Conferencia de Clausura

The Future of Natural Science Collections into the 21st Century

F.P.D. Cotterill

El Comité Organizador había invitado al Sr. Cotterill, *Principal Curator* de vertebrados en el *Natural History Museum of Zimbabwe*, donde reside la Secretaría de la *Biodiversity Foundation for Africa*, a pronunciar la conferencia de clausura de este I Simposio, dado el destacado valor de sus ideas relativas al significado del patrimonio natural y al imperativo de su conservación. Los lamentables acontecimientos derivados del acto terrorista del 11 de septiembre, relativos a comunicaciones y puente aéreo, nos imposibilitó cerrar los vuelos necesarios para la llegada desde Zimbabwe, vía Londres, del Sr. Cotterill. Él ha tenido la amabilidad de remitirnos el contenido de su conferencia para ser incluida en la edición de estas Actas. Incluimos aquí el texto original en inglés y su traducción al castellano.

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Abstract

This paper explores three issues: One is why biodiversity collections are so important in the natural sciences with respect to the knowledge their preserved specimens provide and maintain. I argue that natural history - centred around organismal and comparative biology in its broadest sense - is the core discipline of the life sciences. It structures and integrates all biological knowledge. Second, there are a wealth of very critical reasons why human welfare hinges on radically improving scientific knowledge of the dynamic properties of biodiversity. It is here that preserved specimens hold a fundamental and unique role in providing and maintaining this knowledge. These relationships between natural science collections, science and society are the singular reason why collections should be preserved and expanded. It is logically why museums exist, and why they deserve unprecedented societal support. Third, and in this respect, I argue that the demise of natural science collections and associated science constitutes a global disaster. It is especially disturbing that the museum community has collectively failed to build up their institutions around their singular corporate strength and *raison d'être*. In this respect, I devote some attention to exposing the epistemological weaknesses and pseudoscientific status of the theories and ideas of management "science" with which museum administrations increasingly interact in trying to survive. It is high time that museums stop apologizing to society for the natural science collections in their corporate care, and change priorities and activities accordingly. These arguments are founded on an ontology of biodiversity, which is structured by the ubiquity of the uniqueness of living entities. This ontology, in turn, explains why natural science specimens hold a critical role in the epistemology of biology. The urgency of improving this knowledge is highlighted by our very poor and incomplete knowledge of biodiversity and the environmental crisis. Museums are poised to enjoy unparalleled corporate growth if they reorientate their corporate policies and activities toward charting the biosphere.

INTRODUCTION

Didactic Stance

This is yet another discussion on the values, uses, plights, and especially the futures of natural science collections. Such presentations can be classified into one of two species: the one is more upbeat in tone and prognosis, and also long on political correctness - especially (e.g. Hughes, 1992; Chalmers, 1993) in rhapsodising on the opportunities for corporate growth that paradoxically impinge on the health of the science in museums. These trend to an infatuation with ideas borrowed from management science. The latter is often seen as an elixir for the corporations housing natural science collections. In contrast, more reactionary reviews tend to denigrate the orthodoxy and seek to rectify declining support for science and collections in museums. These commonly cast a doom and gloom approach on the state and future of herbaria and museums (De La Penha, 1993; Miller, 1993; Seymour, 1994; Cotterill, 1995a, 1997).

My stance in this lecture is perhaps even less politically correct than previous diatribes; for I argue that misdirected corporate policies and failed leadership is the singular reason for the decline and threats to collections and museum science. Some space is devoted to defending what some may perceive to be an erroneous, if not malicious, accusation. My overarching stanchion is that the attention and resources demanded to secure the future integrity of natural science collections and associated knowledge far supersedes the arguments and prevarications that seek preservation of administrative empires in museums, and/or personalities of key persons therein. One response by bureaucrat or xenophobe to my criticisms will be that it is seditious for a museum employee to candidly examine the state of museums, and especially sacrosanct to dwell on their foibles and state what many scientists in museums suspect, privately agree on, but too rarely publicize. I hypothesize my statements will especially antagonize those who do not understand science, and consider it peripheral to their particular ambitions.

Nevertheless, I believe that there is hope for collections; provided a critical mass of scientists defend, maintain and build up natural history as a core discipline in the life sciences. The criticality of the arguments for the supremacy of natural history, and the collections on which it stands or falls, are magnified by an environmental crisis of global extent.

The Problem

Biosystematic resources comprise all natural history collections in the world's museums and herbaria, and the human skills vital to interpret and maintain the specimens therein. They hold a unique role in science as they provide and maintain a reliable and consensible knowledge of the

Box 1. How Little We Know about Biodiversity

Any discussion of how to realistically measure biodiversity *in situ* should take note of its dimensions. An objective understanding of the true domains of organismal biodiversity and the spatial extent of ecological biodiversity rebounds on plans and attempts to measure biodiversity in ecological landscapes and maintain its benefits (Table V). We are still discovering the true extent of the vastness of the biological world, and it is frequently acknowledged that biodiversity is poorly known. In Wilson's (1992) words, we live on an unexplored planet and are still establishing how incomplete this knowledge is. Our increasing reconciliation with a state of affairs that we know very little about organismal biodiversity began with Erwin's (1982, 1988) assertion that tropical moist forests constitute the heart of biodiversity in view of their exceptional arthropod fauna; containing many more different organisms awaiting scientific recognition than customarily believed. Since then our attention has been expanded to marine biodiversity (May, 1994) and soil biota (André, Noti and LeBrun, 1994).

