An assessment of zoological research collections in South Africa

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Natural science collections are accepted globally as critical research assets. A total of 71 zoological collections in South Africa, consisting of over 15 million specimens housed at 22 institutions, were assessed to determine their current status and to make recommendations for their future security. The two greatest challenges to the sustainability of the collections are (1) that natural science museums report to departments with an arts and culture rather than a science mandate and (2) staffing. The total staff complement within these 22 institutions is 115, with many collections understaffed or not staffed, and the loss of a single staff member often leaves a collection neglected and unused. Consolidation of collections so that there is a critical mass of staff is essential to address understaffing and would also allow for the establishment of a more dynamic research and curation environment. Consolidation under an appropriate department would also enable concentration of resources rather than dilution across all institutions, which would improve the storage environment (currently 28% of collections have reliable temperature control and only 8% (five collections) have humidity control), and increase the efficiency of the use of available funds (the curation budget was R1.08 million in 2009/2010 for all 71 collections). Consolidation could also ensure the improvement of data storage, management and dissemination, thereby increasing accessibility to the collections and the use of the collections for research.

Introduction

Natural science collections have been assembled throughout the world for almost 300 years, with the first collections comprising mostly curiosities collected by travellers. There are currently an estimated 2.5 to 3 billion preserved biological specimens in collections throughout the world. These collections have formed the basis for much biological research over the last two centuries, and their use and relevance for research and for understanding, using and protecting our natural resources is rapidly growing.[1] Increasingly, biological specimens in collections and information in associated databases are used internationally for examining changes in biodiversity related to habitat loss, global climate change, biological invasions, consumptive use and for conservation planning, environmental impact assessments, and for determining the threat status of species. The value of the collections for academic and applied research cannot be underestimated; much of the material is irreplaceable because of its collection over a long time, often from many localities from which the species have been extirpated as a result of habitat loss or degradation.

Natural science collections comprise a wide variety of preserved biological specimens, from pressed and dried plants, to fossils and frozen animal sperm or plant seeds. Zoological collections include skeletons, skulls, skins, pinned insects, bird eggs and nests, snail shells, whole animals in various preservative liquids such as ethanol alcohol or formalin, whole specimens or tissues or DNA extracts kept frozen at various temperatures, parts of animals such as tissue samples, stomachs and their contents in preservatives, or diagnostic parts of animals such as fish otoliths (ear bones), or squid beaks, as well as specimens mounted on microscope slides.

Internationally, there has been increasing concern about the state of natural science collections[1,2,3] as a result of declining funding as well as decreasing scientific expertise to research the collections, particularly in the field of taxonomic studies which document biodiversity.[4,5] The irony is that there is an increasing awareness of the importance of biodiversity to human survival, but at the same time a rapidly accelerating loss of species, habitats and ecosystem processes. In response, the demand for biodiversity information is increasing, while at the same time, the resourcing of the collections on which this information is based is decreasing. This irony has been recognised by the natural science community and at least two major international meetings have been held recently to discuss the problems facing research collections.[6,7]

Few comprehensive and qualified assessments of the status of natural science collections are publically accessible, but recently documents on research collections in the USA have been

released,[8,9] which highlight major problems with resource limitations, strategic direction, policy, documentation and accessibility of information for research collections in the USA.

In South Africa, zoological collections in museums have been the subject of reviews and assessments since at least 1974.[10] Three later assessments, performed between 1994 and 2005,[11,12,13] examined the scope of the collections and also highlighted problems, all of which were recurring. In 2008, the National Research Foundation (NRF) commissioned an assessment of natural science research collections in South Africa, mainly in response to concerns raised by the biodiversity research community. The main aim of this assessment was to determine the current status of collections in terms of scale and scope, governance, environmental conditions, resourcing, curation and accessibility and to make recommendations to ensure the future security and increased use of these collections. Aspects of the main results of the zoological component of this assessment are presented here.

Methods

A draft questionnaire was developed and presented at five regional workshops (held in Pretoria, Bloemfontein, Durban, Grahamstown and Cape Town), so that curators and other interested parties could provide inputs to improve the questionnaire. Zoological collections were visited by the author between September 2009 and May 2010, and the questionnaire was completed together with the curator or other staff responsible for the collection. The collections were also examined, focusing on aspects covered by the questionnaire. Once the completed questionnaire had been edited and checked, it was sent back to the curator or collection manager for verification and to ensure that they were satisfied that the data and comments captured were accurate. In cases where the collections were not captured in databases, the collection size and scope were estimated, and data were excluded from some analyses.

All aspects of the assessment which were considered to indicate some element of risk or threat to the sustainability of the collections were combined to provide an overall risk assessment. These aspects included staffing (the ratio of specimens to staff, number of staff, staff retirements and qualifications of curator), budget, environmental conditions (temperature and humidity control, building condition, fire prevention), scientific curation (proportion of unsorted and unidentified specimens, updating of names and classification), extent to which specimen data had been captured in a database and extent of use, as well as an overall impression score given by the author when the collection was visited. The collections were ordered in terms of total score, and the scores for the 25th percentile, the median and the 75th percentile were identified and this ranking was used to categorise collections as 'least risk' (score in the lower 25th percentile), 'moderate risk' (between the median and the 25th percentile), 'vulnerable' (between the 75th percentile and the median) and 'highest risk' (above the 75th percentile).

Results

Scope of South African zoological collections

In total, 22 institutions holding 71 different collections were included in the assessment (Table 1). The total holdings of the zoological collections were counted as 10 088 921 samples but the actual number of individual specimens is likely to be closer to 15–18 million because some samples contain many specimens. In comparison, the Natural History Museum in London houses 28 million specimens in its entomology section[14] and an additional 29 million specimens in its zoology section,[15] the Smithsonian Institute Entomology Collection houses 35 million specimens[16] and the Australian Museum houses over 11 million animal specimens.[17]

Institutional governance

The collections are managed by six national government departments, five universities (which report to the Department of Higher Education and Training), two provincial departments (Eastern Cape and Northern Cape Departments of Sport, Recreation, Arts and Culture), one municipality (eThekwini Municipality) and one 'not-for-gain' company (Oceanographic Research Institute). See Table 1 for details.

The four national and five provincial museums fall under departments responsible for arts and culture. Seven of these museums hold both human science and natural science collections (Table 1). While the human science collections fit comfortably within culture and heritage, the natural science collections do not and rather have a science, especially biodiversity, research related function. This function means that the zoological collections in museums are not included in the core functions, mandate or strategy of departments responsible for arts, culture, sport or recreation (Table 1).

