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Threatened and extinct amphibians and reptiles in Italian natural history collections are useful conservation tools

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Abstract. Natural history museums are irreplaceable tools to study and preserve the biological diversity around the globe and among the primary actors in the recognition of species and the logical repositories for their type specimens. In this paper we surveyed the consistency of the preserved specimens of amphibians and reptiles housed in the major Italian scientific collections, and verified the presence of threatened species according to the IUCN Red List, including the Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) categories. Altogether, we analyzed 39 Italian zoological collections. We confirmed the presence of one extinct reptile (*Chioninia coctei*) and five extinct or extinct in the wild amphibian species (*Atelopus longirostris, Nectophrynoides asperginis, Pseudophilautus leucorhinus, P. nasutus,* and *P. variabilis*). Seven CR amphibians, fourteen CR reptile species and the extinct skink *C. coctei* are shared by more than one institution. Museums which host the highest number of threatened and extinct amphibian species are respectively Turin (17 CR and 1 EX), Florence (13 CR and 1 EX), and Trento (15 CR and 1 EW), while for reptiles the richest museums are those from Genoa (15 CR and 1 EX), Florence (11 CR and 1 EX), and Pisa (7 CR). Finally, we discussed the utility of natural history museums and the strategies to follow for the implementation of their functionality.

Keywords. Biodiversity, collections, conservation, herpetology, IUCN categories, natural history museums.

INTRODUCTION

Biodiversity collections hosted in natural history museums, universities and other institutions are important cultural, scientific heritages, irreplaceable resources, and useful tools for a great array of studies to enhance biodiversity understanding and conservation. These include systematic investigations, taxonomic revisions, species descriptions, epidemiology, anatomy, historical reconstructions (e.g., about collectors and the institutions housing their collections, as well as about the history of science in general), but also many more science-outreach purposes, such as educational activities, and exhibitions (Bakker et al., 2020).

The origin and the history of biological – in particular zoological - "voucher specimens" or, simply, "vouchers" (Schilthuizen et al., 2015) housed in scientific collections, are rather heterogeneous, since they may result from various activities, e.g., field surveys with collecting, sampling for scientific research, recovery of dead animals (e.g., on roads, from zoological parks, captive breeders, etc.), direct purchases from dealers (for collections increase, exhibits and education), and others (Funk et al., 2005). Data associated with vouchers may also vary substantially across periods, going from just a rough species determination (as it was often the case in the past, especially for specimens obtained from commercial dealers), to an exhaustive set of information, including place and date of collection, collectors, donors, ecological and behavioral parameters, etc.

The different kind of preservation techniques may also affect the degree of scientific, expositive and utility of specimens, going from traditionally naturalized / preserved specimens used for display, to "ad hoc" prepared series for scientific research, accompanied by tissue samples, photographs, parasitological/epidemiological specimens, etc. (Lorch et al., 2021). Particular and precious vouchers hosted in collections of museums are the so-called «type specimens», i.e., preserved individuals upon which new taxa are described, including, among the others, holotypes, paratypes, lectotypes, and syntypes (Dubois, 2017).

Natural history museums (hereafter NHMs or museums) are considered the heirs of the 16th-17th century "Wunderkammern", also known as "cabinets of curiosities" (Butler et al., 1998; McCarter et al., 2001). The collections of "mirabilia", "naturalia" and "exotica" (as natural history objects were sometimes labeled in the

past) were accumulated over the time by naturalists and "savants". In a first phase of museums' life, these objects were mainly used to solicit and address the wonders and varieties of nature, at those times still largely unknown. Until then, objects were at the same time the origin and the pulsing heart of these collections and early museums, as well as one of the few ways to discover and describe nature (Findlen, 1996).

Nowadays, the ultimate profile of scientific collections can be drawn looking at what happened in medium-large and national museums (Suarez and Tsutsui, 2004). These institutions, which are true documenting centers and repositories of the world's geo- and biodiversity, manage specimens and associated materials that often represent unique evidence of species distribution and evolution patterns (Clemann et al., 2014). The information gathered from extinct species is irreplaceable and lost forever: the International Union for Conservation of Nature (IUCN) declared 160 animal and plant species extinct between 2010 and 2019, although recent estimates suggest that this estimate may be as high as one thousand species per year (Ceballos et al., 2015; Shivanna, 2020).

NHMs are relevant in preserving specimens and other materials, and this is gradually becoming one of the modern museums' top finalities. Indeed, vouchers of extinct species are useful reservoirs of information, crucial to understand the reasons and history of their extinction. At the same time, the availability of samples belonging to threatened species is an important and irreplaceable source of data for better understanding the conservation threats (e.g., Reed and Shine, 2002).

