003). The relationships between taxonomy and conservation biology in the century of extinctions. Compte Rendue Biologies, 326, S9-S21.
Dubois, A. (2006) Species introductions and reintroductions, faunistic and genetic pollution: Some provocative thoughts. Alytes, 24, 147-164.
Fennessy, J., Bidon, T., Reuss, F., Kumar, V., Elkan, P., Nilsson, M.A., Vamberger, M., Fritz, U., & Janke, A. (2016). Multi-locus analyses reveal four giraffe species instead of one. Current Biology, 26, 2543-2549.
Folch, A. (1992). Family Apterygidae (Kiwis). Pp 104-110 in: Handbook of the Birds of the World. Vol. 1. Ostrich to Ducks (del Hoyo, J., Elliott, A., & Sargatal, J., eds). Barcelona: Lynx Edicions.
Fowler, M.E., & Miller, R.E. (2003). Zoo and wild animal medicine. (5th ed.). Philadelphia: W.B. Saunders & Co.
Garnett, S.T. & Christidis, L. (2017). Taxonomy anarchy hampers conservation. Nature, 546(7656), 25-27.
Geist, V. (2007). Defining subspecies, invalid taxonomic tools, and the fate of the woodland Caribou. Rangifer, 17, 25-28.
Gese, E.M., Knowlton, F.F., Adams, J.R., Beck, K., Fuller, T.K., Murray, D.L. et al. (2015). Managing hybridization of a recovering endangered species: the red wolf Canis rufus as a case study. Current Zoology, 61, 191-205.
Gewiss. L.R., Ngo, H.N., van Schingen-Khan, M., Bernardes, M., Rauhaus, A., Pham, C.T., Nguyen, T.Q., & Ziegler T. (2020). Population assessment and impact of trade on the Asian Water Dragon (*Physignathus cocincinus* Cuvier, 1829) in Vietnam. Global Ecology and Conservation, 23 e01193: 1-10.
Gippoliti, S. (2019). Conservation breeding programs and refined taxonomy as a political tool for biodiversity conservation: The de Beaux's and Durrell's legacies. Journal of Animal Diversity, 1, 26-33.
Gippoliti, S. & Amori, G. (2002). Mammal diversity and taxonomy in Italy: implications for conservation. Journal for Nature Conservation, 10, 33-44.
Gippoliti, S., Cotterill, F.P.D., Groves, C.P., & Zinner, D. (2018). Poor taxonomy and genetic rescue are possible co-agents of silent extinction and biogeographic homogenization among ungulate mammals. Biogeographia Journal of Integrative Biogeography, 33, 41-54.
Gippoliti, S., & Groves, C.P. (2018). Overlooked mammal diversity and conservation priorities in Italy: impacts of taxonomic neglect on a biodiversity hotspot in Europe. Zootaxa, 4434, 511-528
Gippoliti, S., & Groves, C.P. (2020). Cryptic problematic species and troublesome taxonomists: a tale of the Apennine bear and the Nile white rhinoceros. Pp. 509-527 in: Problematic Wildlife II – new conservation and management challenge in the human-wildlife interactions (Angelici, F.A., & Rossi, L., eds). Springer Chasm: Berlin.
Gippoliti, S., Robovský, J., & Angelici, F.M. (2021). Taxonomy and translocations of African mammals: a plea for a cautionary approach. Conservation, 1, 121-136.
Goldstein, P.Z., DeSalle, R., Amato, G., & Vogler, A.P. (2000). Conservation genetics at the species boundary. Conservation Biology, 14, 120-131.
Gong, Y.-A., Peng, L.-F., Huang, S., Lin, Y.-F., Huang, R.-Y., Xu, Y.-H., Yang, D.-C. & Nie L.-W.A. (2021). New species of the Genus *Pelodiscus* Fitzinger, 1835 (Testudines: Trionychidae) from Huangshan, Anhui, China. Zootaxa, 5060 (1), 137-145.
Groves, C.G., & Grubb, P. (2011). Ungulate taxonomy. Baltimore: The Johns Hopkins University Press.
Hazevoet, C.J. (1996). Conservation and species lists: taxonomic neglect promotes the extinction of endemic birds, as exemplified by taxa from eastern Atlantic islands. Bird Conservation International, 6, 181-196.
Hinton, J.W., Chamberlain, M.J., & Rabon, J.R., (2013). Red wolf (*Canis rufus*) recovery: a review with suggestions for future research. Animals, 3, 722-744.
Kitchener, A.C., Breitenmoser-Würsten, C., Eizirik, E., Gentry, A., Werdelin, L., Wilting, A., Yamaguchi, N., Abramov, A.V., Christiansen, P., Driscoll, C., Duckworth, J.W., Johnson, W., Luo, S.-J., Meijaard, E., O'Donoghue, P., Sanderson, J., Seymour, K., Bruford, M., Groves, C.,
Hoffmann, M., Nowell, K., Timmons, Z., & Tobe, S.A. (2017). Revised taxonomy of the Felidae. The final report of the Cat Classification Task Force of the IUCN/SSC Cat Specialist Group. Cat News Special Issue, 11, 1-80.
Le, M.D., McCormack, T.E.M., Hoang, H.V., Duong, H.T., Nguyen, T.Q., Ziegler, T., Nguyen, H.D., Ngo, H.T. (2020). Threats from wildlife trade: The importance of genetic data in safeguarding the endangered four-eyed turtle (). Nature Conservation, 41, 91-111.