Most of the curators of collections that report to such departments believed that this was not the appropriate structure for the institution (Figure 1). Half of the curators believed that the institution should fall under the Department of Science and Technology (DST), and 37% believed that they should be associated with an educational institute or were unsure which structure they should fall under. Only one collection institution (the South African Institute of Aquatic Biodiversity (SAIAB), Table 1) is governed through the DST, and none are governed directly through the Department of Environmental Affairs, which has the mandate for biodiversity conservation.

The curators perceived the purpose of the collections as having a science and research emphasis rather than a cultural or historical function, with taxonomic research and reference collection or identification value being rated as the most important functions of the collections, and cultural, aesthetic and tourism value being considered the least important functions (Figure 2).

Size of collections

The size of collections housed at the major museums could only be estimated because of the large number of

TABLE 1: Institutions with zoological collections: Their governance structure, extent of zoological collections and permanent staff associated with the collections (technical and research).

Governance	Institution	Estimated number of specimens	Number of collection staff
Department of Arts & Culture (national)	Ditsong National Museum of Natural History, Pretoria (previously the Transvaal Museum)	2 840 000†	19
	Iziko South African Museum, Cape Town	3 630 000†	12
	KwaZulu-Natal Museum, Pietermaritzburg (HS+NS)	700 000	8
	National Museum, Bloemfontein (HS+NS)	280 000	14
Department of Agriculture, Forestry & Fisheries, Agricultural Research Council	Biosystematics Division, National Collections, Pretoria	1 350 000	22
Department of Agriculture, Forestry & Fisheries, Onderstepoort Veterinary Institute	Gertrude Theiler Tick Collection	2 723	1
Department of Agriculture, Forestry & Fisheries, Plant Protection Research Institute	Biocontrol Unit, Cedara, Hilton (reference collection)	1 900	0
National Department of Health (parastatal, 30% of funding provided)	National Health Laboratory Services, Vector Control Unit, Medically Important Arthropod Collection	60 000	0
Department of Environmental Affairs, SANParks	Skukuza Reference Collection	13 000	2
Department of Science & Technology, National Research Foundation national facility	South African Institute for Aquatic Biodiversity National Fish Collection, Grahamstown,	86 000	5
Eastern Cape Department of Sport, Recreation, Arts & Culture	Albany Museum, Grahamstown (HS+NS)	650 500	6
	Amatole Museum, King Williams Town (HS+NS)	34 200	3
	East London Museum (HS+NS)	38 800	3
	Port Elizabeth Museum (HS+NS)	52 998	9
Northern Cape Department of Sport, Recreation, Arts & Culture	McGregor Museum, Kimberley (HS+NS)	31 100	2
eThekwini Municipality	Durban Natural Science Museum	159 000	5
Oceanographic Research Institute	Coral Collection	500	0
Rhodes University	Entomology Collection (mostly educational collections)	31 500	1
Stellenbosch University	Entomology Collection (including educational collections)	12 000	0
University of the Free State	Aquatic Parasite Collection	24 000	0
University of Pretoria	Scarabaeidae Beetle Collection	30 000	1
University of the Witwatersrand	Various zoological collections (including educational collections)	60 700	2
Total	–	10 088 921	115

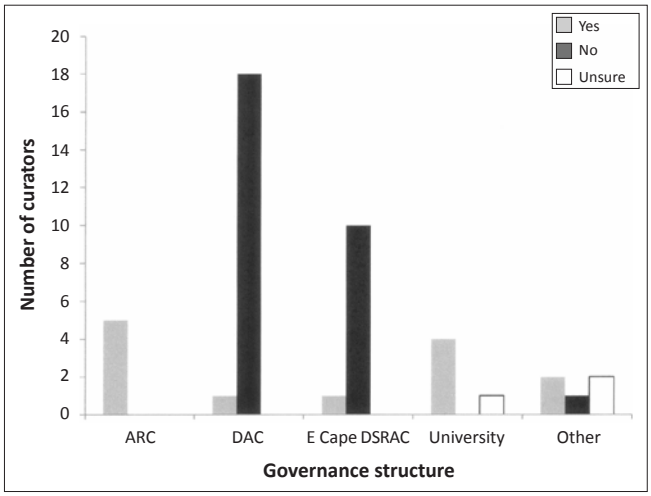
Museums where both human and natural science collections are housed within the same institution are indicated by HS (human science collections) + NS (natural science collections).
†, The figures presented may represent different counting approaches by these two institutions with Ditsong National Museum of Natural History underestimating or even excluding the number of unsorted specimens while these have been included in the Iziko South African Museum estimate.

samples containing many individuals, and the absence of a comprehensive inventory of samples and specimens for many collections. The Iziko South African Museum (Iziko SAM) and the Ditsong National Museum of Natural History (Ditsong NMNH) (previously known as the Transvaal Museum) were the institutions with the largest zoological collections (Table 1). The other institutions with large insect collections – KwaZulu-Natal Museum (KZN Museum), Agricultural Research Council Plant Protection Research Institute (ARC) and Albany Museum – were amongst the five institutions with the largest holdings.

In terms of the broad taxonomic focus of the collections, the ARC had the most diverse collections with 74 105 species represented, followed by Ditsong NMNH with 47 440 species, Iziko SAM with 45 640, KZN Museum with 31 134 and Albany Museum with 19 719 species (Table 2). All other institutions held fewer than 10 000 species.

Iziko SAM had the largest number of type specimens (23 515), followed by the ARC (21 678), Albany Museum (20 925), Ditsong NMNH (19 351) and KZN Museum (11 087). All other institutions held fewer than 3000 type specimens.

In terms of the number of species represented by types, Ditsong NMNH had the most diverse holdings with 13 314 species, followed by Iziko SAM (10 113), ARC (4329), KZN Museum (4105) and SAIAB (1803). All other institutions had fewer than 506 species represented by types.



'Yes' indicates curators who believe the collection falls under the most appropriate governance structure and 'No' indicates curators who believe that the collection is not currently under the most appropriate governance structure.
ARC, Agricultural Research Council; DAC, Department of Arts & Culture; E Cape DSRAC, Eastern Cape Department of Sports, Recreation, Arts & Culture.

FIGURE 1: Opinion of curators of collections on the appropriateness of the governance of their institution.

