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THE ITALIAN ZOOLOGICAL GARDENS AND THEIR ROLE IN MAMMAL SYSTEMATIC STUDIES, CONSERVATION BIOLOGY AND MUSEUM COLLECTIONS

SPARTACO GIPPOLITI[1a], ANDREW C. KITCHENER[2]

[1] Giardino Zoologico di Pistoia and Istituto Italiano di Antropologia, Roma, Italy
[a] corresponding author, e-mail: spartacolobus@hotmail.com
[2] National Museums Scotland, Chambers Street, Edinburgh EH1 1JF, UK
e-mail: a.kitchener@nms.ac.uk

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ABSTRACT - The opportunities offered to scientific research by living mammal collections are generally overlooked in Italy. This paper presents a short historical overview of the scientific investigations done on captive mammals from Italian zoos, especially those concerning taxonomic research. A glimpse of the opportunities offered by zoo specimens for scientific research is presented utilising examples from the National Museums Scotland. The importance of increasing care in the identification of individual animals by studbook and ISIS numbers is also highlighted. We argue that a stronger collaboration between zoos, museums and universities is needed to maximise the scientific and conservation value of Italian mammal collections.

Key words: Taxonomy, zoological gardens, natural history museums, *ex situ* conservation

RIASSUNTO - ***I giardini zoologici italiani e il loro ruolo negli studi sistematici sui mammiferi, biologia della conservazione e collezioni museali***. Generalmente, in Italia, le opportunità scientifiche offerte dai reperti provenienti da giardini zoologici sono sottovalutate. Il presente lavoro offre una sintesi storica delle ricerche, soprattutto di carattere tassonomico e sistematico, realizzate su materiale di zoo italiani. Vengono presentati poi esempi delle ricerche compiute presso i *National Museums* della Scozia utilizzando materiale proveniente da zoo di tutta Europa, e le loro ricadute nel campo della sistematica, biologia della conservazione e benessere animale. Viene evidenziata la necessità di incrementare le informazioni concernenti ogni individuo in cattività, anche utilizzando i sistemi identificativi quali studbook e ISIS, per massimizzarne il valore scientifico. Si conclude chiedendo una maggiore collaborazione tra zoo e musei italiani, a tutto vantaggio della comunità scientifica nazionale.

Parole chiave: Tassonomia, giardini zoologici, musei di storia naturale, conservazione *ex situ*

INTRODUCTION

Natural history museums and research have generally greatly benefited from living animal collections in Italy, since the time of Ulisse Aldrovandi, whose books include illustrations of animals living in the Medici's menageries in

Florence. In some cases, a particular captive animal became a sort of symbolic icon for a museum. For example, the mounted skin of an Asian elephant, *Elephas maximus*, known as 'Fritz' in Turin or the articulated skeleton of an African elephant, *Loxodonta africana*, called 'Toto' in Rome. Despite this centenarian relationship, the scientific value of museum specimens of zoo origin has often been overlooked. It seems nowadays that museum specimens represent a source of historical knowledge about living collections (albeit a little-explored field in Italy), rather than a valuable addition to the scientific diversity of museum collections. At least three major Italian museums appear to have received substantial numbers of zoo specimens: the Museo Civico di Storia Naturale in Milan, the Museo Civico di Zoologia in Rome and the Museo Regionale di Scienze Naturali in Turin. However, other important museums, such as those of Genova and Florence, hold several specimens from zoos. For the ungulate collection of the Museo Civico di Storia Naturale in Milan (Oriani and Castiglioni, 2003), it is evident that zoos provided the only available specimens of three genera: *Choeropsis* (cranium of a young female pygmy hippopotamus, *C. l. liberiensis*, from Parco Faunistico La Torbiera), *Moschus* (skeletons and skins of a male and a female musk deer, *M. moschiferus*, from Parco Faunistico La Torbiera) and *Hippocamelus* (mounted skin of a female guemal, *H. bisulcus*, from the Zoo in Milan). Therefore, zoos seems to be an important potential source of scientifically relevant specimens, which are essential for research in the fields of zoology, archaeozoology, palaeontology, conservation biology and genetics. This paper reviews the history of scientific utilization of zoo animals in Italian institutions, with particular attention to taxonomy. Finally, it provides some examples of the scientific information and research opportunities provided by specimens originating from zoos, which have been explored in recent years by the National Museums Scotland.