Liu, Y.-C., Sun, X., Driscoll, C., Miquelle, D.G., Xiao, X., Martelli, P., Uphyrkina, O., Smith, J.L.D., O'Brien, S.J., & Luo. S.-J. (2018). Genome-wide evolutionary analysis of natural history and adaptation in the world's tigers. Current Biology, 28, 3840-3849.

Luo, S.-L., Johnson, W.E., & O'Brien, S.J. (2010). Applying molecular genetic tools to tiger conservation. Integrative Zoology, 5, 351-362. doi:10.1111/j.1749-4877.2010.00222.x.

National Academies of Sciences, Engineering, and Medicine (2019). Evaluating the taxonomic status of the Mexican gray wolf and the red wolf. Washington, DC: The National Academies Press. https://doi.org/10.17226/25351.

Ngo, H.N., Nguyen, T.Q., Nguyen, T.V., Barsch, F., Ziegler, T.M., & van Schingen, M. (2016). First population assessment of the endemic insular Psychedelic rock gecko (*Cnemaspis psychedelica*) in southern Vietnam with implications for conservation. Amphibian & Reptile Conservation, 10(2), 18-26.

Ngo, H.N., Nguyen, T.Q., Phan, T.Q., van Schingen, M., & Ziegler, T. (2019). A case study on trade in threatened tiger geckos (*Goniurosaurus*) in Vietnam including updated information on the abundance of the endangered G. catbaensis. Nature Conservation, 33, 1-19.

Ngo, H.T., Do, Q.H., Pham, C.T., Luu, V.Q., Grismer, L.L., Ziegler, T., Nguyen, V.T.H., Nguyen, T.Q., & Le, M.D. (2022). How many more species are out there? Current taxonomy substantially underestimates the diversity of bent-toed geckos (Gekkonidae, *Cyrtodactylus*) in Laos and Vietnam ZooKeys 1097, 135-152 doi: 10.3897/zookeys.1097.78127

Ngo, H.T., Nguyen, T.T., Le, M.D., van Schingen-Khan, M., Nguyen, T.Q., Rauhaus, R., Vences, M., & Ziegler, T. (2020). Genetic screening of captive crocodile lizards (*Shinisaurus crocodilurus*) in Europe. Zoologische Garten NF, 88, 17-30.

Norman, A.J., Putnam, A.S., & Ivy, J.A. (2018). Use of molecular data in zoo and aquarium collection management: Benefits, challenges, and best practices. Zoo Biology, 38, 106-118.

Petzold, A., Magnant, A.-S., Edderai, D., Chardonnet, B., Rigoulet, J., Saint-Jalme, M., Hassanin, A. (2020). First insights into past biodiversity of giraffes based on mitochondrial sequences from museum specimens. European Journal of Taxonomy, 703, 1-33.

Pohlová, L., Schepsky, P., Lehmann, T., Hochkirch, A., Masopustová, R., Šimek, J., Schoo, W., Roman Vodika, R., & Robovský J. (2014). Defining management units for European captive aardvarks. Zoo Biology, 33, 433-439.

Robovský, J., Melichar, L. & Gippoliti, S. (2020). Zoos and conservation in the Anthropocene: opportunities and problems. Pp. 451-484 in: Problematic Wildlife II – new conservation and management challenge in the human-wildlife interactions (Angelici, F.M., & L. Rossi, L., eds). Berlin: Springer Chasm.

Schreiber, A. (2022). Evolution of horn shape and sex dimorphism in subspecies of the dama gazelle (Bovidae: *Nanger dama* (Pallas, 1766)). Hystrix Italian Journal of Mammalogy, 33(2):172-185.

Schreiber, A., Moreno, E., Groves, C., & Robovský, J. (2018). Systematics and the management units of the dama gazelle Nanger dama. Gnusletter, 35(1), 8-12.

Senn, H., Banfield, L., Wacher, T., Newby, J., Rabeil, T., Kaden, J., Kitchener, A.C., Abaigar, T. Silva, T.L., Maunder, M., & Ogden, R. (2014). Splitting or lumping? A conservation dilemma exemplified by the critically endangered Dama Gazelle (*Nanger dama*). PLoS One, 9(6), e98693.