These analyses and rankings illustrate that there is no single institution that dominates the zoological holdings, and that all

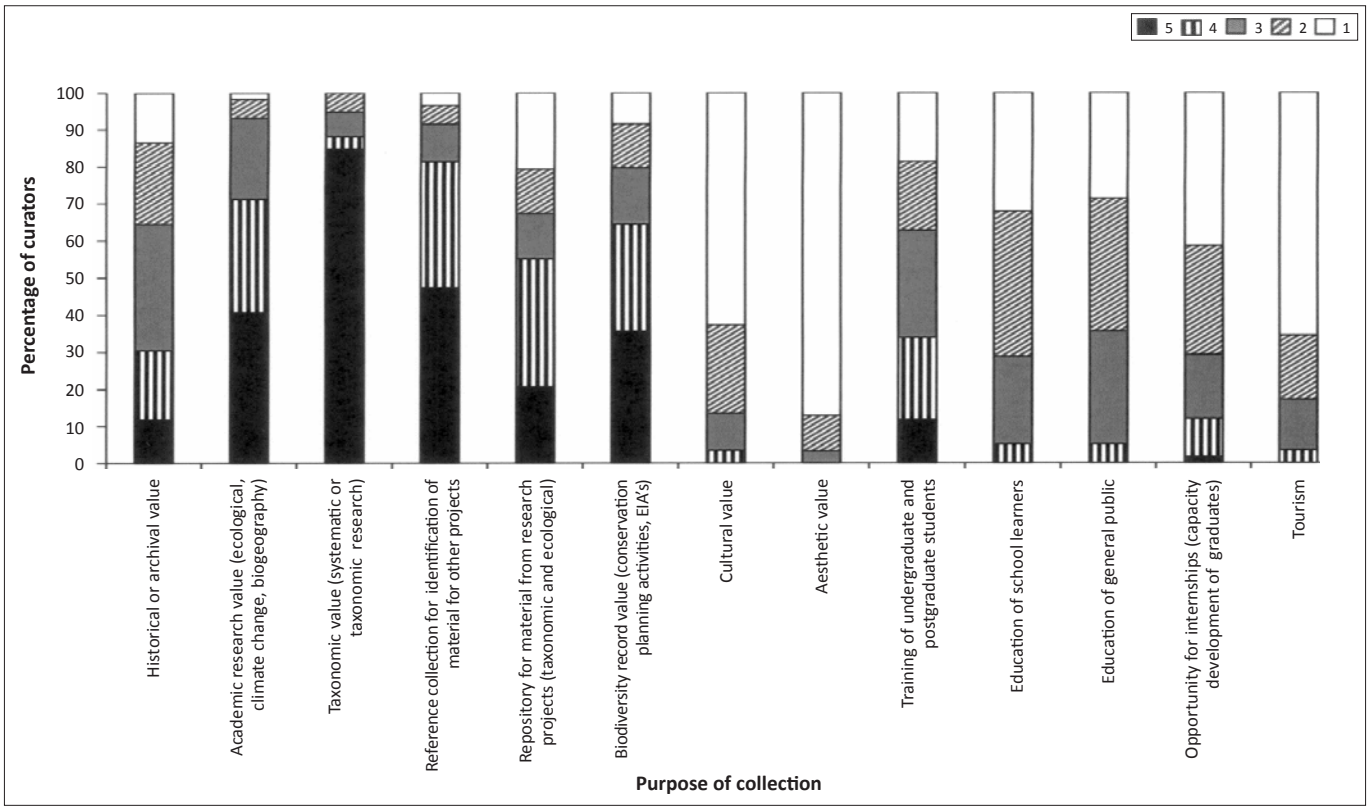


FIGURE 2: Curators' perceptions of the main purpose of the collections for which they are responsible, from most (1) to least (5) important.

institutions included have at least one collection of value. Five collections were rated the largest for number of specimens, number of species and number of type specimens: Iziko SAM's marine invertebrates, Ditsong NMNH's terrestrial mammals, KZN Museum's molluscs, Albany Museum's freshwater invertebrates and SAIAB's fishes (Table 2).

Temporal spread of collections

Collections holding large quantities of historical material have immense value because they reflect the biodiversity prior to major land-use changes and development, and can therefore be used to track, understand and manage such changes. However, the expectation is that collections should be dynamic and act as ongoing repositories for material collected in recent projects and be continuously added to by researchers. Across all collections, an average of 21% of the specimens (2 047 047) were collected before 1950, 64% between 1950 and 2000 (12.8% per 10-year interval) and 13% in the last 10 years, indicating exponential growth. The following collections could be considered to have major historical value, with over 50% of their holdings dating back to before 1950: Albany Museum Bird Collection, Amatole Museum Shortridge Mammal Collection, Onderstepoort Veterinary Institute (OVI) Gertrude Theiler Tick Collection, Ditsong NMNH Lower Invertebrate Collection, Ditsong NMNH Museum Bird Collection, McGregor Museum Herpetology Collection, National Health Laboratory Service (NHLS) Vector Control Reference Collection, and the University of the Witwatersrand Zoological Collections.

Only four collections were considered to be mostly new, with the largest percentage of material collected in the last 10 years: University of Pretoria Scarabaeinae Beetle Collection, University of the Free State Aquatic Parasite Collection, ARC National Arachnida Collection (non-Acari) and the National Museum Arachnology Collection.

Geographical origins of specimens

Most (an average of 75%) of the material housed in the animal collections originates from South Africa, with a range of 28% – 100% of the material having been collected in South Africa. Those collections with low national representivity include large amounts of marine material, which may be from the southern African coast, but may not have been counted as being of national origin. Such is the case for the following collections: SAIAB Fish Collection (28% from South Africa), Port Elizabeth Museum Marine Mammal Collection (47% from South Africa) and KZN Museum Mollusc Collection (55% from South Africa).

In other collections, a particular researcher or curator had collected a large amount of material outside South Africa, mainly in other African countries. Those collections that were categorised as having at least 50% of their material originating outside South Africa were: Amatole Museum Shortridge Mammal Collection (40% from South Africa), NHLS Vector Control Unit (40% from South Africa), ARC Mite Collection (50% from South Africa), OVI Gertrude Theiler Tick Collection (50% from South Africa), Port Elizabeth Museum Amphibian Collection (40% from South Africa) and Ditsong NMNH Herpetology Collection (50% from South Africa).