MODERN ZOOS AND RESEARCH: AN HISTORICAL OUTLINE

The first and most convincing example of a fruitful relationship between a living animal collection and a university museum is found in Turin. Here Giuseppe Gené, Alfredo Corti, Filippo De Filippi and Lorenzo Camerano published a number of papers dealing with living animals and their remains originating from the several collections of the Savoia Kings kept in Piedmont between 1830 and 1880 (Gippoliti, 1997). Among the papers dealing with taxonomy, there was the first description of the female Nubian ibex, *Capra nubiana* (Gené, 1834) and the description of a species of striped hyaena, *Hyaena suilla* (De Filippi, 1851), now a synonim of *Hyaena hyaena barbara*. Agnelli *et al.* (1991), while reviewing the collection of the Zoological Museum "La Specola" in Florence, found evidence of several specimens originating from the Royal Zoological Gardens of Florence around 1860-1880, but nothing appears to have been previously published on these specimens. Between 1843 and 1862 the same Museum received some specimens from the menagerie of Anatoly Demidoff at Villa S. Donato in Florence. Mammals included some rare or now-extinct taxa, such as bubal hartebeest, *Alcelaphus buselaphus buselaphus*, bontebok, *Damaliscus pygargus*, grysbok, *Raphicerus melanotis*, and mountain zebra, *Equus zebra* (Agnelli *et al*., 1991).

After the closure of the zoos in Turin and Florence, Italy had to wait until 1911 to have another zoological garden, this time in Rome. For the first time in Italy the director was a zoologist, the German Theodor Knottnerus-Meyer, who had already been a collaborator of Carl Hagenbeck, the planner of the Rome Zoo. Thanks to Knottnerus-Meyer, we know, often in great detail, the origin and taxonomy of the first animals of the new zoo. From the beginning a close link was established with the Zoological Museum of the University of Rome and several specimens were sent and studied there (Carruccio, 1913; Vram, 1913). Regrettably no remains seem to have been preserved of a specimen of the now-extinct Javan tiger, *Panthera tigris sondaica,* which was once held at the zoo in those years, while those of the holotype of *Giraffa hagenbecki* Knottnerus-Meyer 1910, were probably sold abroad. In 1925 the scientific direction of the Roman Zoo was entrusted to Giuseppe Lepri, a former collaborator of Antonio Carruccio at the Zoological Museum. A few years later Lepri described a new subspecies of Barbary sheep, *Ammotragus lervia fassini*, utilising live animals imported from the Garian region of Libya and, incidentally, without fixing a type specimen (Lepri, 1930). In 1932 the Institute of Zoology of the University of Rome loaned most of the specimens from the former Museum of Zoology to the Municipality of Rome, in order to create the Museo Civico di Zoologia inside the zoo. However, owing to several reasons, the full potential of this promising situation was never realised. In some cases important specimens were not preserved at all, such as the male Bornean bay cat, *Catopuma badia,* which was received from Beherend on 1st December 1934 and died on 18 January 1935, according to the zoo's records. In other cases the documentation accompanying the specimens that reached the museum was incomplete, although at that time most individuals came from the wild, including the Italian colonies in Africa. The scientific utilization of the zoo-mammal collection was greatly hampered by the absence of a mammalogist on the staff. For only a brief period the staff included Alula Taibel, a world expert on the birds of the Family Cracidae, but also a keen mammalogist, who published a note on some anomalies of the pelage in zoo mammals (Taibel, 1937). However, observation of live animals in the zoo allowed interesting developments in the taxidermy of large mammals at the Museo Civico di Zoologia (Bertoni and Bertoni, 1938).