The dimensions of the biosphere are still, quite literally, being bottomed. Life not only exists in mid ocean rifts, but has recently been demonstrated to extend hundreds of metres into the sediments of oceans and continents (Pedros-Alio, 1993; Parkes *et al.*, 1994). The limits of the continents' soils require reevaluation, being far deeper than originally believed. This reconsideration is based on recent demonstrations that bacteria live at hitherto unrecognised depths in the parent material (Richter & Markewitz, 1995).

Deeper cognisance of the immense dimensions of organismal biodiversity has partly arisen from hitherto unavailable technologies, particularly in molecular biology where novel means of screening genetic macromolecules has generated unimagined insights into the extent and dimensions of microbial diversity (Delong, Wu, Prezelin & Jovine, 1994; Embley, Hirt & Williams, 1994; Woese, 1994; Holmes, 1996) and also in studies which have sought to quantify the extent of organismal biodiversity in the soil (André *et al.*, 1994; Lawton *et al.*, 1996). Not only do we know very little about the dimensions of the biosphere but the composition of familiar groups of organisms, and especially their interrelationships are still poorly understood. For example, objective characterizations (robust cladistic phylogenies) of familiar and apparently well known groups of organisms, notably birds, are still far from complete (Cotterill, 2002a,b; Zink, 1996). In conclusion, Donoghue & Alverson (2000) have argued convincingly that biology is in the mainstream of a new age of discovery of the dimensions and intricacies of biodiversity. This remarkable situation where the biosphere is so poorly known ridicules claims (e.g. Horgan, 1997) that science has discovered nearly everything about the natural world. Such claimants seriously misconstrue the nature of biology and the biodiversity we are challenged to explore.

natural world (Cotterill, 1995a, 1997, 1999). Despite the billions of preserved specimens sampled across the planet, scientific knowledge of biodiversity and the biophysical environment is very incomplete. Yet, this knowledge is critical to evaluate and manage biodiversity in the marine and terrestrial landscapes we increasingly modify for human use (Box 1; Cracraft, 1995; Wilson, 1992; Cotterill, 1997, 1999, and references therein). Yet, the corporations housing biosystematic resources have failed dismally to meet the challenges embodied in the biodiversity crisis. In particular, they have failed to respond to many other opportunities and needs for biological knowledge. This paper examines three main subjects, which underlie the future of natural science collections as repositories of irreplaceable knowledge:

1. One, the principal contribution from herbaria and natural history museums to society is the scientific knowledge derived from the specimens preserved in their collections. This core value of collections is very poorly appreciated and widely ignored.
2. Second, the success and management of science in museums leaves much to be desired. I focus especially on the management "science" and corporate plans with which the museum community increasingly flirts in attempts to survive. Here, a severe scrutiny falls on the management cultures that afflict many museums.
3. Third, science in museums is poised for unprecedented growth. This is subject to adequate recognition and support from society, and especially revolutionary changes in how museums are managed. I argue that scientific research not only must be maintained, but the capacity to carry out this research, and its outputs must be considerably enhanced.

Many of my examples, as indeed my experience, is drawn from Africa, but these ideas apply to and are also drawn from visits to and publications about museums elsewhere. All these institutions experience similar challenges, declines and problems. This mixture of subjects may appear as an unorthodox juxta-positioning of seemingly disparate phenomena, but each is critical to understand how and why museums have deviated sharply from a foundation of vigorous natural history as the core science of biology. As I will argue, a consideration of them in their entirety is a precursor to understand critical deficiencies in museum science, and move forward to rectify problems.

I have structured this presentation into three consecutive sections: Part I provides a conceptual platform in defining what biodiversity is, and explicating the scientific values of all those billions of specimens preserved in natural science collections; Part II reviews the decline of science in museums, and discusses its singular cause; and Part III tackles the opportunities for collections and associated science into the future.

PART I

THE VALUES OF MUSEUM SCIENCE AND ITS SCOPE

Much has been written about the values of natural science collections and museums to contemporary society. These can be summarised in three categories:

1. Education. Public displays and out reach programmes in museums have conferred considerable services in education, and many museums hold important roles in tertiary education in the natural sciences - especially for postgraduates.

2. Research in natural history museums has delivered unprecedented breakthroughs in human understanding of the living world. These considerable advances in biological theory have been especially in evolutionary biology (Table I). Applications of biological knowledge derived from collections to solve problems in agriculture and human health, and create wealth (Cracraft, 1995; Cotterill, 1995a, 1997; Nudds & Pettitt, 1997, Janzen, 1993, 1999 and references therein).
3. Third, specimens preserved in natural science collections maintain biological knowledge. The critical roles of specimens in the epistemology of the natural sciences are not widely known, but these collections are libraries of life (Table IV; Cotterill, 1995a, 1997, 1999)

The singular importance of this last category is too seldom acknowledged. Natural history museums, for example those collections in Berlin, London, and Paris, were the core foci, and thus indispensable to the pioneering discoveries of Cuvier, Buffon, Agassiz, Owen, T. H. Huxley, Wallace, Hooker and Haeckel (amongst others) in decades past. Knowledge derived from a uncounted wealth of natural science specimens underpinned Charles Darwin's revolutionary philosophy and much of his allied researches (Ghiselin, 1984; White & Gribbin, 1995).

This academic function of collections-based research in the natural sciences has flourished through the 20^{th} century. Not only have their collections formed the focus of significant findings in the geological and biological sciences, but have served a too rarely acknowledged role in tremendous breakthroughs, especially in evolutionary biology (on which all biology is structured). Foundations of understanding that integrate much theory and knowledge of the Neo Darwinian Synthesis of biology (Mayr & Provine, 1980) were generated from research centred on collections. Here, one may single out the seminal works of Mayr (1942) and Simpson (1944, 1961). They relied directly on studies of, respectively, collections of extant organisms (birds in Mayr's case) and fossils (for Simpson's palaeontological discoveries and syntheses). Museums have continued to foster immense breakthroughs in the life sciences (Table I), notably in macroevolutionary theory (Eldredge, 1971; Eldredge & Gould, 1972; Vrba, 1980, 1983, 1985; Eldredge, 1985, 1995). Museum based contributions can also be singled out in the development of phylogenetic systematics initiated in Germany (Hennig, 1966; Donoghue & Kadereit, 1992) and also the southern hemisphere (Craw, 1992).

