Mastozoología Neotropical / *J. Neotrop. Mammal.*; 9(2):253-262
©SAREM, 2002
ISSN 0327-9383
Versión on-line ISSN 1666-0536

ON THE CONTINUING NEED FOR SCIENTIFIC COLLECTING OF MAMMALS

Bruce D. Patterson

Department of Zoology, Field Museum of Natural History, 1400 S. Lake Shore Dr, Chicago IL 60605-2496 U.S.A. Ph: 312-665-7750. Fax: 312-665-7754, <bpatterson@fieldmuseum.org>

ABSTRACT. Nature's imperiled state during the present biodiversity crisis has caused many to question the justification for continued scientific collecting. Public opposition to and criticism of biological collecting is especially strong for "charismatic megafauna" like birds and mammals. This article reviews the various ways that biodiversity science is dependent on biological collections, drawing illustrations from on-going work on Neotropical mammals. Modern collections are directly responsible for many of the major discoveries now being made on this remarkable fauna. Not a single case is known where scientific collecting has imperiled or caused the extinction of any Neotropical mammal; all professional scientific organizations have guidelines to prevent this negative impact from developing. Biological collecting is an essential feature of data acquisition and validation. It must continue if biodiversity science is to inform global conservation efforts.

RESUMEN. Sobre la continua necesidad de efectuar recolección científica de mamíferos. La actual crisis de la biodiversidad y sus consecuencias negativas en la naturaleza ha provocado el cuestionamiento a la recolección científica continua. La oposición pública y la crítica a la recolección biológica se hacen particularmente fuertes cuando se trata de "megafauna carismática", como los pájaros y los mamíferos. El presente artículo revisa las diversas maneras en que la ciencia de la biodiversidad depende de las colecciones biológicas, ilustrándolas a partir de trabajos sobre mamíferos neotropicales, actualmente en curso. Las colecciones modernas son directamente responsables de muchos de los grandes descubrimientos actuales relacionados con esta notable fauna. No se conoce un solo caso en el cual la recolección científica haya puesto en peligro a un mamífero neotropical o haya causado su extinción. Todas las organizaciones científicas profesionales se ajustan a ciertas pautas para evitar este tipo de impacto. La recolección biológica es un aspecto esencial de la adquisición y validación de datos, y debe continuar si la ciencia de la biodiversidad quiere brindar información que contribuya efectivamente a la conservación a nivel mundial.

Key words: museum collections, biogeography, systematics, conservation, biodiversity, vouchers, identification, taxonomy.

Palabras clave: colecciones de museos, biogeografía, sistemática, conservación, biodiversidad, ejemplares de referencia, identificación, taxonomía.

Around the world, burgeoning human populations have laid siege to the natural world. Through habitat conversion and depletion, direct exploitation, biological introductions, and pervasive pollution, humans have pushed Nature to the brink of annihilation. And the situation will certainly worsen, because the onslaught has been so rapid that Nature's responses are lagging. Surviving populations of long-lived vertebrates and trees in tiny forest

Editor reponsable para el presente artículo: Carlos E. Borghi.

fragments are certainly doomed to extinction by small forest area. Although it is impossible to extrapolate human resource requirements, we may be witnessing the opening rounds of a mass extinction event akin to the worst in the geological record (Leakey and Lewin, 1995).

In the face of such undeniable threats, is there any place for biological collecting? Biological collecting may be defined as the gathering of biological specimens and samples to further understanding of the natural world. Can any resulting knowledge be so compelling as to justify making further inroads on nature? Dividing scientists and the public alike, this question has generated much heat and little light. Biologists who depend on biological samples to answer scientific questions face mounting pressures to justify this activity from the standpoint of conservation. What follows is my attempt to voice a considered response from a mammalogist's standpoint. Systematics Agenda 2000 (1994) underscored the general importance of this discussion, and others have addressed this same issue from the standpoints of ornithology (Goodman and Lanyon, 1994; Remsen, 1995; Winker, 1996) and herpetology (Stuebing, 1998). Wherever possible, I have sought to illustrate my points using Neotropical mammals, but the arguments apply equally well to other taxa and to other regions.

This article makes no attempt to refute ethical challenges that collecting is immoral—those are philosophical arguments best left to philosophers. I note only that, as metazoans, humans are heterotrophs that must consume other organisms as food before making any other declarations or prescriptions about the world around them.