As reported elsewhere (Alberch et al., 1994; Bakker et al., 2020), NHMs should be primarily considered as research, documentation and divulgation centers, since their role in biodiversity discovery and nature valorization is central, and useful in showing variations in abundance, florae and faunae (Ewers-Saucedo et al., 2021). Natural history and biodiversity museums are also the logical repositories for vouchers of species becoming rarer, and in some cases extinct (Buckingham et al., 2021). This allows to keep track of biological changes since preserved specimens are excellent scientific resources representing unique means through which such species can be studied for their morphology, ecology, genetics, and other traits. In addition, they can be used in comparative studies, e.g., with extant species, not only for taxonomic and phylogenetic studies, but also to unveil ecological and life history traits (Figueirido and Janis, 2011).

Notwithstanding, while the advancement in our understanding of nature and the drafting of a life catalogue of our planet are still badly needed and considered as a humankind priority mission, in many cases NHMs themselves are increasingly facing severe problems of identity and survivorship, due not only to economic reasons but also to a generalized shift and diffused amnesia of their original missions (Boero, 2010; Andreone et al., 2014, 2022; Andreone, 2015; Ceríaco et al., 2021). On the other hand, we also believe that it is imperative to reconcile the research/collection and outreach/education components within NHMs, and that vouchers and scientific collections can be efficiently used for this aim.

In the course of two national projects focused on the valorization of natural history collections – namely "VertEx (Vertebrata Extincta)" and "Estinzioni" (Extinctions) (Nicolosi et al., 2013, 2019) – we evaluated the consistency of vertebrate collections in Italian NHMs, with the aim to define the conservation status and IUCN Red List placement of the housed voucher specimens. Hopefully, the identification of threatened and extinct species within museum collections is useful to address scientists and the public to understand and contrast the rarefaction and disappearance of our biodiversity, with dedicated temporary expositions, books, postcards, and gadgets.

So far, in the present paper we focused our attention on amphibians and non-avian reptiles, two vertebrate groups often treated together in both research and the traditional imagery, which represent a major component of museum collections. Here, we also give a general overview of the overall Italian herpetological/museological patrimony, about ten years after the first comprehensive work (Mazzotti, 2010) and provide indications on their conservation assessment.

MATERIAL AND METHODS

We selected the major Italian herpetological collections, basing upon data provided by the National Association of Scientific Museums (Associazione Nazionale dei Musei Scientifici - ANMS), associated projects, e.g., CollMap (Vomero, 2013), and previously published contributions (Mazzotti, 2010). Basing upon feedbacks from curators and referring institutions, we gathered useful information from 39 natural history collections (managed by public museums, universities, and/or a few private bodies), which replied positively to our request and provided relevant data (Table 1). A few NHMs were excluded since, although known for possessing herpetological specimens, they did not reply, or did not provide sufficiently complete information.

The existence of published/unpublished catalogues and/or lists of species/specimens housed in each collection was assured by the relative curator/referent, as well as through bibliography [(Carmagnola: Boano and Del-

Table 1. List of the Italian natural history museums contributing with collections data (abbreviations of provinces are reported between parentheses; TAEI = taxonomic auto-evaluation index; total number of species of amphibians and reptiles preserved in the collection is reported). Museums accompanied by an asterisk (*) are those having a herpetologist as curator.