Certain museums in Africa, for example, have made significant contributions to scientific discoveries in many fields. A famous example has been in the field of human origins, involving museums in Pretoria, Nairobi and not least Addis Ababa (Table IV). Another example is the collection of Afrotropical Odonata in the Natural History Museum of Zimbabwe (NMZB) in which the central foundations for any future study of the group reside (Pinhey, 1984; Vick, 2001). One should also remember that the revolution in the earth sciences was initiated very largely from southern Africa, where the pioneering synthesis by Alexander du Toit (1937) drew heavily on palaeontological evidence (much of it collated from Karoo sediments) to develop his theory of continental drift.

In equally important developments, one needs to acknowledge the applied research in entomology and allied field conducted on species of agricultural and medical relevance over many decades. These have depended on biological collections to guarantee not just taxonomic accuracy but breakthroughs in control. Pioneering work in parasite control (including malarial mosquitos) at the South African Institute of Medical Research (SAIMR) can be singled out in this respect (Coetzee, 1999).

It is most important to emphasize that these advances in human understanding of the natural world - achieved in philosophy and the natural sciences - have arisen from individuals working in museums (Table I). Equally, least I should appear discriminatory, a huge quantity of empiri-

Table I

Subject	Author	Museum
Homology	Richard Owen	BM (NH)
Allopatric speciation, and ontology of species	Ernst Mayr	AMNH
Articulation of population thinking	Ernst Mayr	AMNH and MCZ
Philosophy of biology	Ernst Mayr	MCZ
Tree Thinking and Evolutionary Chronicle	Robert J. O'Hara	MCZ
Stasis and Punctuated Equilibria	Niles Eldredge and Stephen Jay Gould	AMNH
Evolutionary species concept	George Gaylord Simpson and E. O. Wiley	AMNH, MCZ, Kansas
General Lineage Concept of the Species Category, and species criteria	Kevin de Queiroz	USNM
Consilient Solution to the Species Problem	Many authors	Various (Cotterill, 2002b)
Mass extinction dynamics	David Raup and J.J. Sepkoski	Synthetic - from global resources of earth science collections
Sociobiology and Consilience	Edward O. Wilson	MCZ
Development of cladistic methodologies	Willi Hennig Biologists in southern hemisphere[1]	Berlin? (see Craw, 1992)
Modern adoption of Cladistics and cladistic biogeography	Gareth Nelson, Norman Platnick, Donald Rosen	AMNH, BM(NH)
Species as individuals thesis	Michael Ghiselin	CalaCAD
Conservation algorithms	Vane Wright *et al.* (1989) Terry Erwin (1991)	BM (NH) NMNH
Concepts of disparity and contingency in evolutionary history	Stephen Jay Gould	MCZ
Phylogenetic Taxonomy and the Phylocode	Kevin de Queiroz, Jacques Gauthier, Michael Donoghue	Various
Hierarchy theory in evolutionary biology	Eldredge, Gould, Stanley, and Vrba	AMNH, MCZ, TM
Effect hypothesis and Turn-Over Pulse hypothesis	Elizabeth Vrba	TM
African origin of humans	Louis S. B. and Mary Leakey Robert Broom	NMK TM

[1] Craw (1992) has emphasized that the researches of several individuals, (principally entomologists) in South America, South Africa and New Zealand, pioneered and expansion of the methods and philosophy of cladistics.

Tabla I: Some contributions to science and evolutionary theory provided by researches in natural history museums. This list is by no means exhaustive, but attempts to represent some pertinent developments (including some originating in African museums). These developments continue to fuel energetic and fruitful growth in biological knowledge. Key to acronyms: AMNH - American Museum of Natural History, New York; BM (NH) - British Museum (Natural History) London; CalaCAD - California Academy of Sciences, San Francisco; MCZ - Museum of Comparative Zoology, Harvard University, Camdridge, Massachusetts; NME - National Museums of Ethiopia; USNM - National Museum of Natural History, Smithsonian Institution, Washington DC; NMK - National Museums of Kenya; SAIMVR - South African Institute of Medical and Veterinary Research; TM - Transvaal Museum, Pretoria. Some key institutions and individuals may have been excluded, and any such omissions are apologized for; the aim of this taxonomy is simply to provide a few examples to emphasize a key point.

cal research by these and many other scientists has been published under the auspices of natural history museums. Much more information resides unpublished in collection catalogues and "grey literature". This work continues, but is afflicted by a mass extinction of biosystematic resources - the 2nd Alexandrian Tragedy (Cotterill, 1995a, 1997).

ONTOLOGICAL FOUNDATIONS

"Museum", "biodiversity", "natural history", and "science" hold different meanings for different people. So these epithets deserve unequivocal definition; biodiversity in particular is interpreted in disparate ways. A natural history museum is an institution where preserved specimens collected from the natural world are studied, and the results of these studies interpreted to society by earth and life scientists. Hereafter, use of museum refers to any scientific institution whose core identity revolves around collections and their interpretation. Natural history is the biological discipline that carries out these enquiries and discoveries into extinct and extant biodiversity. Natural history encompasses systematics, taxonomy, and the various subdisciplines of comparative and organismal biology: they all share two commonalities. One, natural history research focuses on whole organisms; and two all are held in a fascination with understanding the evolutionary history of the earth, and its extant properties - following the principles of historical science (Ghiselin, 1984). Science is that academic pursuit whose nature has been eloquently elucidated by Wolpert (1992); but most unfortunately, science is often misunderstood. In this vein, there is no credibility in any postmodern notion that those explanations purported to explain reality, yet bereft of factual evidence, should enjoy equal credibility as sound scientific explanations of the properties of the natural world. For in this extreme view, as Wilson (1997) has argued, postmodernism is the antithesis of science. I now review the ontology of biodiversity in some detail. This attention is crucial to this paper's argument.