TABLE 2: Collections held by the institutions, with each collection categorised according to number of specimens, number of species and number of types.

Institution	Largest collection in South Africa for the collection category	Second or third largest collection in South Africa	Major collections not in top three	Minor collections	Total number of collections (total number in top three)
Iziko South African Museum	Marine invertebrates‡*† Insects	Terrestrial invertebrates Fish Birds‡	Herpetology Marine mammals‡ Terrestrial mammals	–	8(5)
Ditsong National Museum of Natural History	Herpetology* Birds* Terrestrial mammals‡*†	Insects	Terrestrial invertebrates‡ Archaeozoology	–	6(4)
KwaZulu-Natal Museum	Molluscs‡*†	Terrestrial invertebrates	Insects Herpetology	Marine invertebrates Freshwater invertebrates	6(2)
National Museum, Bloemfontein	–	Herpetology	Terrestrial invertebrates Insects Birds Terrestrial mammals	–	5(1)
Port Elizabeth Museum	Marine mammals	Herpetology‡	Fish (otoliths)	Molluscs (cephalopod beaks)	4(2)
Albany Museum	Freshwater invertebrates‡*†	Fish	Insects*	Terrestrial invertebrates Birds	5(2)
East London Museum	–	–	Molluscs Birds	Marine invertebrates Insects Herpetology	5(0)
Amatole Museum	–	Terrestrial mammals	–	–	1(1)
McGregor Museum	Archaeozoology (actual size uncertain)	–	–	Herpetology Birds Terrestrial mammals	4(1)
Durban Natural Science Museum	–	Birds Terrestrial mammals	Insects	Terrestrial invertebrates Fish Herpetology	6(2)
Agricultural Research Council	Terrestrial Invertebrates*	Insects‡	–	–	2(2)
South African Institute of Aquatic Biodiversity	Fish‡*†	–	–	Herpetology (amphibians)	2(1)
University of the Witwatersrand, Zoology Museum	Embryology	–	Molluscs	Marine invertebrates Insects Fish Herpetology Birds (eggs)	7(1)
University of the Free State	–	–	Freshwater invertebrates	–	1(0)

Where categories of collection based on taxa and habitat had less than five collections nationally, only the largest collection was identified, and others with substantial holdings were considered as a 'major collection'.
Marine invertebrates includes all taxa except molluscs (except for Iziko where molluscs are included); terrestrial invertebrates includes all taxa except insects and molluscs; freshwater invertebrates includes all taxa except molluscs; insects includes all terrestrial insects, although some collections may include some freshwater taxa; herpetology includes reptiles and amphibians.
The last column indicates the total number of collections held by the institution and the number of these categorised in the top three collections in their broad grouping according to taxa and habitat.
‡, indicates a collection with the highest number of species.
*, indicates where the collection has the largest number of type specimens.
†, indicates those collections with the largest number of specimens, the highest number of species and the highest number of type specimens.

Therefore most of the collections and material have direct relevance to applications and research in South Africa, and some have relevance for Africa. The maximum amount of extra-African material (30%) was held in the KZN Museum Mollusc Collection. The only collection which was considered to have a purely local focus was the Skukuza Reference Collection, of which, understandably, 98% originated in the Kruger National Park.

Of the 52 collections for which data were available, 24 had collections with more than half the specimens originating in the province in which the institutions are based. The implication of this trend is that the provinces where no museums are based are likely to be less represented in collections. However, the Eastern Cape museums had a large proportion of their holdings originating from outside the Eastern Cape, indicating their national rather than provincial relevance. Similarly, the Durban Natural Science Museum (DNSM) had most of its specimens originating outside its municipal area. There is therefore no simple classification of collection institutions into those with a national or a provincial focus.

Assessment of collection resourcing and storage environment

Resourcing: Staffing of collections

A total of 66 curators employed to research the collections and 53 technicians or collections managers were employed in zoological collections in South Africa. Four of the researchers were retired and worked on an honorary basis, and the university collections did not have full-time curatorial staff. In total then, the permanent staff complement was 115, of

TABLE 3: List of collections in the top 75th quartile for the highest growth rate, and the lowest 25% for the least growth over the last 10 years relative to average growth rate per 10-year interval between 1950 and 2000.

Name of institution	Name of collection	Current size	Post-2000 growth (%)	Average growth per 10 years, 1950–2000 (%)	Change in average growth post-2000 growth (%)
University of Pretoria	Scarab Collection	30 000	59	8	51
Agricultural Research Council	National Collection of Arachnida	46 589	55	9	46
National Museum	Arachnology	14 440	50	10	40
University of the Free State	Aquatic Parasite Collection	24 000	49	10	39
Onderstepoort Veterinary Institute	Gertrude Theiler Tick Collection	2723	20	1	19
Iziko South African Museum	Herpetology	13 712	28	10	18
Durban Natural Science Museum	Mammal Collection	14 000	30	13	17
South African Institute of Aquatic Biodiversity	National Fish Collection	86 000	27	14	13
Iziko South African Museum	Bird Collection	2600	18	10	8
KwaZulu-Natal Museum	Oligochaeta	50 000	23	15	8
Stellenbosch University	Insects	12 000	20	12	8
East London Museum	Malacology	19 372	19	12	7
Iziko South African Museum	Mammal Collection	12 030	20	13	7
Agricultural Research Council	Mite Collection	30 907	10	18	-8
National Museum	Herpetology	16 833	8	17	-9
Iziko South African Museum	Marine mammals	1437	5	15	-10
Albany Museum	Freshwater fish	15 475	8	18	-10
Durban Natural Science Museum	Invertebrates	102 012	1	11	-10
McGregor Museum	Mammals	7300	5	17	-12
KwaZulu-Natal Museum	Insects	530 000	5	19	-14
Durban Natural Science Museum	Bird Collection	39 442	2	19	-17
Durban Natural Science Museum	Herpetology & Fish	3594	1	18	-17
East London Museum	Bird Collection	16 330	0	18	-18
East London Museum	Butterfly Collection	1543	0	20	-20

The last column provides an indication of the difference in rate calculated as the difference between the average per 10-year period between 1950 and 2000 and the percentage growth over the last 10 years. Negative values therefore represent a decrease in growth rate.
Collections with fewer than 1000 specimens were excluded.

whom 81 were at museums (excluding ARC, OVI and SAIAB). The total number of researchers at the museums was 38, with most (6) at the National Museum. The average number of researchers was 1.03 per collection and technicians was 0.85 per collection. A total of 15 collections had no researcher associated with them and 10 collections had no technical or collection management support.