THE UTILITY OF COLLECTIONS

Natural history collections are the principal repositories for biological specimens and have incalculable value for many biological disciplines. A major mammal collection like the Field Museum's is studied by anatomists, morphologists, veterinarians, physicians (especially rheumatologists, otolarynologists, and epidemiologists), molecular biologists, and those who study taxonomy, systematics, genetics, phylogenetics, and biogeography. The collections are used by archaeologists studying faunal remains, physical anthropologists, paleontologists, and paleobiologists, as well as by environmental scientists studying climate change or toxicology. The museum-going public uses them in exhibitions, public and continuing education, and classroom and independent instruction. Government officials routinely consult collections and their staffs on forensic matters and enforcement issues relating to wildlife laws.

Natural history collections also serve the needs of biological conservation. Although conservation is only one of the responsibilities of natural history museums, their contributions in this area are impressive and warrant enumeration, if only to underscore the integral role of museums in biodiversity studies (McCarter et al., 2001). These contributions derive from three unique and interdependent resources of museums: encyclopedic collections, associated libraries describing and analyzing them, and scientists responsible for building, managing, and interpreting them. So equipped, natural history museums uniquely document and serve as authorities on all matters relating to biodiversity.

At any time, less than 1% of the world's known species are under active investigation by scientists (Wilson, 1985). Consequently, knowledge of the remaining 99% of living species (to say nothing of extinct forms) depends on prior studies and their principal documentation, namely specimen collections and libraries.

THE NEED TO COLLECT

Mammals include the largest living animals, but most mammal species are small and inconspicuous. About 45% of all known living species are rodents, and half of the remainder are bats and insectivores (Nowak, 1999). Most are nocturnal and cannot be directly observed. Whereas larger species can sometimes be tracked or monitored by photo "traps" or tracking plates distributed through their home ranges, most smaller species must be captured and handled before one can identify them and document their presence, much less assess their ecology, physiology, and behavior.

Unlike most birds, mammal species are generally distinguished by subtle characteristics that render species identification problematic. Species limits in birds are often signaled by conspicuous differences in plumage or call notes, and such differences are apparent to human and avian observers alike. In contrast, most mammals rely more heavily on olfactory and gustatory criteria (Rieger and Jakob, 1988)—scientists are far less acute in these senses than in sight or sound. As a consequence, mammalogists are forced to rely on incidental characteristics that have diverged since speciation, and many of these are internal and can only be assessed with specimens in the hand. Spiny rats (*Proechimys*) are notoriously difficult to identify on the basis of external characters but can be readily distinguished by features of the male genitalia (Martin, 1970; Patton, 1987). Different rice rats (*Oryzomys*) may be similar externally, but often show dramatic chromosomal differences that are useful in diagnosis (Gardner and Patton, 1976; Reig and Useche, 1976). Many of the differences that distinguish mammal species are restricted to a single sex or life-stage, or are sufficiently subtle or variable that whole series of individuals may be needed to establish the diagnostic condition (Patton, 1987; Myers, 1989).

Collecting and specimen preparation and examination is essential for many highly diverse but poorly known groups, such as rodents, marsupials, insectivores and bats. However, the same points also apply to "charismatic megafauna" such as primates. When Philip Hershkovitz revised the titis, genus *Callicebus* (then thought to contain only 3 species but now known to include at least 19; Rylands et al., 2000), he scoured 26 museum collections in Europe, North America and South America, eventually locating post-cranial skeletons for only three of these (Hershkovitz, 1990). Basic knowledge of biodiversity is limited by the availability of samples.

There are also persistent suggestions that some common species must be removed before rarer, more cryptic species can be detected (Patterson et al., 1989). Studies relying exclusively on mark-recapture methods often encounter trap biases or trap competition that color their data (Pizzimenti, 1979; Woodman et al., 1995).

ESTIMATING DIVERSITY

Scientists do not know, even to the nearest order of magnitude, the number of species living on the planet (May, 1990). Surprisingly, this sad situation applies even to mammals. Although birds and mammals are thought to be well known in most quarters of biology, enormous gaps in knowledge exist and new species are continually discovered in all groups. Actually, the rate of new species discovery is currently ten times greater in mammals than in birds (Patterson, 2000). And for every species of mammal newly encountered in the fields, forests, and deserts of the Neotropics, three others are discovered in museum collections and biochemical labs. Such bench discoveries are products of taxonomic revisions that "resurrect" names previously thought to be synonyms of valid names (Patterson, 1996), and are no less real or significant for conservation than those uncovered in jungles and malpais. Jointly, field and lab discoveries have accumulated at the rate of about 25 species per year, causing a 50% growth in estimates of global mammal diversity over the last half-century (Patterson, 2001). For the foreseeable future, the actual diversity of mammals (and other groups) will remain conjectural. In addition, biodiversity funding should earmark new resources for **studying collections** besides those set aside for **mounting field expeditions**, if we are to resolve the "species alias" problem.