Biodiversity: A Brief History of the Concept

The term, biodiversity, was coined during preparations for the National Forum on Biological Diversity held in the USA at the Smithsonian Institution's National Museum of Natural History in Washington DC. This forum was held in 1986 and was organized by the prestigious National Academy of Sciences under the leadership of Walter H. Rosen. The proceedings were edited by Wilson & Peter (1988). It was at this forum that the word "biodiversity" gained widespread use and attracted media attention: this attention has grown exponentially - not only in the scientific literature but among environmentalists and in environmental policy. The reason for interest and concern is fueled largely by the threats to life on earth - the extinction of species and pollution and unprecedented changes of the biosphere by human activities and global climate change.

Nonetheless, the term, biodiversity, remains loosely defined, and many people working in different sectors of society grasp at the word and use it with gay abandon and scant cognisance of what it really means. Considered in retrospect, it is somewhat ironic that the word was originally conceived in semantic acrimony amongst academics!

> "As a member of the Program Committee for the Forum with Rosen and others, I would like to add an anecdotal footnote. Some of us from the Smithsonian insisted on using the conventional term "*biological* diversity," but editorial types at the Academy kept insisting that "*biotic* diversity" was the more correct term. Back and forth it went.

Table II

Authority	Increasing size of physical domain occupied by entities comprising biological variety →			
Reid and Miller, 1989	"Genetic diversity"	"..variety of the world's organisms"	"..and the assemblages they [organisms] form"	
Noss, 1990	"genes ...genetic processes ..genetic structure"	"species, populations ..demographic processes, life histories ..population structure"	"communities, ecosystems..interspecific interactions, ecosystem processes, ..physiognomy, habitat structure"	"landscape processes, and disturbances, land-use trends ..landscape types ..landscape patterns"
Wilson, 1992	"..genetic variants"	"The variety of organisms considered at all levels, from genetic variants belonging to the same species, through arrays of species to arrays of genera, families, and still higher taxonomic levels"	"..the variety of ecosystems, which comprise the communities of organisms within habitats	"and the physical conditions under which they live."
Biodiversity Convention (UNEP, 1992)	"Variability among all living organisms from all sources ..diversity within species, between species.."		"terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they [living organisms] are part."	
Eldredge 1992	"*genealogical diversity*: the number of taxa within a monophyletic clade—for example, the number of species or a family"			
		"*ecological diversity*: the number of different sorts of organisms present in a local ecosystem"		
	"*phenotypic*, or the amount of variation (or differentiation) within or among populations, or within species or still larger taxa"			
Harper and Hawkesworth 1994	Genetic	Organismal	Ecological	
This paper	Genetic biodiversity -- manifested in uncountable different enzymes and other regulatory molecules; and all other structural and metabolic organic compounds produced in cells.	Billions of populations of organisms in the biosphere, typically described and conceptualized as an immense diversity of species, most of which are extinct. Species can be discovered, and evolutionary relationships estimated between phyla	Coevolutionary complexes among organisms. These patterns are historical entities which can be quantified.	

Table II. Comparison of the conceptual structure of pertinent definitions of biodiversity in relation to the biological variety of the material biosphere. The domain of biological variety increases from the left to right of the table. These components roughly equate to the levels of genetic, organismal and ecological complexity.

> Just when Walt Rosen finally despaired of the impasse and coined the eminently sensible contraction "biodiversity," I never knew, but one thing is certain: the new term caught on with a vengeance. Probably few words have entered the vocabulary of science and attained widespread acceptance with such ease and speed." (S. G. Shetler, 1991: 37)

It is revealing to dwell a little more on the origin of concerns and awareness about the properties and future of biodiversity. An important contribution which drew together key issues and concerns on the threats to the variety of life and humanity's poor knowledge of its scope and properties was a review paper by E. O. Wilson (1985a) - originally in *Issues in Science and Technology*, and republished by the American Association for the Advancement of Science (AAAS) in *Bioscience* (Wilson, 1985b) These issues Wilson synthesized so eloquently had been independently raised in the 1960s and earlier. In fact, the genesis of these issues and concerns can be traced back at least to Rachel Carson (who wrote *Silent Spring* in 1962) and Aldo Leopold (environmentalist, writer, and founder of the science of wildlife management). Even earlier, Vogt (1949) had discussed environmental concerns in relation to human welfare. I suggest that at least two factors propagated the focus on biodiversity in the 1980s. One was the growing evidence of landscape modifications and extinctions of species - across continents and oceans. Second, attention to these phenomena fell on the receptive ears of a swelling audience of environmentalists.

Furthermore, important contributions by Norman Myers, the Ehrlichs, and Michael Soulé - in the late 1970s and early 1980s - can also be singled out: all emphasized the facts and grim consequences of species extinctions. E.O. Wilson's key contribution (which culminated in his 1992 book, *The Diversity of Life*) was to cast the problem in eloquent prose backed by a synthesis of arresting statistics; biospheric context; and built on a readable summary of ecological and evolutionary theory. Thus, Wilson probed and revealed global dimensions and threats to biodiversity in all its awesome dimensions. He has not been a lone voice. Concern and awareness has generated a cottage industry in publishing about biodiversity and conservation which continues to grow.