The average number of specimens per staff member for institutions was 67 502. At the level of collections, insect and general invertebrate collections had the highest ratio of specimens to staff and all the institutions with major insect collections had ratios of specimens to staff vastly exceeding the average. The discrepancy between these collections and those for vertebrates was extreme, with most vertebrate collections having 40 000 or fewer specimens per staff member and invertebrate collections with more than 100 000 specimens per staff member. This trend is global and calculations from the websites of even the largest museums in the world (Natural History Museum, London [14,15] Smithsonian Institute[16,18] and the Australian Museum[17]) suggest that insect and invertebrate collections have more than 500 000 specimens per staff member, while figures are lower for herpetology collections (28 000 at the Australian Museum[17] and 47 500 at the Smithsonian Institute[18]). There is no evidence that the processes involved in accessioning, identifying and cataloguing individual specimens of different types is vastly different between different taxonomic groups, although the preparation of a mammal or bird study skin and skeleton does take longer than the preparation of an invertebrate stored in ethanol.

Half of the research staff of the collections held a PhD and 85% had at least an MSc (Figure 3a). For technical staff, the majority (64%) had only a matric or lower qualification (Figure 3b), but they had an average of 13.7 years relevant experience. The NRF rates researchers into categories (A for world leaders, B for researchers with an international reputation in their field, and C for established and experienced researchers[19]). Only 16 researchers (24%) had a rating from the NRF (5 B ratings and 11 C ratings). Of these, four of the B-rated researchers were retiring within the next 5 years (one of these had retired and was an honorary associate), and of the C-rated researchers, two had already retired, and another five were retiring, leaving only five NRF-rated researchers in the next 5 years. None of the researchers had a Y-rating, which would indicate promising young scientists to replace these retirees.

In terms of age profile, 74 staff were 50 years old or younger, and 51 were over 50 years old (Figures 4a and 4b), meaning that within the next 10 years, at least 50 staff would need to be replaced and trained in the curation and/or research of collections.

Staff retention also has to be considered in terms of risk to collections, and this factor has been perceived to be problematic within institutions that house collections. However, low levels of staff retention were not reflected by an analysis of the duration of employment for existing staff (Figure 5). For all staff combined, 59% (69 individuals) had been employed in the same institution for more than 10 years; this figure was even higher for researchers at 86% (or 41 individuals). However, these figures did not include

the staff that had left and had not been replaced. At the four nationally funded museums, the number of researchers had declined from 23 in the 1990s to 17 in 2009/2010, so actual retention may not be as high as reflected in Figure 5.

Resourcing: Funding available for curation

Funds available for curation activities excluding staffing and infrastructure maintenance were non-existent to small. The range recorded was from zero to R300 000 per collection, with an average of R21 000 per collection and about 10 cents per specimen. The total national allocation of funds for curation consumables was approximately R1.08 million for 2009/2010. SAIAB, which reports to the NRF, received the most funding, while the largest institutions each received less than R160 000 per annum for curation costs, resulting in much less than the average of 10 cents per specimen being available (Figure 6). University collections did not receive dedicated funds, and the research grants of the academic responsible for the collection were used to cover the costs of curation. While the curation needs vary for different types of specimens, it is likely that most of the major museum collections are severely underfunded in terms of curation needs, especially storage consumables and infrastructure.

Storage environment

Extremes and fluctuations in temperature and humidity, fire, pests and mould pose serious risks to collections, necessitating protection from them. Purpose-built storerooms were used to house 16 (26%) of the collections. Most of the collections were stored in buildings or rooms which had been modified and 24 (39%) have experienced problems with leaking, dampness or dust. As many as 25 collections (40%) were housed with no temperature control, and the temperature control was reliable in only 20 of the remaining collections that did have some form of temperature control; only 5 collections (8%) were housed in an environment with humidity control. Pest control was highly variable, ranging from the use of an external pest control company, to the use of a variety of pesticides including camphor, Vapona®, Fumitabs®, naphthalene, Phostoxin® or aerosol foggers. In several collections no pesticides were used, but pest infestation was monitored and localised treatments were carried out. A relatively large proportion (73%) of the collections had fire detectors, and alarms linked to the fire station (57%), but only 32% had a sprinkler system and 25% had the storeroom sealed off from the rest of the building. In addition to the risk to the collections, staff in many collections were exposed to pesticides (some of which are highly toxic or possibly carcinogenic) and to the risk of fires, especially dangerous in the case of wet collections stored in highly flammable ethanol.

Based on scores allocated for the environmental conditions described above, six collections could be rated as being exposed to low risk from environmental conditions: the ARC Arachnida (non-Acari and Acari) and Nematode Collections, Iziko SAM Mammal Collection, DNSM Bird Collection and the SAIAB Collection. Three collections were identified as being at severe and immediate risk from the environmental conditions in which they were stored: Ditsong NMNH Mammal and Archaeozoology Collection, East London

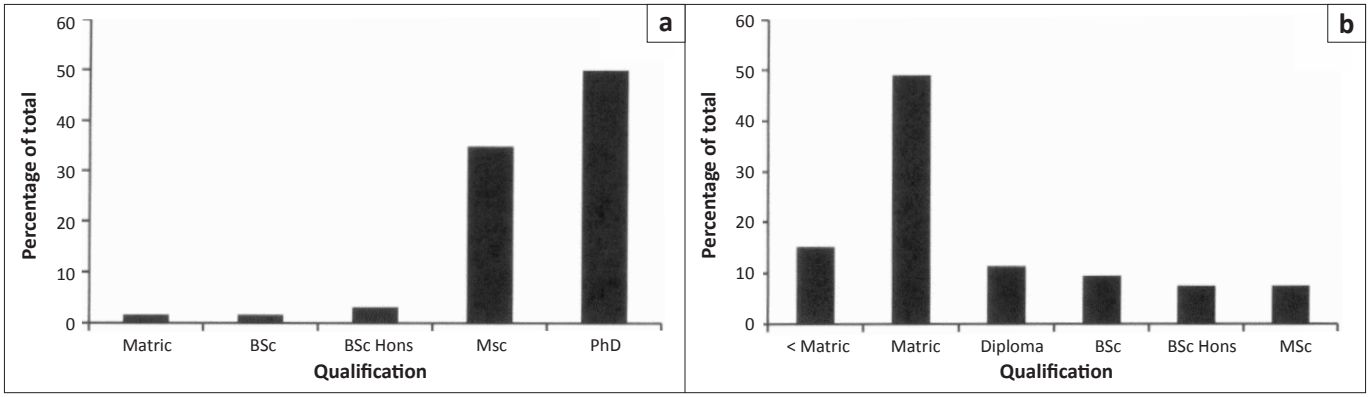


FIGURE 3: The highest qualification obtained by (a) research or curation staff and (b) collection managers, assistants, technicians or preparators, across all institutions.