Before the Second World War the leading mammalogist in Italy was

Oscar de Beaux at the Museo Civico di Storia Naturale in Genova. Interestingly de Beaux had replaced Knottnerus-Meyer as scientific assistant at the Stellingen Tierpark in Hamburg between 1911 and 1913. Later he became curator and director of the museum in Genova and in 1931 he created a small zoo in the gardens of Genova Nervi under the auspices of the museum. Here a series of hybridisation experiments were carried out between different species (i.e. blackbuck *Antilope cervicapra* x Dorcas gazelle *Gazella dorcas isabella*) or geographical forms of leopards, *Panthera pardus*, and jackals, *Canis* spp. (Gippoliti, 1997). The remains of most of these animals are still preserved and meticously labelled in the Genovan Museum, as is other material, which was studied by de Beaux, originating from the Stellingen Tierpark (de Beaux, 1929). He was also one of the first mammalogists to highlight the possible effects of captivity on parts of the skeleton and the colour of the pelage (de Beaux, 1915). In a paper on a recently deceased gelada, *Theropithecus gelada,* de Beaux (1926) added behavioural notes to the anatomical descriptions, correctly assuming the terrestrial mode of life of this species.

De Beaux probably did not maintain regular contact with the Zoo in Rome; on one occcasion only he referred to a photo of a female Nubian wild ass, *Equus a. africanus,* captured in Eritrea, which was living at Rome Zoo (de Beaux, 1928).

After World War II there was a shift of interest from classical taxonomy to karyology and genetics, which obviously influenced the fields of research done on zoo mammals too. In particular in 1960 Brunetto Chiarelli founded a Primatological Centre at the University of Turin, with close links to the city zoo, where karyological research on primates from various Italian zoos was carried out (e.g. Chiarelli, 1961, 1962). Some studies on the serology of primates living in the zoos of Rome and Naples were carried out at the Institute of Anthropology of the University of Rome (Cresta, 1959).

In Rome, with funds from the C.N.R. and following a path already traced in the pre-war period, a Parasitological Centre was established in 1950 through a collaboration between the Institute of Parasitology and Rome Zoo. Several new species of parasites from Italian, Somalian, Eritrean and other exotic mammal species (e.g. badger, *Meles meles*, red panda, *Ailurus fulgens*, serval, *Leptailurus serval*, mongoose, *Herpestes ichneumon*, genet, *Genetta genetta,* aardvark, *Orycteropus afer* and ground squirrels *Xerus* spp.) were described (Bronzini, 1954; Biocca and Bronzini, 1961).

Theoretically all this research carried out '*in vivo*' should have enormously increased the value of museum specimens originating from zoos. However, in practice this was not the case because, when preserved, the labels of most museum specimens included only the taxonomic name and the zoo of origin, but with no reference about exact date and cause of death, age, origin and any research done on them in captivity. Details on individual zoo animals have been rarely published with the aim of improving the scientific value of museum collections, as was

done for the great apes held at Rome Zoo by D'Alessandro and Gippoliti (1996) and live Apennine brown bears, *Ursus arctos marsicanus*, from various Italian collections (Gippoliti, 2006a).
In the last two decades of the 20th century most scientific research in zoos focused on animal behaviour, particularly of primates (Majolo *et al*., 2005). However, the recent renewal of interest in taxonomy, also encouraged by the development of biomolecular techniques, makes zoo animals (alive and dead) a useful and sometime unique resource for this kind of study.

EXAMPLES OF RESEARCH ON ZOO SPECIMENS

Over the last 15 years the National Museums Scotland (NMS) have preserved in their collections large samples of dead zoo animals. Although the rationale for collecting these specimens was initially purely for use in taxonomic research combined with a need to acquire specimens for use, in taxidermy for new exhibitions, this has broadened considerably over time as the full research potential of these specimens is realised. Unfortunately there remains in the museum world a strong belief that specimens derived from captive animals are in some way inferior or unrepresentative of wild populations (e.g. Hollister, 1917). Recently, research on the morphological differences between captive and wild-caught cheetahs, *Acinonyx jubatus*, and other big cats of the genus *Panthera* has demonstrated that while a few skull measurements may not be comparable, many others did not vary and could be used in taxonomic and other studies (O'Regan, 2002).