Used acronym and official museum denomination		Municipality (Province)	Management type	TAEI	Species number	
					Amphibians	Reptiles
TO	Museo Regionale di Scienze Naturali *	Turin (To)	Region	3	593	855
TO-DB	Museo di Storia Naturale "Don Bosco"	Turin (To)	High school	2	12	49
TO-C	Museo Civico di Storia Naturale *	Carmagnola (To)	Municipality	4	69	374
CN-A	Museo Civico "Federico Eusebio"	Alba (Cn)	Municipality	4	8	9
CN-B	Museo Civico "Craveri" di Storia Naturale	Bra (Cn)	Municipality	4	10	53
VC-V	Museo di Storia Naturale "Pietro Calderini"	Varallo Sesia (Vc)	Foundation	4	2	20
VCO-D	Civico Museo di Storia Naturale "G. G. Galletti"	Domodossola (VCO)	Municipality	3	28	46
GE	Museo Civico di Storia Naturale "Giacomo Doria" *	Genoa (Ge)	Municipality	4	590	1450
MI	Museo di Storia Naturale *	Milan (Mi)	Municipality	4	116	637
PV	Museo di Storia Naturale dell'Università *	Pavia (Pv)	University	4	100	310
PV-V	Civico Museo di Scienze Naturali	Voghera (Pv)	Municipality	4	6	16
BG	Museo Civico di Scienze Naturali	Bergamo (Bg)	Municipality	4	28	153
SO-M	Museo Civico di Storia Naturale *	Morbegno (So)	Municipality	4	10	16
TV	Museo Zoologico "G. Scarpa"	Treviso (Tv)	Diocese	4	83	285
VR	Museo di Storia Naturale *	Verona (Vr)	Municipality	4	99	263
VI	Museo Naturalistico Archeologico di Vicenza	Vicenza (Vi)	Municipality	1	12	23
PD	Museo di Zoologia dell'Università	Padova (Pd)	University	3	75	115
VE	Museo di Storia Naturale "G. Ligabue" *	Venice (Ve)	Foundation	4	77	170
RO	Fondazione Museo Civico di Rovereto	Rovereto (Tn)	Foundation	4	11	41
TN	MUSE - Museo delle Scienze *	Trento (Tn)	Province	4	185	170
PN	Museo Civico di Storia Naturale	Pordenone (Pn)	Municipality	3	1	23
UD	Museo Friulano di Storia Naturale *	Udine (Ud)	Municipality	4	153	63
TS	Museo Civico di Storia Naturale *	Trieste (Ts)	Municipality	4	78	360
PR	Museo di Storia Naturale dell'Università	Parma (Pr)	University	2	17	75
MR	Museo di Zoologia e Anatomia Comparata dell'Università	Modena (Mo) / Reggio Emilia (Re)	University	3	37	112
BO	Collezione di Anatomia Comparata, Sistema Museale di Ateneo	Bologna (Bo)	University	4	4	53
FE	Museo Civico di Storia Naturale *	Ferrara (Fe)	Municipality	4	77	95
AN-O	Museo di scienze naturali "Luigi Paolucci"	Offagna (An)	Municipality	3	10	12
FI	Museo di Storia Naturale dell'Università *	Florence (Fi)	University	3	627	1268
PI	Museo di Storia Naturale dell'Università *	Calci di Pisa (Pi)	University	2	158	582
GR	Museo di Storia Naturale della Maremma	Grosseto (Gr)	Municipality	3	3	14
LI	Museo di storia naturale del Mediterraneo	Livorno (Li)	Province	3	6	31
SI	Museo di Storia Naturale dell'Accademia dei Fisiocritici	Siena (Si)	Association	3	26	95
RM	Museo Civico di Zoologia *	Rome (Rm)	Municipality	4	168	194
RM-S	Società Romana di Scienze Naturali	Rome (Rm)	Association	4	43	117
LE	Museo di Storia Naturale del Salento *	Calimera (Le)	Municipality	4	29	77
NA	Centro Museale Centro Musei delle Scienze Naturali dell'Università	Naples (Na)	University	2	35	72
BA	Museo di Zoologia "Lidia Liaci" dell'Università	Bari (Ba)	University	4	25	71
PA	Museo di zoologia "Pietro Doderlein" dell'Università	Palermo (Pa)	University	2	32	85

mastro, 1990; Sindaco, 1990); (Turin: Elter, 1982; Gavetti and Andreone, 1993; Andreone et al., 2007); (Domodossola: Andreone et al., 2005); (Genoa: Doria et al., 2002); (Milan: Leonardi et al., 1995; Scali, 1996; Blackburn and Scali, 2014); (Varese: Danini and Baratelli, 2000); (Morbegno: Zuffi, 1990); (Padua: Centis, 2004); (Udine: Lap-

ini, 1984); (Trieste: Bressi, 1996); (Florence: Lanza et al., 2005, 2006); (Ferrara: Mazzotti and Miserocchi, 2009, 2010); (Rome: Capula et al., 2011; Crucitti et al., 2017, 2021); (Naples: Maio et al., 2004)].

We used as taxonomic references "Amphibian Species of the World" (Frost, 2021), "AmphibiaWeb" (AmphibiaWeb, 2021), and "The Reptile Database" (Uetz et al., 2021). Exhaustiveness and correctness of the reported information is warranted directly by curators of the museums in this study. Taken into account that the degree of past and ongoing curatorial activity and taxonomic revisions are rather variable among institutions and since it was impossible to revise all the collections, we asked to provide a "taxonomic auto-evaluation index" (TAEI), as follows: 1 (lowest taxonomic accurateness and/or collection without a proper revision), 2 (collection revised for the 30-40%), 3 (collection revised for the 60-70%), 4 (highest taxonomic accurateness, with both the amphibian and reptile collections fully revised).