This rapidly increasing interest culminated in over 160 governments signing a Biodiversity Convention at the Earth Summit in 1992, and the publishing of numerous writings on the subject. It is notable that museums have taken the centre stage since the 1980s as key players in environmental conservation (AMNH, 1999; Cotterill, 1995a, 1997, 1999; Cracraft, 1995; May, 1993; Wheeler, 1995; Wilson, 1985, 1992). The reasons for the widespread attention increasingly paid to biodiversity centre around the consequences of burgeoning global change. Humanity's enthusiastic and belligerent appropriation of the products of natural resources is significantly altering the biosphere (Hannah, Carr & Lankerani, 1995; Morris, 1995). The speed, spatial extent and impacts of these modifications are unprecedented in geological history: the most irreversible change is biodepletion - the mass extinction of the earth's biota (Wilson, 1992; Savage, 1995; Stiassny, 1999) with these losses, although having "exploded" over recent decades, beginning in the Pleistocene (Ward, 1994). The three major impacts of global change have been succinctly summarised by Vitousek (1994) as the ramifying modifications of landscapes (and biodiversity therein); and respective alterations of the carbon and nitrogen cycles at global scales. Immediate affects of the biodiversity crisis target local populations in modified landscapes. The summation of these impacts ramify through the structure of meta-populations to impact at spatial scales sufficiently large to cause species' extinctions (Lawton, 1995). To evaluate these impacts (especially changes to landscapes and biodiversity) of global change on humanity, we need to consider the socioeconomic values of biodiversity (Table V).

Table III

Property	Genetic	Organismal	Ecological
Material Properties	All biochemicals. Structural and regulatory genes	All extinct and extant organisms -- each of which is unique; and the populations they form. Organismal biodiversity includes all relevant products of evolution -- extinct and living -- occurring in populations and diversified into species.	Material manifestations of all interactions between organisms involving transfer and modification of matter and energy, including modifications of landscapes
Biological Domain	Possibly billions of chemicals. The totality of reactions and interactions among biochemicals is orders of magnitude higher	Trillions of organisms (each unique) have populated the earth since the origin of life. Billions of populations extant representing perhaps 30–80 million species of eukaryotes, but difficulties estimating the extent of microbial species complicates the overview.	Ecological biodiversity occurs where ever organisms live and have lived -- the material extent of the biosphere within aquatic, marine and terrestrial landscapes.
State of Scientific Knowledge	Extant molecular biodiversity is poorly known -- Mechanisms of metabolism and genetic inheritance established for model organisms (exemplified by *Rattus norvegicus*, *Drosophilia*, *Homo sapiens* etc) and broad surveys of bioactive chemicals in plants and some microbes. Virtually unknown from *in situ* fossils (exceptions are some fossil nucleic acids)	Very poorly known. Broad patterns of hierarchical descent estimated and classified by systematics for some phyla. 1.8 million species are estimated to have been described. Estimating the total extent of organismal biodiversity depends on how boundaries are delimited in space and time, with respect to lineages of organisms. Known fossil taxa well documented but are a fragmented representation of extinct biodiversity.	Physical complexes (structural domain) mapped at broad landscapes, especially for species associations of ecologically dominant terrestrial plants, and coral reefs. Some paleoecological complexes have been reconstructed for extinct landscapes (see Behrensmeyer, et al. 1992; and Afrotropical Pleistocene savannas as an example, Harris, 1993)

Table III. Overview of the properties of genetic, organismal and ecological biodiversity at a global scales

Publishing about biodiversity - a veritable cottage industry - shows no sign of abating. There are now very few countries whose government agencies are not considering how to evaluate and manage their biodiversity. Biodiversity has become the umbrella term and mandate under which environmental agencies have grouped and redefined their missions and activities. The focus of traditional biological disciplines has also shifted to explore different properties of biodiversity at various levels of its organization. Exactly how much variety (different organisms) occurs, and has occurred on earth, is the subject of considerable conjecture in biology.

What is Biodiversity?

Several definitions of biodiversity are compared in Table II; where comparison reveals commonalities in their scope and properties, which are implicitly assumed. Two of these commonalities can be singled out. First, all definitions of biodiversity recognize a hierarchical structure of biological complexity; at the levels of the gene, the organism, and the complexes formed by organisms. Second, all acknowledge the existence of a totality of biological variety:

> "Strictly speaking the word biodiversity refers to the quality, range or extent of differences between the biological entities in a given set. In total it would thus be the diversity of all life and is a characteristic or property of nature, not an entity or resource. But the word has also come to be used in a looser fashion for the set of diverse organisms themselves, i.e. not the *diversity* of all life on earth, but *all life itself*." (Heywood & Watson, 1995: 8 - italics theirs)

Collectively, all of life encompasses a totality of entities of mind-boggling variety and abundance. This implicit recognition of a totality of biological variety begs clearer articulation. Inclusive cognisance of a range (or extent) of biological entities has been pursued to its logical extreme to recognize a connectedness (albeit subtle and apparently cryptic) among billions of unique biological entities which have existed since the origin of life. This means that global biodiversity incorporates all life itself. Biodiversity has been interpreted in different ways (Table I). In fact, biodiversity all genes, biochemicals and organisms, and the material evidence of ecological interactions. This includes all biochemicals, and structural and regulatory genes. The scope of biodiversity includes all extinct and extant organisms - each of which is unique; and the populations they form. Organismal biodiversity includes all relevant products of evolution - extinct and living - occurring in populations, and diversified into higher taxa. In addition to fossils, knowledge about biodiversity includes evidence of organisms' activities and interactions in the physical landscapes of the biosphere; which include modifications of marine, aquatic and terrestrial landscapes, depicting patterns of organisms' associations in space, time and form (Tables II & III).