1. Taxonomic and systematic studies

Of course, museum collections are the vital source of specimens for taxonomic and systematic studies. Type specimens remain the vouchers for scientific names in taxonomy and can be used for comparison with new samples or resolving taxonomic uncertainties. Collecting from zoos can fill important gaps in museum collections. For example, traditionally only the skulls and skins of mammals and the skins of birds were collected, so that much of the post-cranial skeleton is either unknown or poorly known for many species. As a result of contemporary collecting, the NMS hold the only complete skeletons of the red-shanked douc langurs, *Pygathrix nemaeus*, in UK museums (Kitchener, 1997b). Zoos may unwittingly or knowingly hold new species and subspecies, and it is vital that these specimens are preserved for future research. For example, the Siberut macaque, *Macaca siberu*, was recently recognised as a valid species when an old male from Bristol Zoo died and was sent to NMS (Kitchener and Groves, 2002), and several new species of mouse lemur, *Microcebus* spp. were described from living animals in Parc Botanique et Zoologique de Tsimbazaza (Louis *et al.,* 2006).
Whatever the effects of captivity on morphology, dead zoo animals are an important source of tissues for the extraction of DNA for molecular research. NMS maintain a -40°C freezer for storing muscle samples from

all specimens acquired from zoos and wild sources. These are used extensively by the research community and whole genetic phylogenies have been produced mostly from NMS samples (e.g. Mundy and Kelly, 2003; Surridge and Mundy, 2002). The importance of voucher skins and/or skeletons in museum collections, to allow later confirmation of identity, should not be underestimated, especially when taxonomies remain in a state of flux because new species concepts are adopted and new research reveals previously unrecorded species and geographical variation.

2. Population variation

Owing to the popularity of field guides, we sometimes have a very fixed view of individual variation in populations. Captive populations inevitably sample only a small proportion of the original morphological and genetic diversity of their wild populations. For example, in the 1990s Howletts Wild Animal Park imported a group of Javan grey langurs, *Presbytis comata*, from Indonesia, in order to try to establish a new captive population. Unfortunately the darkest and lightest individuals from the group died soon after arrival, so that variation within this small population was more or less limited to intermediate shades of grey (ACK pers. obs.). By preserving the founders and their progeny, we can study the inheritance of variation within captive populations and compare it with that occurring in wild populations. Restricted variation or the development of anomalies in captive populations may compromise the survival of reintroduced animals in the wild. For example, a wild-caught founder of the European zoo population of the Asian lion, *Panthera leo persica*, which died in 1995 at London Zoo, had a malformed skull (Kitchener, 1996). By preserving his progeny from the European Endangered Species Programme (EEP) for Asian lions, we will be able to determine whether this abnormality occurs in the wild population, owing to a severe population bottleneck in the early 20th century, or whether it is the result of pathology, such as metabolic bone disease.

3. Ageing

Although rates of growth may be faster in captive-bred animals and toothwear rates may differ because of generally softer diets in captivity, captive specimens may be an important source of information about ageing, including sequences of epiphyseal fusion, sequences of tooth replacement and toothwear, and the growth and development of specific bones, e.g. bacula, which are often used in ageing studies of wild populations. The great advantage of most captive specimens is that their age is accurately known, so that they can be used to age wild specimens. In 1993 a female Sumatran rhinoceros, *Dicerorhinus s. sumatrensis,* died at Port Lympne Wild Animal Park, having failed to breed successfully. Subsequent analysis of her skeleton and toothwear suggested that she was probably in her mid-30s and that she was possibly beyond breeding age when she was imported from the wild (Kitchener, 1997a). As a result of this study a model for ageing Sumatran rhinoceroses based on toothwear is now also available for field workers.