Finally, we carried out a conservation assessment for each species, including attribution of threat categories according to the IUCN Red List (IUCN, 2021).

RESULTS

The examination of the Italian herpetological collections produced a catalogue including more than 1400 species and 67 families of amphibians, and more than 2500 species and 80 families of reptiles (respectively 1418 and 2513 species).

Of the amphibians, 257 (18.1%) belong to a threat category. Of these species, 5 (1.9%) are Extinct (EX), 47 (18.3%) Critically Endangered (CR), 100 (38.9%) Endangered (EN), and 105 (40.9%) Vulnerable (VU). Regarding reptiles, 210 (8.3%) belong to a threat category: one species (0.5%) is considered EX, 32 (15,2%) CR, 74 (35.2%) EN, and 103 (49.1%) VU (Fig. 1). Museums and collections were quite heterogeneous, varying in size and finalities. Overall, the NHMs hosting the greatest number of threatened species of amphibians and reptiles (> 50 species of each group) are Genoa (174 in total), Florence (166 in total), and Turin (161 in total) (Fig. 2).

Amphibians hosted in the Italian institutions belong to 7 Gymnophiona, 52 Anura, and 8 Urodela families, while reptiles are represented by 13 Testudines, one Rhyncocephalia, three Crocodylia, 38 Sauria, and 25 Ophidia families (Appendix I). Species assessed as CR constitute respectively the 0.56% and 0.28% of the amphibian and reptile world fauna, on the basis of the global numbers provided by AmphibiaWeb (8384 amphibians on 25th October 2021) and Reptile Database (11570 reptiles on May 2021; Uetz et al., 2021).

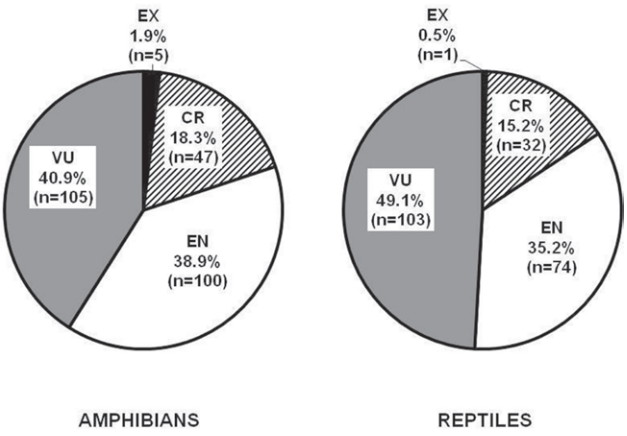

Fig. 1. Percentage of threatened species of amphibians (left) and reptiles (right) in the different IUCN categories.

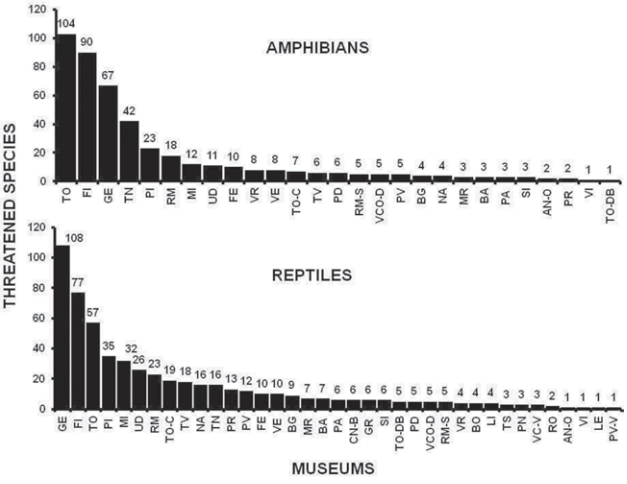

Fig. 2. Presence of threatened species in Italian museums for amphibians (above) and reptiles (below). Museum abbreviation as in Table 1.

Preserved CR amphibians include five urodeles and 46 anurans (Table 2). *Atelopus longirostris, Nectophrynoides asperginis*, *Pseudophilautus leucorhinus, P. nasutus,* and *P. variabilis* are currently assessed as EW or EX. About reptiles, we found respectively 32 CR and one EX species, *Chioninia coctei* (Table 3). Four CR species are loricates, 14 chelonians, 12 saurians, and one snake. Fourteen CR reptile species and the extinct *C. coctei* are shared by more than one collection.