This enormous increase in known diversity is not based solely on discoveries of bats, mice, or shrews, although these groups encompass many newly described species. For example, the number of Neotropical primate species has risen from 47 to 114 species in only two decades (Honacki et al., 1982; Rylands et al., 2000). On average, three large-bodied species are described each decade, forms that had simply escaped scientific notice (Pine, 1994), such as the supposedly extinct Chacoan peccary (Wetzel, 1977) or a new beaked whale from

Peru (Reyes et al., 1991). In mammals and other groups, new discoveries are not just augmenting diversity, but changing the silhouette of organic diversity as we know it—new traits and characters, novel bauplanes, and extreme size limits (Donoghue and Alverson, 2000).

Every one of these species discoveries has rested on collections of specimens, and most are triggered by **new collections** that challenge current understanding and prompt further research. To name a species, an author must designate a type specimen to serve as name-bearer for the new species. Regardless of the author's insights or eloquence, the validity of his or her name for the new species rests with the identity of the type specimens (International Commission on Zoological Nomenclature, 1999). Collections of type specimens serve nomenclature as much as voucher specimens serve all other branches of science: they make science repeatable and verifiable, bringing needed rigor and definition to biodiversity studies. In order to name a given species or to reevaluate its validity, scientists routinely examine specimens of related forms. Lists of diagnostic characters are the ultimate conclusions of these essential comparisons.

The preservation of biodiversity is a principal goal of conservationists, and careful management and stewardship depend on understanding the basic currency of biodiversity—species. Collections are essential to document and understand biodiversity in scientific terms. It follows then that the steps leading to the assembly and use of encyclopedic collections, including collecting and preserving specimens, are also necessary.

ESTABLISHING BENCHMARKS

Besides documenting nomenclature and shoring up the foundations of biodiversity, specimens acquire additional value as they are melded into collections that encompass spans of time and space. For example, two series of specimens, each collected in precisely the same place but decades or centuries apart, can offer evidence of genetic or morphological change over time in natural populations. Such information may indicate short-term range contraction and apparent local extinctions (Shaffer et al., 1998), as of the cerrado mouse *Juscelinomys candango* near Brasilia (Moojen, 1965; Hershkovitz, 1998) or very rapid evolutionary change (Pergams and Ashley, 2001). Replicated samples may also greatly extend the scope and power of Quaternary studies of range dynamics in response to climate change (Simonetti and Saavedra, 1998). Temporal comparisons may also be of crucial significance for managing endangered species, as for example in assessing pre-bottleneck levels of genetic variation in the endangered northern elephant seal, *Mirounga* (Hoelzel, 1999). Inventories of hyper-diverse protected areas provide park managers with biotic benchmarks to gauge the effectiveness of reserve management and protection (Pacheco et al., 1993; Lim and Engstrom, 2001). They may also serve to promote public understanding and ecotourism by fostering a direct appreciation for the diversity and interest of natural resources (Patterson et al., 1992).

Assessing variation among specimens in morphology, reproduction, and/or genetics makes it possible to recognize differentiation and geographic cohesion. This is usually the first step in identifying a new species and illustrates the manner in which new specimens prompt the re-use and re-examination of older collections. Literally stumbling upon a single dead rat along a trail in montane forest in Cusco, Peru, led Louise Emmons to reexamine all members of the family Abrocomidae. She concluded that the new rat represented a new genus and species, *Cuscomys*, well known to the Incas and previously reported from zooarchaeological remains associated with their burials under the name *Abrocoma* (Emmons, 1999). Although new collections may furnish the first known examples of a new species, more commonly they yield morphological, anatomical, histological or genetic samples that permit new and refined tests of species identity. Although the mouse "*Oxymycterus iheringi*" was known for more than a century, it took extensive new collections from Brazil and Argentina to distinguish this form from *Oxymycterus*, *Akodon*, and other akodonts as a distinct new genus (Hershkovitz, 1998; Mares and Braun, 2000). Similarly, Steppan's morphometric analyses of hundreds of specimens elevated *Phyllotis limatus* to specific rank, nearly 85 years after its description as a subspecies of *P. darwini* (see also Voss and Angermann, 1997; Steppan, 1998). Series of specimens are needed to establish patterns of growth and ontogeny, molt, and sexual dimorphism. For many species, our only knowledge of reproductive cycles, seasonality and litter size come from reproductive autopsies during scientific collecting.