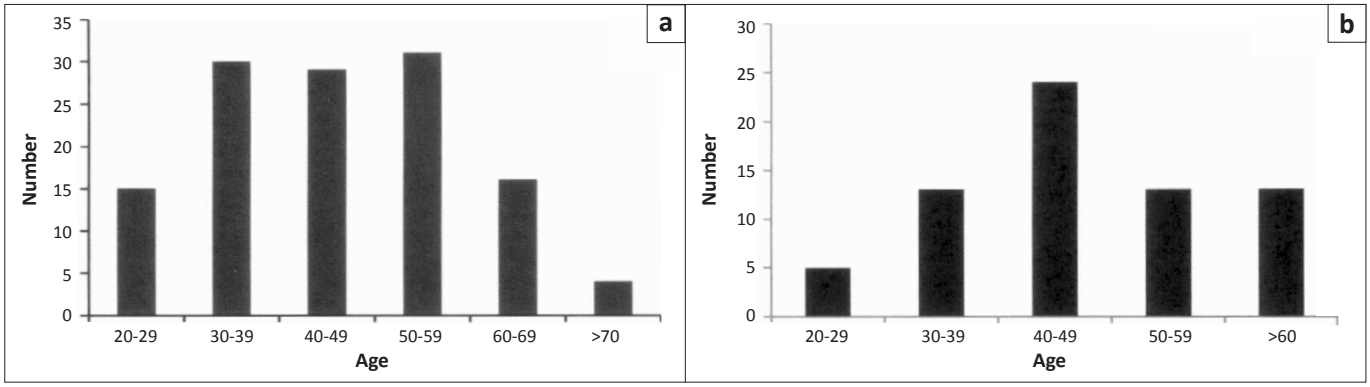


FIGURE 4: The age profile of (a) all staff (n = 66) and (b) research staff (n = 53).

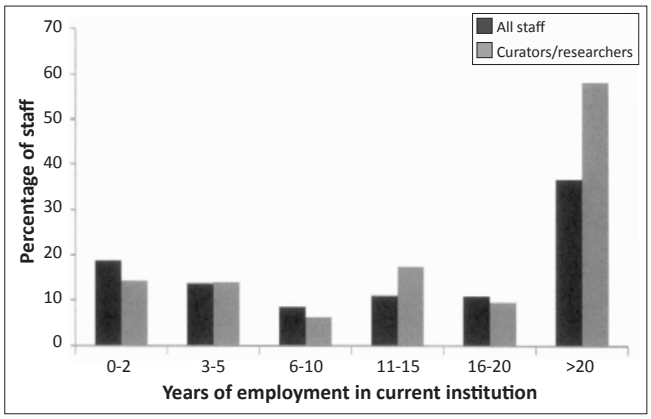
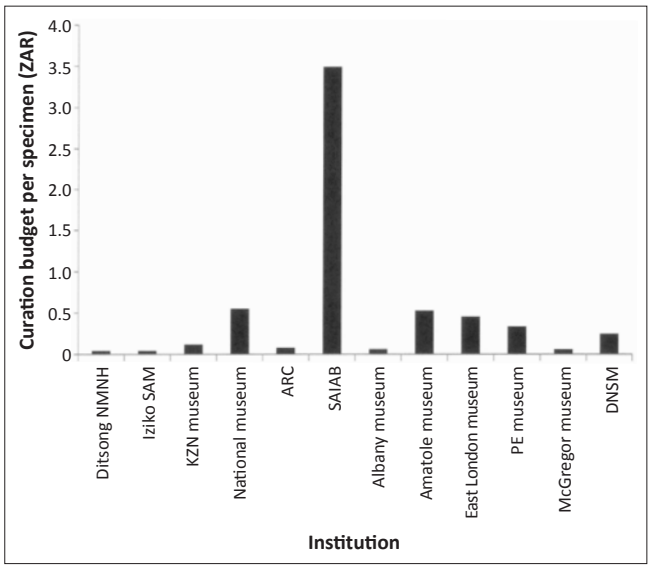


FIGURE 5: Staff retention as measured by the length of time all staff and curation or research staff have been employed by their institution.



Ditsong NMNH, Ditsong National Museum of Natural History; Iziko SAM, Iziko South African Museum; ARC, Agricultural Research Council; SAIAB, South African Institute for Aquatic Biodiversity; DNSM, Durban Natural Science Museum.

FIGURE 6: Approximate curation budget per specimen for main collection institutions.

Museum Bird Collection and Amatole Museum Shortridge Mammal Collection, while another 11 collections were identified as being at high risk as a result of their environment.

Assessment of accessibility and use of collections

A combination of unprotected storage environments and inadequate funding and staff means that collections are at risk of deterioration or loss, at least in the short term. A longer-term risk is that collections that are not used by the broader research community will not be perceived as worthy recipients of scarce resources. Growing collections that are well documented and frequently used would have a better chance of survival than those that are not. For this reason, aspects of accessibility and use were assessed.

Collection growth

The relative growth of collections over the last 10 years indicates the extent to which collections are being used as repositories for specimens, either by curation staff or by external researchers. Growth over the last 10 years ranged between 0% and 59% (Table 3). Three of the collections that had the highest relative growth rate were at universities, possibly indicating the influence of active research programmes with student involvement.

Scientific curation

Biological specimens that are not identified, not separated from mixed samples or have outdated classifications (i.e. they belong to groups in which taxonomic revisions have resulted in name changes), cannot be readily accessed[20] and used by the broader community. Of all the collections, 48% had been updated according to the latest classification, but this updating was largely incomplete. In terms of databases, the percentage of collections for which names and classifications were updated was slightly higher (53%). Invertebrate collections had vast quantities of unidentified and unprocessed samples which may be physically secured, but they and their associated data are essentially inaccessible. Curators listed inadequate staffing as the main reason for the lack of scientific curation, but in some cases a lack of expertise to identify specimens also limited this activity.