NHMs hosting the highest number of high threatened and extinct amphibian species are respectively Turin (17 CR / 1 EX), Florence (13 CR / 1 EX), and Trento (15

Table 2. List of Critically Endangered (CR), Extinct (EX) and Extinct in the Wild (EW) amphibian species housed in Italian natural history museums and their occurrence in the analysed collections. Extinct species are given in bold. Museums are reported according to the abbreviations provided in Table 1.

Species	IUCN	Family	Museums
Hynobius abei	CR	Hynobiidae	FI
Hynobius okiensis	CR	Hynobiidae	FI
Chiropterotriton magnipes	CR	Plethodontidae	RM
Thorius pennatulus	CR	Plethodontidae	FI
Pseudoeurycea goebeli	CR	Plethodontidae	GE
Latonia nigriventer	CR	Alytidae	FI
Arthroleptis nikeae	CR	Arthroleptidae	TN
Atelognathus patagonicus	CR	Batrachylidae	FI
Callulina hanseni	CR	Brevicipitidae	TN
Callulina kanga	CR	Brevicipitidae	TN
Callulina laphami	CR	Brevicipitidae	TN
Callulina meteora	CR	Brevicipitidae	TN
Callulina shengena	CR	Brevicipitidae	TN
Callulina stanleyi	CR	Brevicipitidae	TN
Altiphrynoides osgoodi	CR	Bufonidae	FI
Atelopus boulengeri	CR	Bufonidae	TO
Atelopus cruciger	CR	Bufonidae	TO
Atelopus ignescens	CR	Bufonidae	FI, PD, PI, TO
Atelopus longirostris	EX	Bufonidae	FI
Atelopus varius	CR	Bufonidae	PI, TO
Churamiti maridadi	CR	Bufonidae	TN
Incilius cristatus	CR	Bufonidae	FI
Leptophryne cruentata	CR	Bufonidae	GE
Nectophrynoides asperginis	EW	Bufonidae	TN
Nectophrynoides laticeps	CR	Bufonidae	TN
Nectophrynoides paulae	CR	Bufonidae	TN
Nectophrynoides poyntoni	CR	Bufonidae	TN
Nectophrynoides wendyae	CR	Bufonidae	TN
Werneria mertensiana	CR	Bufonidae	TN
Wolterstorffina parvipalmata	CR	Bufonidae	TN
Craugastor fleischmanni	CR	Craugastoridae	TO
Craugastor lineatus	CR	Craugastoridae	FI
Craugastor milesi	CR	Craugastoridae	GE
Hyloxalus vertebralis	CR	Dendrobatidae	GE
Isthmohyla debilis	CR	Hylidae	RM
Hyperolius davenporti	CR	Hyperoliidae	TN
Pleurodema somuncurense	CR	Leptodactylidae	FI, TO
Boophis ankarafensis	CR	Mantellidae	TO
Boophis tsilomaro	CR	Mantellidae	TO
Boophis williamsii	CR	Mantellidae	TO
Guibemantis diphonus	CR	Mantellidae	TO
Guibemantis punctatus	CR	Mantellidae	TO
Mantella milotympanum	CR	Mantellidae	TO
Mantidactylus pauliani	CR	Mantellidae	TO
Platypelis karenae	CR	Microhylidae	TO
Rana holtzi	CR	Ranidae	FI, TO
Pseudophilautus leucorhinus	EX	Rhacophoridae	GE
Pseudophilautus nasutus	EX	Rhacophoridae	TO
Pseudophilautus variabilis	EX	Rhacophoridae	GE, PI
Rhinoderma rufum	CR	Rhinodermatidae	TO
Telmatobius laticeps	CR	Telmatobiidae	FI, TO

CR / 1 EW), while for reptiles are Genoa (15 CR / 1 EX), Florence (11 CR / 1 EX), and Pisa (7 CR). A large part of the CR amphibian and reptile species (26) comes from a single museum/collection (Florence). The most shared CR species are, among the amphibians, *Atelopus ignescens,* which is present in four collections, and, among the reptiles, *Eretmochelys imbricata* and *Gavialis gangeticus,* respectively hosted by fourteen and eleven institutions.

A particular consideration should be deserved for the case of the axolotl *Ambystoma mexicanum.* This urodele species is present in 16 of the examined collections, and, according to the IUCN Red List, it should be assessed as CR. Anyhow, since it is likely that most of the preserved specimens derivate from captive and laboratory strains and given the impossibility of determining whether these animals (especially the historical ones) introgressed with *Ambystoma tigrinum* (Torres-Sánchez, 2020), we decided not to consider them within the list of threatened taxa housed in Italian museums.