Technological developments in genetics have ushered in a succession of methodologies for addressing systematic questions, each with its own sampling requirements, such as karyology, differentially stained chromosomes, allozyme electrophoresis, RFLP analyses of mitochondria, and most recently the polymerase chain reaction (PCR). Collectors of yesteryear could not possibly anticipate that allozyme analyses would require that tissue samples be preserved at ultra-low temperatures at the time of collection or that preserving samples with formalin would preclude genetic analyses using PCR. To take advantage of these and succeeding analytical tools for conservation will require new collections.

PCR technologies have made possible the analysis of DNA from historic and prehistoric specimens and from small biopsies collected from living animals (Pääbo, 1989; Diamond, 1990). These analyses are now routinely applied to such non-invasive materials as hair and scat, and ease the tensions between scientific sampling and conservation in cases involving protected areas or highly vulnerable species. However, in the absence of voucher specimens, documenting the origin of the DNA sample so that it can be reanalyzed and rein-

Fig. 1. Specimen of unidentified species of Echimyidae (Rodentia), shot in 1999 in cloud forest habitats (ca. 2000 m) in southeastern Peru. During the prior three weeks, 5 experienced ornithologists had combed the area's roads and trails by day and 4 veteran mammalogists had worked by day and night, using snap and live traps, nets, and pitfall buckets—no other individuals were captured or sighted. The single specimen is thought to be the only record of the existence of this new undescribed species (photo by B. D. Patterson).

terpreted remains a vexing issue (Ruedas et al., 2000). Ironically but inevitably, key information and analytical rigor is sacrificed when specimens are not.

New collections are also needed to redress historical imbalances in the distribution of natural history museums and the opportunities their collections represent. Sadly, the world's largest and most comprehensive collection of Chilean mammals is not the Museo Nacional de Historia Natural in Santiago but the Field Museum's in Chicago. Many of the Museo's early collections, including most of Philippi's types, were lost or succumbed to insects (Osgood, 1943). Museums in developed countries employ web-accessible collection databases and loan, scientific visitation, graduate training, and specimen exchange programs to alleviate problems associated with access and repatriation of information. But building the capacity and resources of museums in developing nations is crucial to provide biologists in those countries with key biodiversity resources. In most cases, this involves building new facilities and making new collections.

SETTING PRIORITIES

Increasingly, computer databases originally developed to manage and utilize natural history collections are being used in conservation planning and public policy (Young et al., 2001). Technological advances have enabled scientists to relate collections data to various datasets, reflecting geology, meteorology, land-use, economics, and sociology (Fjeldsa, 1999). The increasing complexity of these relationships has carried us into an "informatics" era, where models and binary operations on databases play an increasing prominent role (e.g., Anderson et al., 2002). When these data are synthesized into met-analyses, it is easy to overlook that their foundations rest on natural history collections.

An enormous literature has reviewed how conservation should allocate scarce resources. Besides variables intrinsic to the reserve itself, such as size or distance or shape, are various properties characterizing its contents. All of these—richness, endemism, and taxonomic rank (Vane-Wright et al., 1991; Mittermeier et al., 1998), as well as synthetic attributes like faunal similarity and difference—derive from natural history collections. No biota is sufficiently well known that additional collections would not improve the scale or accuracy of such predictions. Some, like the *cerrado* are so undersampled relative to their diversity that even a collection of a few hundred mice can uncover numerous new species and genera (Hershkovitz, 1993).

ECOLOGICAL EFFECTS

As an agency of mortality, scientific collecting does not warrant mention alongside the more pervasive agents of endangerment: habitat loss, hunting and exploitation, and biological introductions. A recent FAO report estimates that 14.5 million ha of forest are cleared each year (Stokstad, 2001); rapid and irreversible losses of habitat cause the deaths of millions, even billions of animals. Annual clearing rates in Queensland, Australia between 1997 and 1999 averaged 425,000 ha; an estimated 170 million reptiles are thought to have died during that recent two-year period (Cogger and Fellow, 2001). I know of no comparable figures for Neotropical mammals. Using a range of annual deforestation rates for tropical forests worldwide (71,000-110,000 km^2; Simberloff, 1986) and a range of densities for terrestrial mammals (excluding bats, which may predominate tropical samples in both numbers of species and numbers of individuals) from two savanna forests in Venezuela (1246-2064 individuals/km^2; Eisenberg et al., 1979), one can calculate that tropical deforestation alone is responsible for the deaths of 88 to 227 million mammals *each year*. Of course, roads, settlements, bushmeat commerce and the like would all act additively with habitat loss, greatly elevating its toll.