Streicher, J.W., Sadler, R., & Loader, S.P. (2020). Amphibian taxonomy: early 21st century case studies Journal of Natural History, 54, 1-13. https://doi.org/10.1080/00222933.2020.1777339

Taylor, P.J., Denys, C., & Cotterill, F.P.D. (2019). Taxonomic anarchy or an inconvenient truth for conservation? Accelerated species discovery reveals evolutionary patterns and heightened extinction threat in Afro-Malagasy small mammals. Mammalia, 83, 313-329. https://doi.org/10.1515/mammalia-2018-0031.

Thakur, M., Wullschleger Schättin, E. & McShea, W.J. (2018). Globally common, locally rare: revisiting disregarded genetic diversity for conservation planning of widespread species. Biodiversity and Conservation, 27, 3031-3035

Turvey, S.T., Marr, M.M., Barnes, I., Brace, S., Tapley, B., Murphy, R.W., Zhao, E., & Cunninham, A.A. (2019). Historical museum collections clarify the evolutionary history of cryptic species radiation in the world's largest amphibians. Ecology and Evolution, 9(18), 10070-10084.

Uphyrkina, O., & O'Brien, S.J. (2003). Applying molecular genetic tools to the conservation and action plan for the critically endangered Far Eastern leopard (*Panthera pardus orientalis*). Compte Rendue Biologies, 326, S93-S97.

van Bemmel, A.C.V. (1971). Keeping and breeding of pure subspecies in zoos and national parks. Zoologische Garten NF, 40, 160-162

Vietes, D.R., Wollenberg, K.C., Andreone, F., Köhler, J., Glaw, F., & Vences, M. (2009). Vast underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. Proceedings National Academy Science USA, 106, 8261-8272

Vinarski, M.V. (2015a). The fate of subspecies category in zoological systematics. 1. The history. Biology Bulletin Review, 5(5), 395-404.

Vinarski, M.V. (2015b). The fate of subspecies category in zoological systematics. 2. The present. Biology Bulletin Review, 5(5), 405-414.

Welton, L.J., Siler, C.D., Linkem, C.W., Diesmos, A.C., Diesmos, M.L., Sy. E., & Brown, R.M. (2013) Dragons in our mist: Phyloforensics of illegally traded Southeast Asian monitor lizards. Biological Conservation, 159, 7-15.

Yan, F., Lü, J.C., Zhang, B.L., Yuan, Z.Y., Zhao, H.P., Huang, S., Wei, G., Mi, X., Zou, D., Xu, W., Chen, S., Wang, J., Xie, F., Wu, S., Xu, C., Tapley, B., Turvey, S.T., Papenfuss, T.J., Cunningham, A.A., Murphy, R.W., Zhang, Y., & Che, J. (2018). The Chinese giant salamander exemplifies the hidden extinction of cryptic species. Current Biology, 28, R590-R592.

Zachos, F.E. (2016). Species concepts in biology. Historical development, theoretical foundations and practical relevance. Springer International Publishing: Switzerland.

Zachos, F.E., Clutton-Brock, T.H., Festa-Bianchet, M., Lovari, S., Macdonald, D.W., & Schaller, G.B. (2013). Taxonomy: species splitting puts conservation at risk. Nature, 494, 35.

Ziegler, T., Frank-Klein, N., Ommer, S., Hürche, R., Loiselle, P.V., & Vences, M. (2020b). Keeping and breeding of threatened endemic Malagasy freshwater fishes at Cologne Zoo (Germany): a contribution towards the advancement of a conservation breeding network. Zoologische Garten NF, 88, 123-155.

Ziegler, T., Hauswaldt, S., & Vences, M. (2015). The necessity of genetic screening for proper management of captive crocodile populations based on the examples of *Crocodylus suchus* and *C. mindorensis*. Journal of Zoo and Aquarium Research, 3, 123-127.

Ziegler, T., Rauhaus, A., & Vences, M. (2019a). Does genetic screening reveal first zoo breeding of the cryptic golden tegu (*Tupinambis cryptus*)? Zoologische Garten N.F., 87, 25-40

Ziegler, T., van Schingen, M., Rauhaus, A., Dang, P.H., Pham, D.T.K., Pham, C.T., & Nguyen T.Q. (2019b). New insights into the habitat use and husbandry of crocodile lizards (Reptilia: Shinisauridae) including the conception of new facilities for Vietnamese crocodile lizards *Shinisaurus crocodilurus vietnamensis* in Vietnam and Germany. International Zoo Yearbook, 53, 250-269.

Ziegler, T., Nguyen, T.T., Ong, A.V., Pham, C.T., & Nguyen T.Q. (2020a). In search of the spotted softshell turtle in Vietnam: An implementation of the One Plan Approach. WAZA News, 1, 24-27.

Zinner, D., Atickem, A., Beehner, J.C., Bekele, A., Bergman, T.J., Burke, R., Dolotovskaya, S., Fashing, P.J., Gippoliti, & S., Knauf, (2018). Phylogeography, mitochondrial DNA diversity, and demographic history of geladas (*Theropithecus gelada*). PLoS One, 13(8), e0202303.