DISCUSSION

Extinct and threatened species in scientific collections

The presence in natural history collections of amphibian and reptile species included within the IUCN's threatened categories gives the opportunity to unveil aspects otherwise difficult to obtain in the wild. As an example, the availability of a sufficiently large voucher series of some frogs of the genus *Mantella* from Madagascar allowed to investigate their fecundity (Tessa et al., 2009), age structure (Andreone et al., 2011) and, successively, to use these parameters to draw a general model exploitation method (Andreone et al., 2021).

Differently from collecting for food, traditional medicine, fashion market, handicraft production, and other purposes, which are clearly recognized as relevant threats affecting rare and localized species (especially for the high number of traded individuals), a reasoned collecting of scientific vouchers is unlikely to be or become an

Table 3. List of Critically Endangered (CR) and Extinct (EX) species of reptiles and natural history museums where they are preserved. Extinct species are given in bold. Museums are reported according to the abbreviations provided in Table 1.

Species	IUCN	Family	Museums
Crocodylus intermedius	CR	Crocodylidae	PI, PR, RM
Crocodylus rhombifer	CR	Crocodylidae	FI, GE, GR, MI, VCO-D,
Crocodylus siamensis	CR	Crocodylidae	FI, GE, MI, NA, PI, PV, RM, TO, TO-DB, TV
Mecistops cataphractus	CR	Crocodylidae	PI, TO
Gavialis gangeticus	CR	Gavialidae	FI, GE, MI, NA, PI, PR, PV, RM, TO, TO-DB, TV
Eretmochelys imbricata	CR	Cheloniidae	BG, BR, FI, GE, LI, MI, PI, PR, PV, TO, TV, UD, VCO-D, VE
Lepidochelys kempii	CR	Cheloniidae	BG, GE
Dermatemys mawii	CR	Dermatemydidae	TV
Batagur baska	CR	Geoemydidae	GE
Batagur dhongoka	CR	Geoemydidae	GE
Batagur kachunga	CR	Geoemydidae	GE
Batagur trivittata	CR	Geoemydidae	BG, GE
Cuora trifasciata	CR	Geoemydidae	FI, UD
Heosemys depressa	CR	Geoemydidae	GE
Astrochelys radiata	CR	Testudinidae	FI, MI, NA, PI, RM, SI, TO, UD
Chelonoidis porteri	CR	Testudinidae	RM
Geochelone platynota	CR	Testudinidae	GE
Psammobates geometricus	CR	Testudinidae	FI, PI, PV, RM
Testudo kleinmanni	CR	Testudinidae	GE
Hemidactylus bouvieri	CR	Gekkonidae	CN-B, GE
Lygodactylus williamsi	CR	Gekkonidae	TN
Conolophus marthae	CR	Iguanidae	RM
Acanthodactylus beershebensis	CR	Lacertidae	FI
Acanthodactylus harranensis	CR	Lacertidae	FI, RM-S, TO-C
Eremias pleskei	CR	Lacertidae	TO-C
Erythrolamprus cursor	CR	Lacertidae	GE
Gallotia simonyi	CR	Lacertidae	GE
Podarcis raffonei	CR	Lacertidae	FE, FI, PA, PD, RM
Liolaemus rabinoi	CR	Liolaemidae	FI
Chioninia coctei	EX	Scincidae	FI, GE, PA, TO, TV
Mabuya mabouya	CR	Scincidae	FI, MI
Pseudoacontias menamainty	CR	Scincidae	TO
Spondylurus culebrae	CR	Scincidae	GE
Atheris matildae	CR	Viperidae	TN

extinction cause (Rocha et al., 2014). We stress that specimen collection for scientific purposes is usually limited to a few vouchers, whose capture and collecting need to be authorised by national authorities and regulated by legislation. At the same time, we believe that the collecting activity of vouchers still remains crucial and should be maintained, as stressed by Dubois (2003, 2010, 2017), to document not only the presence of rare and threatened species, but also biological parameters and represents an unsurpassed source of scientific data that are only in part exploited. Finally, it is often crucial to witness the presence of a species at a confirmed geographic locality, possibly integrated with further evidences, such as eDNA, acoustic recordings, photographs, and footage. This is particularly important, as the collecting of series of specimens is also useful for conservation purposes, e.g., to identify negative trends in populations, especially in current times which are featured by dramatic changes of climatic and environmental parameters (e.g., Hoffmann et al., 2010; Hou et al., 2021).