Documentation and databases

Old catalogue books, field notes and other historical documents associated with the collections often provide invaluable information about the specimens, including habitat, weather, exact location and the collectors. Storage of these documents was generally haphazard, and no institutions had scanned or duplicated these documents. With the exception of the SAIAB collection, there was also no standardised storage system for data sheets associated with the material.

Of the 67 collections assessed in terms of the degree to which specimen information was captured on a database, 24 (36%) were completely captured, an improvement since the assessment done in 1999,[12] and just lower than the federal collections in the USA (40%).[9] A total of 6 478 426 specimens were yet to be captured on databases. The collections which did not have a curator and which could be considered as 'orphaned', as well as university collections, did not have databases, or had only a small percentage of their specimens recorded on databases. Information pertaining to the large insect collections remained largely uncaptured on databases.

Software used for databases ranged from simple Microsoft Excel spreadsheets, to more complex relational databases such as those in Microsoft Access, to packages developed specifically for natural science collections, such as Specify. The fields included in the databases varied widely, both within and across institutions. Some institutions had made efforts to comply with the international standards set by the Global Biodiversity Information Facility (GBIF), but this was uncommon. Most collections did have a backup system, but this backup system was generally uncoordinated and rather *ad hoc*. Exceptions were the ARC collections, which had a backup system provided by an external company.

Data from 15 of the collections had been provided to the South African node of the GBIF – a surprisingly low number considering that funding had been provided for the last 4 years to enable data capture. In some cases, this lack of provision was related to policies and negative attitudes towards data sharing. There was a similar trend in terms of providing data to large atlasing or conservation planning projects – only 27% of collections had been used to provide data for these activities.

Extent of use of collections by internal and external researchers

The total number of visitors using the collections over the last 5 years was 1312: an average of 262 visitors per year, 22 visitors per collection or 4.4 visitors per year per collection. A total of 2223 loans were sent out from the collections to other institutions (an average of 444 per year, 38 per collection or 7.6 per year per collection). Global benchmarks are problematic because European and British museums hold collections from a wide range of countries and so will probably send out more loans. For example, the Natural History Museum in London sends out 600–700 loans per annum from its Entomology Collection,[14] but considering that the collection has material from all over the world, it is probably about 100 loans per continent. The South African National Biodiversity Institute (SANBI) herbaria which hold about 1.5 million plant specimens send out about 50 loans per annum. These figures suggest that the average use by 13 researchers outside the institution a year for each zoological collection is low. Four of the eight high-use (50–144 loans, 45–153 visitors per annum) collections in South Africa were mammal collections, which is probably a reflection of the number of researchers working on this group both nationally and globally.

Low-use collections included those held by individual university academics, or small orphaned and reference collections. The reasons for the low rate of use for the other collections (ARC Acari Collection, OVI Gertrude Theiler Tick Collection, PE Museum Amphibian Collection and East London Museum Bird and Mollusc Collections) are unknown, because, apart from the OVI Tick Collection, similar collections in other institutions were more frequently used.

Policy, procedures and standards for collections

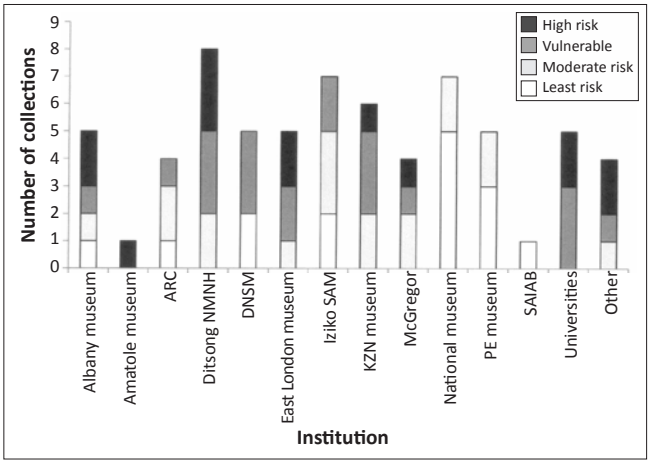
The material that is accepted by the collection, how it is processed and documented, curated and used should all be regulated by formal policy, procedures and standards. Most of the museums did have a general collections policy which provided useful guidelines, but the policies seemed to be inconsistently implemented by individual staff and across different collections within the institution. The situation was similar for procedures documents. The National Museum was the only institution which had a standardised stocktaking or audit process which was implemented on a regular basis (annually).

Overall risk assessment of collections

Risk in the sense of the analysis presented in Figure 7 is relative, but it at least allows the identification of those institutions with a high number of collections with a higher than average number of threats to sustainability, and an assessment of trends in terms of which institutions and type of collections face more threats.

There is no clear suite of conditions or a single score that accurately reflects the risks to collections. For example, a collection may be stored in a building lacking climate control, and while in some locations and for some types of collection this may be problematic, in others it may not be. Not all of the collections categorised as 'vulnerable' and 'highest risk' were physically neglected, and the risk status may be as a result of the environment, insufficient funding, the lack of a database, use and staffing issues rather than lack of care. This categorisation was especially true of university research collections. However, based on the overall impression rating by the author, 21 of the 35 collections in the upper 50% for risk were given an overall rating of 'fair' or 'poor', indicating that the problems were usually quite obvious.

The analysis shows that 17 institutions had collections categorised as 'vulnerable' or 'highest risk', and these institutions spanned the range of governance structures from universities to national museums. The ARC, Iziko SAM, SAIAB, the National Museum and PE Museum had no collections in the 'highest risk' category (Figure 7). Six of the large insect or invertebrate collections fell in the 'highest risk' category: Albany Museum Freshwater Invertebrates and Insects, KZN Museum Arthropoda (non-insects), and Ditsong NMNH Coleoptera, Lepidoptera and General Entomology Collections, which was attributed mostly to the high specimen to staff ratio (and in the case of the Albany Museum and Ditsong NMNH General Entomology, the absence of staff), the large amount of unsorted and unidentified material and the low proportion of the collection that was captured in a database. All the other 'high risk' collections could be considered orphaned (i.e. no permanent staff were caring for the collection): NHLS, Cedara, Albany Museum Arachnida, Oligochaetes and Myriapods, McGregor Museum Archaeozoology, East London Museum Marine Invertebrate



ARC, Agricultural Research Council; Ditsong NMNH, Ditsong National Museum of Natural History; DNSM, Durban Natural Science Museum; Iziko SAM, Iziko South African Museum; SAIAB, South African Institute for Aquatic Biodiversity.