Biodiversity has a scale-dependent composition, ranging from biochemicals to organisms, through to the ecological complexes created among organisms. This structure is scale-dependent, because it is historically derived - simply because organisms have engaged in more-making: a worthy activity for millions of years. Thus, the structure of biodiversity is manifested in patterns of reticulate descent (gene trees and genealogies) related parents and offspring within a population; and diversification at a higher level. At these higher levels - over longer time scales - populations have diverged into species and the phyla of which species are part. The properties of biodiversity are inherently dynamic. These dynamics are associated with movements

Table IV

Property	Attributes	Epistemology	Implications
1. Specimens preserve complex information.	1.1.0 Each biological specimen is an original sample from a population comprising organismal biodiversity 1.2.0 Best available means to preserve the complex information represented in its genetic and phenotypic traits	1.1.1 Preservation allows unprecedented investigations and discoveries; such as novel characters in comparative biology 1.2.1 Collections store huge potential information for scientific investigations	1.1.2 Impossible to predict future uses and thus 1.2.2 Impossible to categorize values of specimens based solely on current uses
2. Historical information preserved in collections ramifies through biology	2.1.0 Singular origin in time and space 2.2.0 Confers a unique historicity on each specimen 2.3.0 Specimen replacement is impossible	2.1.1 Each specimen is unique 2.2.1 No specimen can be replaced 2.3.1 Specimen preservation allows independent refutation (and verification) of biological facts and theories	2.1.2 Particular biological discoveries and studies must be vouched for by tentelic tokens - these are specimens of authentic provenance 2.2.2 Irreplaceable information is lost with extinction of specimens 2.3.2 Relevance and uses of specimens is multidisciplinary
3. Information derived from natural science specimens maintains biological knowledge	3.1.0 Specimen preservation maintains data quality 3.2.0 Disparate facts can be collated, compared, synthesized, and also refuted	3.1.1 Unique role of natural history specimens in science as vouchers of tentelic information. Their preservation creates and maintains **consensible** knowledge through the persistence of tentelic information 3.2.1 Maintain authenticity of taxonomies and syntheses of knowledge in vouching for names and provenance and associations of biodiversity	3.1.2 Dictates unprecedented emphasis on specimen preservation 3.2.2 Specimen preservation is critical to maintain the credibility of biological knowledge

Table IV. A summary of the three principal properties of natural history specimens (modified from Cotterill, 1999.).

of organisms within landscapes and transfers of genes across time and space (through the process of descent).

The term disparity is used to conceptualize (and thus measure and compare) different and also convergent morphologies of organisms. This emphasis is important, as the term, "diversity", is restricted to the differences between species based on their evolutionary histories and does not include the full range of differences. Disparity has been originally used by palaeontologists to describe and understand the evolution of morphologies amongst invertebrates through geological time scales of millions of years (see Gould, 1989; 1991; Wills, 1998; Wills *et al.*, 1994). Study of disparity is crucial to understand how organisms influence the ecology of habitats (Fig. 1)

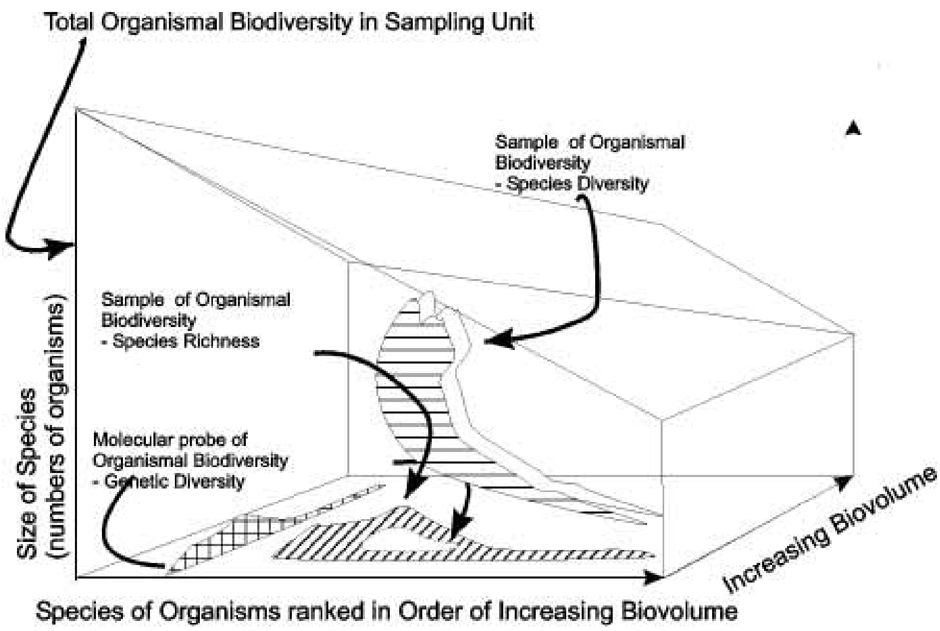

Figure 1. Graphical comparison of three different measurements of organismal biodiversity in the sampled portion of habitat. The larger three dimensional box represents the totality of the biodiversity in the sampled habitat.