Threatened and extinct species of amphibians and reptiles in Italian collections

Some of the analysed Italian NHMs turned out to be especially relevant due to the high number of species

and specimens housed in the scientific collections under their care, and on the amount of threatened species. Most of the extinct species present in these institutions were likely collected during general collecting activities and/or obtained in exchange from other scientists/institutions. In the case of the Kihansi spray toad *Nectophrynoides asperginis,* a species from Tanzania extinct in the wild due to the spread of the chytrid fungus (Channing et al., 2006), the specimens were obtained in the context of structured multi-year research (Menegon et al., 2004; Msuya and Mohamed, 2019). The giant Cape Verde skink *Chioninia coctei* is present in a few Italian museums, which are Florence, Genoa, Palermo, Turin, and Treviso. Of special relevance are the live individuals (around forty) imported by the herpetologist Mario G. Peracca at the end of the 19th century, and currently hosted in Turin (Andreone and Gavetti, 2007, 2010). Such a conspicuous purchase was made through an animal dealer, and was accompanied by the concurrent importation of some other rare or iconic live herps, i.e., *Andrias japonicus, Aldabrachelys gigantea*, *Astrochelys radiata*, *Iguana iguana,* and *Sphenodon punctatus* (Andreone and Gavetti, 1998). Peracca also made some interesting observations on the skink natural history, and then exchanged some individuals with other naturalists of his time, such as G. Scarpa in Treviso (Andreone et al., 2010). After Peracca's death some of these skinks were donated (as other animals) to the Turin Museum, which in fact was not the commissioner for the collecting of a rare and threatened species, but just its final repository.

With respect to amphibians, the institution hosting the highest number of CR species is the Turin Museum, with 17 taxa, eight of which originated from the collecting surveys carried out during field-work in Madagascar (Andreone et al., 2005, 2021), followed by MUSE - Museo delle Scienze in Trento, with 15 species from Tanzania and other eastern African countries. Further remarkable species available in Turin come from Latin America, mostly due to the activity of the Italo-Argentinean herpetologist J. M. Cei (Cei, 1993). Florence and Genoa are also the NHMs holding the highest number of CR reptile species. This highlights the importance of active research in the constitution of study collections. The CR amphibian species housed in Trento originated from systematic field research carried out over the past 20 years in the forests of the Eastern Afromontane Ark (Menegon et al., 2008).

Many natural history museums supported, among their institutional activities, survey works in unexplored or marginally explored areas of our planet. In particular, this was one of the ultimate aims of middle-large museums, where collections were usually regarded as voucher repositories (Grimaldi and Engel, 2007; Engel et al., 2021), much less for smaller museums where the education aspects are usually prioritised.

Is scientific voucher collecting still a needed practice?

In Italy, many museums supported collecting activities in the past, but only a few ones pursue research and specimens collecting, especially overseas. In fact, in the 19th century many naturalists gravitating around Italian museums were engaged to explore the World and to collect new materials (Mazzotti, 2011), such as A. Borelli, E. Festa, and F. De Filippi in Turin, L. D'Albertis, G. Doria, and L. Fea in Genoa, O. Beccari and E. H. Giglioli in Florence, G. Scortecci in Milan, O. Antinori in Perugia, and many others, who mirrored the adventures and travels of Victorian naturalists, contributing to discover new species and describing the still unknown world. The beginning of 20th century, however, coincided with a decrease in such activities in most of the Italian museums: the systematic and taxonomic zoology and botany that fed those travels were largely left behind, often considered useless and subsidiary to the newly affirmed organismic biology. At the same time, museums were often seen as mere repositories and/or expositive locations, and much less (or no more) as research centers (Fischer, 2015). For these reasons too, many ancient collections were neglected and rarely utilised for either scientific or educational purposes (Ceríaco et al., 2021).

To better frame this situation, it should also be remembered that many Italian museums were, and still are, managed by local administrations, such as municipalities, provinces, and regions. This often led to a difficult balance between the expositive/outreach finality and research/collection components, in particular since museums were often nested within culture or education departments and only rarely associated with research and/or environmental ones. Therefore, while research was progressively relegated to a subsidiary activity, most natural history museums acquired a prominent expositive function, sometimes detaching the physiological link between these "souls". Only a few museums appear to have escaped this trend, such as those of Turin (Andreone, 2013), Trento (Menegon et al., 2008), Verona (Latella and Zorzin, 2018), and Florence (Van Lien et al., 2014), whose personnel was able to carry out recent oversea research.