FIGURE 7: Assessment of risk to sustainability of collections across institutions, considering all potential threats (staffing, environmental conditions, scientific curation, databasing and use).

and Tortoise Collections, and two university collections, with the exception of Amatole Museum Mammal Collection, in which there were severe environmental problems.

Discussion

The estimated more than 15 million zoological specimens in South Africa's zoological collections hold a vast amount of largely irreplaceable material and related information, covering most of South Africa, as well as other parts of the continent, and collected over a 170-year period. The value of these collections lies primarily in scientific research. The OECD Global Science Forum report on Scientific Research Collections[7] stated that scientific collections are not only essential parts of the research infrastructure of all countries, but also of the global research community. In South Africa and more widely, the importance of the collections for scientific research is not widely recognised by decision-makers, by the broader research community, or even by the staff within collection institutions who predominantly view them to be of use only to specialist taxonomists (Figure 2). These narrow perceptions and the poor understanding of collections, and the resulting marginalisation from mainstream science and innovation programmes, will continue unless the collections environment is transformed. Evidence for the marginalisation is provided by the current levels of funding and staffing and the relatively low use of most of the collections.

This assessment showed that while there are some well-managed, resourced and used zoological collections in South Africa, this situation is not commonplace. The problems identified were distributed across virtually all institutions. In addition, the collections environment could not generally be considered to be particularly dynamic, especially in terms of the management and dissemination of information associated with the collections. These problems will probably result in the collections never being effectively utilised. These risks are not unique to South Africa and were also highlighted in US and UK reviews and reports.[5,8,9]

In South Africa, there are two essential actions that would be required to bring the collections into the national system of science and innovation and to fully unlock their potential to address questions of broad relevance to society. The first relates to governance. The zoological collections are not part of the public displays at museums and they have no real cultural, art, sport or recreation value. The specimens in zoological collections are not covered by any of the descriptions of natural heritage objects presented in the *National Heritage Resources Act*[21] and they are not included in any way in the Department of Arts and Culture's 'Strategic Plan 2011-2016'.[22] It is not the mandate of the Department of Arts and Culture or a provincial Department of Sport, Recreation, Arts and Culture to maintain scientific infrastructure or to carry out scientific research, which presents major problems for funding and reporting by the zoological collection institutions falling under these departments. It is therefore critical to change the governance structure for zoological research collections in museums falling under departments that cater for arts, culture, sport or recreation. SANBI was given a discretionary function in the *National Environmental Management: Biodiversity Act*[23] to 'establish, manage, control and maintain … collections of dead animals that may exist' but the feasibility and appropriateness of SANBI undertaking this task has not been discussed in depth. Multilateral discussions between relevant government departments are needed to initiate a solution to the existing governance challenge.

Governance of the collections that are not housed by collection institutions constitutes a challenge of a different kind. While several curators believed that their collection should be moved to a higher education institution, this belief was related only to perceived increases in funding for research that would follow such a move. The university collections all face risks associated with long-term storage and care because they are generally developed and used by one or two academic staff; when these people move on, there is no guarantee that the collection would be maintained. Universities could house collections on a temporary basis while researchers work on them, but once the research is completed, or if the researcher leaves the university, there should be a policy or agreement that the collection would be transferred to a more appropriate institution.

The second critical action required to improve and fully engage with the collections relates to the use of these collections for addressing questions of relevance to society. Resources for collections have declined even in the developed world[2,3] and this decline may be related to changes in research priorities. Understanding global change and impacts on ecosystem functioning and services, and developing ways to mitigate impacts are current priorities.[24,25] In South Africa, where even greater demands for social spending exist, the arguments for the collections to be used in line with changing needs are even stronger. Collections do have the potential to be used in answering a wide range of questions relating to climate change, sustainable use of resources and human health and well-being.[1] Globally, one of the main criticisms of collection institutions and taxonomy as a discipline is a lack of strategy,[5,8,9] and while the traditional approach of using the collections purely for taxonomic research has been defended by the curation community, this approach has not resulted in solutions that have improved the situation. There is a need to ensure that fundamental research can be placed in a broader context, in which the research outputs have relevance beyond a small group of experts. There is also a need for the expansion and growth of collections to be strategic rather than on an *ad-hoc* basis with a large amount of duplication in effort and critical geographic and taxonomic gaps not being addressed.

The use of collections or associated data for innovative and relevant research is also key to creating a dynamic environment, which is important for attracting and retaining staff. However, a dynamic research and curation environment cannot be created in the fragmented arrangement of collections and staff that currently exists. A critical mass of people working

as a team, with appropriate training and guidance, would be essential to changing the zoological collections environment. While there are no global benchmarks for the number of staff per collection or the number of researchers required to create a dynamic team, the trend at larger international museums, such as the Smithsonian Institute, the Natural History Museum in London and the Australian Museum is to have at least 6 employees for each major collection, with some of the larger collections requiring 8 to 20 employees. Following this trend would mean that, at institutions like Ditsong NMNH and Iziko SAM, there should be at least 40 employees associated with the zoological collections. It is not realistic to imagine that this scenario could be established at all 22 institutions holding collections, or even at all 11 museums, and consolidation of collections to create focused and dynamic centres would be essential to addressing most of the problems identified here. Critical mass also allows for career development, guidance and succession planning that are impossible when there are fewer than five employees at an institution. SAIAB is an institution that illustrates the difference that an appropriate governance structure, a critical mass of employees and a research focus that addresses a range of inter-related topics around the collection can make.

National government facilitation would be required for both the change in governance and the consolidation and restructuring of collections. A national strategy for the collections that includes research and electronic data management and dissemination would require input from the broader research community. There are also additional actions that would require input from various sectors including the collections community, higher education institutions and government departments. The development and implementation of policy, procedures and standards for curation, as well as capacity development programmes for collection staff, require input from the broader collections stakeholder community, and it is likely that additional state investment will be required for implementation. The recent investment in the buildings at some of the institutions through the Expanded Public Works Programme is recognised and welcomed, but without addressing the more critical operational and strategic problems, the zoological collections environment is not likely to show much improvement.

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Competing interests

I declare that I have no financial or personal relationships which may have inappropriately influenced me in writing this paper.

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