Sport hunting and commercial exploitation also rank as leading mortality agents. Each year, more than 500,000 white-tailed deer (*Odocoileus virginianus*), one of North America's largest living mammals, are harvested from individual U.S. states (Pennsylvania Game Commission, 2001; Wisconsin Department of Natural Resources, 2001). Numbers of white-tailed deer shot in Wisconsin in 2000 alone exceed the aggregate size of the mammal collections at the Smithsonian Institution (National Museum of Natural History), the world's largest scientific collection of mammals (Hafner et al., 1997).

Commercial exploitation is worse, because it is not informed by scientific monitoring and government control. Only two decades ago, Brazilian customs officials could intercept an illegal shipment with 435 jaguar skins, more than exist of this endangered cat than in all of the world's natural history collections combined (Mares, 1982). Legal commerce is equally bad. The mammal specimens legally exported from Argentina over a two-year period in the 1970s outstripped the aggregate holdings of all species in those same collections (Mares, 1982; Ojeda and Mares, 1982). Currently, farmers are thought to harvest between 50 and 100 million murid rodents per year from the fields and forests of Vietnam (David Wade, pers. comm.). Such massive discrepancies in rates—involving many orders of magnitude—render analyses that unite scientific collecting with hunting and commerce both misleading and unfortunate (Flather et al., 1994).

At first glance, mammals appear to have fared better than other groups in the face of biological invasions. However, this cause still ranks as a significant component of mortality, especially on island systems. Introduced *Rattus* have ecologically and behaviorally dominated indigenous rodents in various regions (Goodman, 1995; Pickering and Norris, 1996), including the New World (Carleton and Olson, 1999). If one considers the Recent diaspora of *Homo sapiens* and his commensals as a biological introduction, then mammals have fared worse than most groups, with most large-bodied forms disappearing in a twinkling from all continents save Africa and Asia (Martin and Klein, 1984; Stehli and Webb, 1985).

The author is unaware of a single instance in which scientific collecting caused the imperilment or extinction of a mammal species. The scientific community embraces professional constraints that regulate the activities of scientific collectors beyond legal limits required by governmental agencies. For example, to collect from vulnerable populations (regardless of their legal protection), the American Society of Mammalogists recommends that collectors restrict sampling to a small fraction of available habitat, use well separated lines or stations to allow easy recolonization, and collect as much information and as many types of samples from each specimen as possible, to reduce the need for resampling (Animal Care and Use Committee, 1998). Similar guidelines are in place for societies devoted to other taxa, including the American Society for Ichthyology and Herpetology.

Yates et al. (1987) used several ecological measures to place the substantial holdings of natural history museums into some sort of ecological context. At the time of the latest survey, American mammal collections contained about 4.2 million specimens (Hafner et al., 1997). Although that number may be staggering in view of the limited diversity of New World mammals and the imperiled status of some species, it is in effect ecologically trivial. Those collections were assembled over centuries, by thousands of field parties working in tens of thousands of places, coast to coast. In contrast, the biomass reflected in those collections is equivalent to the plant productivity of only 25 ha (61 acres) for a single year. Over the course of a century, a dozen owls or foxes will consume the equivalent of 4 million *Peromyscus* (Yates et al., 1987).

Although biological conservation represents only one application of natural history collections, it is an exceedingly important one both for museums and for society. To contribute fully, continued collecting is necessary. Contrary to lay impressions, the answers furnished by scientific collecting are most urgently needed where biotas are most endangered and threats are most pressing. Imperiled hotspots such as the tropical Andes (Young, 1997), Philippines (Heaney and Regalado, 1998), and Madagascar (Goodman and Patterson, 1997) need inventory efforts to document what is left, to galvanize and focus protective action, and to gauge the effectiveness of remedial action.

ACKNOWLEDGMENTS

I am honored to offer these perspectives to a volume honoring a most distinguished student of museum collections, Osvaldo Reig. I thank A. Resetar, H. Voris and M. Kearney for collegial feedback, G. Boge for careful and thoughtful feedback on an earlier draft, and two anonymous reviewers for their comments on the manuscript. I wish to express special appreciation to W. Stanley, J. Phelps, and M. Schulenberg for their diligence, energy, and invaluable assistance in managing and developing the Field Museum's mammal collections.

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