The Scope of Biodiversity

An understanding of the scope of biodiversity requires a deep perspective on the extent of the living world (Fig. 1). I will begin with an imaginary scenario. Imagine that a remarkable device exists which allows a human observer to travel back through time and observe all matter which has existed on earth since the origin of life nearly 4,000,000,000 (4 billion) years ago. Our heuristic device would obviously require radical technology - not only having to surmount barriers in space-time, but also possess instruments to examine and describe every single organism which has ever lived, where ever the particular habitat occurs. Since the vast portion of organisms have been and still are microscopic, our space-time traveling module would require even more remarkable apparatus to explore every facet of the planet where life has existed and exists in all its fractal dimensions. It would need to probe the depths of marine sediments to hundreds of metres and describe bacteria, explore the perimeters of volcanic vents on ocean floors where continental plates abut. These explorations would explore all manner of continental habitats, which began to flourish hundreds of millions of years ago and persist in changing structures and compositions into modern landscapes. Our toolkits would also include probes and devices to render larger organisms transparent to reveal the wealth of parasitic and symbiotic organisms which make these multicellular organisms their habitat.

In our hypothetical travels through space-time, we would encounter billions of trillions of organisms of billions of populations. A most remarkable finding would be that no two of these organisms are identical, even cloned organisms - individual histories of their development sees to that. Overall, the variety of form and function of these organisms would be stupendous: from bacteria living on sulphur and in other organisms, to the richness of invertebrates from trilobites to beetles, dinosaurs to mammals, algae to plants. Merely cataloguing this variety would tax the most powerful of multiprocessing digital computers and consume terabytes of optical disk storage. Even more challenging would be understanding what determines the dynamics and continuing evolution of these organisms, how novelties have replaced the extinct; and how persistent forms (such as coelacanths) have persisted through space and time.

The term, global biodiversity, describes all this totality of this life, which has ever existed, and exists today. Biodiversity includes all life forms on earth, in all their coevolutionary complexes. There is no logical way to objectively separate living from non living as lineages are interconnected. We humans can never know all of biodiversity, every organism or each species, especially given that it is estimated that 99% of species no longer exist. This is a humbling circumstance for the museum community to appreciate let alone begin to study. But besides museums no other academic institution can feature in such an enterprise of evolutionary exploration, particularly in the charting of the biosphere in all its historical complexities..

This interconnectedness of all life was first recognized, albeit missing many details, over 150 years ago when Charles Darwin tumbled to a revolutionary view of the biological world. Based on painstakingly gathered evidence from fossils, and living populations around the world, and their domesticated relatives, Darwin concluded that each and every organism are related thanks to the processes of descent with modification. A thorough cognisance of biodiversity diversity and especially the variation among organisms underpinned Darwin's unprecedented contribution to science and philosophy. Today, the contributions of genetics, systematics, palaeontology and ecology have produced a synthesis of scientific theory and evidence showing not only had Darwin been remarkably prescient and right, but that his theory of biological evolution remains the best scientific explanation for the origin of life on earth. Evolutionary biology is so fundamental to all facets of modern biology that nothing in biology makes sense except in the light of evolution, or more correctly in the light of history (Cotterill, 2002b).

In the real material world in which humans evolved and live, and whose barely known properties we are only beginning to understand, an exhaustive exploration of life on earth is philosophically and practically impossible. This is true even of a small unit of habitat (of less than one hectare in extent). There are at least two reasons for this state of affairs. One, biodiversity constantly changes as organisms continue to reproduce and die; and the sizes and distributions of their populations wax and wane. Thus, any survey would have be instantaneous to measure biodiversity truly objectively. Second, we would need gigantic fractionalizing vacuum pumps, which automatically removed every single organism from the sampling area, and preserved it in appropriate form for taxonomists' scrutinies and ecologists' analyses. Not only would no biodiversity be left to conserve, but its properties would change during sampling, especially in bacteria with generation times of tens of minutes. This situation means that we can only estimate the total biodiversity on earth, or in any habitat. I have attempted to depict this situation in graphical terms in Figure 1. This means that global biodiversity incorporates:

> all genes, biochemicals and organisms, and the material evidence of ecological interactions. This includes all biochemicals, and structural and regulatory genes. The scope of biodiversity includes all extinct and extant organisms - each of which is unique; and the populations they form. Organismal biodiversity includes all relevant products of evolution - extinct and living - occurring in populations, and diversified into higher taxa. In addition to fossils, knowledge about biodiversity includes evidence of organisms' activities and interactions in the physical landscapes of the biosphere; which include modifications of marine, aquatic and terrestrial landscapes, depicting patterns of organisms' associations in space, time and form (Tables II & III).