4. Anatomy and functional morphology

Zoo animals are also a source of information about anatomy and functional morphology. A preputial gland has never been previously described for the genus *Nasua,* but was identified from a male coati, *N. nasua,* at Edinburgh Zoo after it became infected (Shannon *et al.,* 1995). On its death this specimen was preserved for future reference by NMS.
NMS has been collecting the hind feet from arboreal cats, which are able to flex and extend their ankles through 180^{o}, so that they can climb head-first down tree trunks and branches. Although this adaptation has been described in detail in the margay, *Leopardus wiedii*, and some other arboreal carnivorans (Taylor, 1989), it has never been described for the marbled cat, *Pardofelis marmorata,* and clouded leopards, *Neofelis* spp. This adaptation has clearly evolved independently two or three times within the Felidae and we are currently investigating it in detail by anatomical examination of captive cats in collaboration with the University of Liverpool.

5. The effects of captivity

It has long been known that the skeletal morphology of captive and wild animals may vary (see O' Regan and Kitchener (2005) for a review). In part this was due to poor nutrition and lack of activity in the past, e.g. Hollister (1917) described distinctive cranial differences between wild and captive lions both from the same locality in Kenya, but these differences are not as apparent in the skulls of captive lions today. Better understanding of nutritional needs, the advent and continuing development of environmental enrichment and the use of larger naturalistic enclosures means that for many captive mammals the development of the musculo-skeletal system is probably much more like that in their wild counterparts than ever before. However, there are still differences, which remain to be quantified, and there have been few investigations as to their probable cause. NMS have carried out several studies to ascertain the effects of captivity on the morphology and development of endangered mammals. For example, an investigation of the flight musculo-skeletal system of Rodrigues fruit bats, *Pteropus rodricensis*, revealed that wild-caught founders had adapted to captivity in a similar way to captive-bred animals (Kitchener *et al.*, 2000). Both wild-caught and captive-bred fruit bats deposited increasing amounts of subcutaneous fat with increasing age, and there was no significant difference in the dry weights of their principal flight muscles and in the dimensions of their limb bones. More recently, we have carried out a pilot study to examine the skeletons of wild and captive-bred callitrichid monkeys, including the genera *Callithrix, Saguinus, Callimico, Cebuella* and *Leontopithecus,* to see if there are significant differences in limb bone densities and to see if gum feeding, which began in zoos in the early 1990s, has had any impact on the skeletal development of captive individuals (Kitchener and Andersen, personal data). Gum is a food source rich in calcium, which is otherwise scarce in the normal mainly insectivorous diet of these monkeys.

6. Skeletal and dental pathologies

During the last 15 years NMS have collected many large mammal skeletons from zoos. Most of these animals have exceeded the average life span of their wild counterparts and many were suffering from a variety of skeletal and dental pathologies, including osteoarthroses of the joints, spondylosis of the vertebral column, and abscesses in the jaws owing to broken canines or dental caries (Kitchener and Macdonald, 2005). For example, 97% of captive bears, aged 16 years or older, of seven species examined so far had developed spondylosis of the vertebral column (Kitchener, 2004). New enrichment techniques, such as wobble trees, may allow assessment of the hip joints as well as well as enriching the behaviour of captive bears (Law and Kitchener, 2002). A bear with badly arthritic hips or back may well not be able to stand to use a wobble tree, thus indicating it is in a great deal of pain. If an old bear is given anti-inflammatories, resulting in a positive change in activity, this may also indicate that an animal is suffering. Dissemination of this information is allowing veterinary surgeons in zoos to make informed judgements about the health of captive large mammals, so that suffering is not prolonged. An obvious consequence of this is an improvement in captive animal welfare by reducing suffering and a boost to captive breeding programmes, which may be hindered by the presence of a high number of aged and suffering animals in participating zoos. For example, only 3% of wild polar bears, *Ursus maritimus*, exceed the age of 20 years old, but a third of the captive population is older than this. However, ageing is not the whole explanantion of the development of these problems. They may also be associated with a poor captive environment, poor nutrition and lack of activity. For example, there is circumstantial evidence that the use of a tiger feeding pole at South Lakes Wild Animal Park in England has benefited the skeletal health of two Sumatran tigers, *P. t. sumatrae*, whose skeletons were expected to show severe pathologies at the ages when they died (Kitchener, 2004). Further research combining meaningful measures of behaviour during an animal's life time, coupled with radiographs of its skeletons at different stage during its life, and preservation of its skeleton at its death will eventually yield much valuable information regarding the causes and development of skeletal and dental pathologies in captive mammals (cf. Schwartz *et al.,* 2006), which may also be applicable to similar conditions in people.