Taking into consideration that many (16) of the analysed Italian NHMs have herpetologists as curators, it is worth to verify whether their presence is accompanied by a better knowledge of amphibian and reptile taxonomy in their collections. The TAEI varied from 1 (one collection) to 4 (22 collections), with a mean value of 3.41 $\pm$

0.82, thus indicating that most of these collections were revised recently. This happened mostly for small collections, which were objectively easier to be studied and catalogued, and usually limited to Italian/European faunae.

Since most of these collections are not formed recently, the majority of Italian collections are increasingly becoming historical, with recent acquisitions largely due to occasional specimen collections. We consider this a heavy bias, since it means a loss of taxonomic expertise which may have a negative impact on the increase and valorization of scientific collections.

Andreone et al. (2014), following a proposal by Minelli (2013, 2015), suggested that, in absence of a traditional national museum, a "diffuse network" or "metamuseum" could be a solution to manage the Italian scientific collections in a joint way, also to share resources and personnel. Although little was done to accomplish this proposal so far, this is still an option to be taken into serious consideration together with the possibility of creating a centralized coordination hub. Considering the present fragmentation and the scarce connection among museums, it is first of all important that all Italian natural history collections are increasingly revised and digitalized by each museum, hopefully using shared protocols. This would be enhanced by the establishment of a national strategy that encompasses the coordination and resource distribution as a priority objective.

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APPENDIX I

List of amphibian and reptile families conserved in the Italian natural history collections

AMPHIBIA

GYMNOPHIONA – Caeciliidae, Dermophiidae, Herpelidae, Ichthyophiidae, Scolecomorphidae, Siphonopidae, Typhlonectidae. ANURA – Alsodidae, Alytidae, Arthroleptidae, Ascaphidae, Batrachylidae, Bombinatoridae, Brachycephalidae, Craugastoridae, Brevicipitidae, Bufonidae, Calyptocephalellidae, Centrolenidae, Ceratobatrachidae, Ceratophryidae, Conrauidae, Eleutherodactylidae, Cycloramphidae, Aromobatidae, Dendrobatidae, Dicroglossidae, Heleophrynidae, Hemiphractidae, Hemisotidae, Hylidae, Hylodidae, Hyperoliidae, Leiopelmatidae, Leptodactylidae, Mantellidae, Megophryidae, Micrixalidae, Microhylidae, Limnodynastidae, Myobatrachidae, Nyctibatrachidae, Odontophrynidae, Pelobatidae, Pelodryadidae, Pelodytidae, Petropedetidae, Phrynobatrachidae, Phyllomedusidae, Pipidae, Ptychadenidae, Pyxicephalidae, Ranidae, Ranixalidae, Rhacophoridae, Rhinodermatidae, Rhinophrynidae, Scaphiopodidae, Telmatobiidae. URODELA – Ambystomatidae, Amphiumidae, Hynobiidae, Plethodontidae, Proteidae, Rhyacotritonidae, Salamandridae, Sirenidae.

REPTILIA

TESTUDINES - Emydidae, Testudinidae, Geoemydidae, Platysternidae, Trionychidae, Chelydridae, Dermatemydidae, Kinosternidae, Cheloniidae, Dermochelyidae, Chelidae, Pelomedusidae, Podocnemididae. RHYNCHOCEPHALIA – Sphenodontidae. CROCODYLIA – Crocodylidae, Gavialidae, Alligatoridae. SAURIA – Agamidae, Chamaeleonidae, Corytophanidae, Crotaphytidae, Dactyloidae, Hoplocercidae, Iguanidae, Leiocephalidae, Leiosauridae, Liolaemidae, Opluridae, Phrynosomatidae, Polychrotidae, Tropiduridae, Gekkonidae, Carphodactylidae, Diplodactylidae, Eublepharidae, Phyllodactylidae, Sphaerodactylidae, Pygopodidae, Cordylidae, Gerrhosauridae, Scincidae, Xantusiidae, Gymnophthalmidae, Lacertidae, Teiidae, Anguidae, Diploglossidae, Xenosauridae, Amphisbaenidae Blanidae, Rhineuridae,

Trogonophidae, Helodermatidae, Varanidae, Dibamidae. OPHIDIA – Acrochordidae, Cylindrophiidae, Uropeltidae, Loxocemidae, Pythonidae, Xenopeltidae, Boidae, Colubridae, Atractaspididae, Cyclocoridae, Lamprophiidae, Psammophiidae, Pseudaspididae, Elapidae, Anomalepididae, Gerrhopilidae, Typhlopidae, Leptotyphlopidae, Xenotyphlopidae, Aniliidae, Homalopsidae, Pareidae, Tropidophiidae, Viperidae, Xenodermidae.