SPECIMEN COLLECTING

NMS have developed a large and responsive network of British and other European collections that donate specimens for research and preservation. This has been facilitated by the development of cosmetic post mortem protocols, which allow the pathologist full access to dead animal specimens, but do not cause so much damage as to render them useless for other kinds of research (Kitchener, 1997b; Kitchener *et al.*, 1996). In order to obtain successfully useful specimens for research, but not to hinder appropriate pathological and other investigations, it requires considerable mutual respect and understanding by all and a willingness to cooperate with each other. Another problem that hinders research is the lack of a critical mass of specimens for answering research questons. In order for research to succeed in realistic time scales, it is vital that specimens of important species can be collected at one or a few museums for preservation, so that statistically significant samples can be made available for research. Even so, it may take several years, if not decades, to gather suitable samples for research projects. If all specimens are just sent to the local museum, and moreover, are not made available for research owing to a lack of resources to process them, this can be highly damaging and will not benefit either *in situ* or *ex situ* conservation and welfare of captive animals. Unfortunately, acquisition of specimens by local museums has in some circumstances hindered promising lines of research and some important samples continue to be inaccessible for the forseeable future. Therefore, we ask for careful consideration as to where specimens go and cooperation to help those museums and other research centres where these kinds of research are currently most active. For example, Rome Zoo very kindly donated the skeleton of an aged female pygmy hippopotamus from Liberia to NMS in order to assist further research on age-related skeletal pathologies in this species, and two jaguars, *Panthera onca*, which were former inhabitants of Rome Zoo, were kindly sent to NMS by Chester Zoo and are now subject to detailed analysis of skeletal pathologies by a PhD student in collaboration with the University of Edinburgh.

THE MODERN ZOO RECORD SYSTEM

The genetic and demographic management of small captive populations is only possible through systematic record keeping of each individual. More than one hundred threatened mammal species are covered by International Studbooks, in which each individual animal is assigned a specific number. By the early 1970s an international computer-based record system for captive specimens ,the International Species Information System (I.S.I.S.) (which is not limited to threatened species), was established (Shoemaker and Flesness, 1996), and is now supported by more than 500 institutions worldwide. ISIS will be superseded by a new system, ZIMS, in 2008. Both studbooks and ISIS contain vital information concerning origin, parentage, age, medical history, etc. of each individual, offering many opportunities for research in several fields. In order to maximise the research potential of captive animals, it is essential that both donor zoos and natural history museums pay more attention to the international identification of specimens, prioritising ISIS-listed animals, and always recording the studbook number of specimens belonging to threatened species (Gippoliti, 2006b).

CONCLUSIONS

In the last two centuries, several Italian zoologists such as Michele Lessona, Alessandro Ghigi and Oscar de Beaux, have stressed the educational and scientific value of zoos as living museums of natural history. In the early seventies of the 20th century, in collaboration with the Accademia Nazionale dei Lincei and the C.N.R., a national association (ANMS), which inclues all scientific museums, zoos and aquaria, was created. Therefore, we advocate that future stronger cooperation between zoos and museums, in order to support research, should be considered in the best tradition of Italian museology.

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