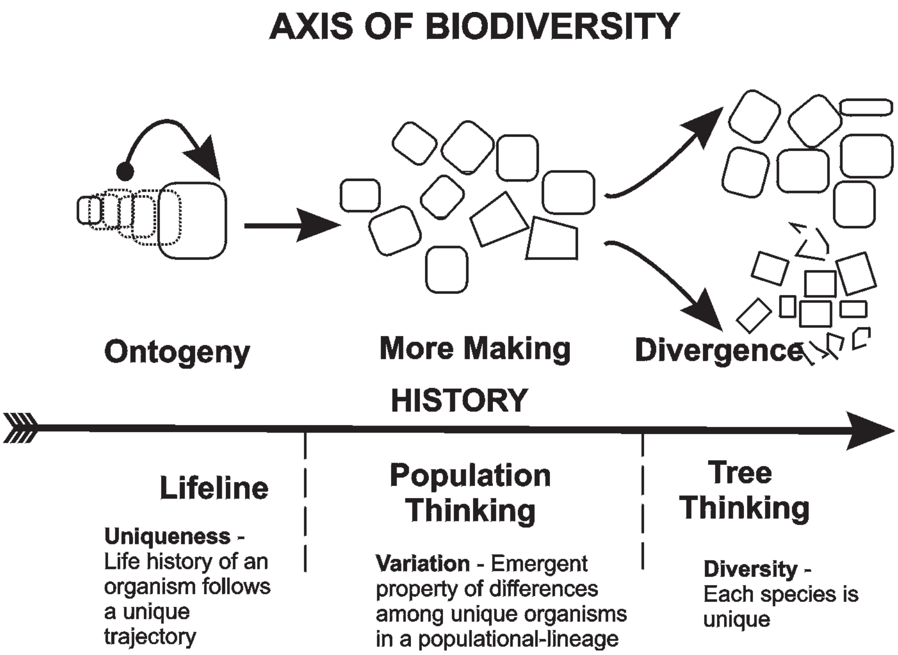

Figure 2. Depiction of uniqueness at different levels of biological organization exhibited as different manifestations of the variety of biodiversity. Complexity increases from left to right within correspondingly different realms of biological organization: within organisms (expressed through its life history); variation among organisms within a lineage; and the diversity of species that arises from lineage divergence. Population-thinking and tree-thinking respectively conceptualize the latter two categories. The concept of a lifeline (Rose, 1997) is the appropriate term to conceptualize the ontogenetic trajectory of an organism embodied in its uniqueness - expressed through time and space during its life history. The ontology of biological individuals (Ghiselin, 1997; Wilson, 1999) lies at the heart of these three conceptual labels (lifeline, population-thinking and tree-thinking) for biological variety. The latter manifests in organisms, populational-lineages, and species and monophyletic taxa. This diagram expands on F. P. D. Cotterill and J. M. Dangerfield, unpublished.

The Axis of Biodiversity

The historically derived properties of biodiversity can be conceptualized along the abstract dimensions of an axis (Figure 2). The processes of ontogeny, more making (reproduction), and diversification account for the hierarchical properties of living variety: Lifeline _ Variation _ Diversity (Figure 2). This triad that underpins the axis of biodiversity is expressed in the particular individuals that are each part (and have been) a part of life. This is true of an organism, population or species. Equally, a monophyletic phyla is a unique individual. This basic structure of biodiversity corresponds to philosophical arguments in biology that species and phyla are individuals (Ghiselin, 1997; Hull & Ruse, 1998).

> «The members of a class usually lack the individuality that is so characteristic of the organic world, where all individuals are unique; all stages in the life cycle are unique; all populations are unique; all species and higher categories are unique; all interindividual contacts are unique; all natural associations of species are unique; and all evolutionary events are unique.» (Mayr, 1961: 1505).

These properties of biodiversity are appropriately encapsulated in the overlapping concepts of Lifeline, Population- thinking and Tree-thinking (Fig. 2). Together, these encompass the vast arenas of enquiry in the life sciences. It must be emphasized that uniqueness and history are unifying attributes of the living world which structure the properties of biodiversity. Their existence endorses multidisciplinary science in exploration of its properties.

SPECIMENS, THE EPISTEMOLOGY OF BIOLOGY, KNOWLEDGE AND SOCIETY

> "This uniqueness is true not only for individuals but even for stages in the life cycle of any individual, and for aggregations of individuals whether they be demes, species, or plant and animal associations. Considering the large number of genes that are either turned on or off in a given cell, it is quite possible that not even any two cells in the body are completely identical. This uniqueness of biological individuals means that we must approach groups of biological entities in a very different spirit from the way we deal with groups of identical inorganic entities. This is the basic meaning of population thinking." (Mayr, 1982:46).

Perhaps the most radical, yet paradoxically under-appreciated aspect - in fact its keystone - of Darwin's philosophy was to recognize that lineages of populations vary because each of their parts (namely organisms) is unique. This discovery was unprecedented in over 2000 years of Western philosophical thought. Its fundamental relevance is self evident when we consider the ontology of biodiversity discussed above. The ubiquity of uniqueness in the ontology of biodiversity and associated historical phenomena in the evolutionary history of the earth is a under-appreciated law of the life and earth sciences (Cotterill, 2002b). As it underpins the ontology of biodiversity, so it is the ultimate reason why natural science specimens are irreplaceable because each is unique. Thus, these specimens hold a crucial role in the epistemology of biology.

The authenticity of the data about biodiversity which are built into reliable taxonomic and biogeographic knowledge is often not considered. Here, reliable refers to the authenticity of the point data: especially occurrences, identities and properties of organisms reported and analyzed. Names for organisms must refer to unique lineages; and these referrals must be open to independent assessment in science. It is here that voucher specimens hold a pivotal and fundamental role in maintaining biological knowledge (Lloyd & Walker, 1967; Cotterill, 1995a, 1999; Winker, 1996). This summary below follows Cotterill (1999, 2002b) closely.

It is critical to distinguish the properties of a specimen from its uses (Table IV). The properties of a specimen are based on the entirety of the preserved organism's genotypic (=genome) and phenotypic constitution. Current and future uses of a specimen hinge on these properties. The many and varied uses of specimens determine in turn their existing and potential values. These collective properties, uses and values potentially influence the economic and scientific values assigned to collections of specimens. In practice, the contemporary values perceived of specimens tend to determine decisions over their integrity. At the centre of this argument, and whether occurring in the past, present or future, each use of a specimen involves derivation and application of its preserved information. This operation - whereby a specimen is used - involves an epistemology unique to biology:

1. *Specimens preserve complex information*.– Each organism is unique (Mayr, 1961, 1997) and each biological specimen is an original sample from its variable population. In its preserved form, a specimen is the best-known means to preserve the complex information represented in its genetic and phenotypic characters (Cotterill, 1995a, 1997). New opportunities to study previously inaccessible properties of specimens (notably molecule characters) permit unprecedented insights into the nature of biological variety. These continue to be facilitated by technological developments. Given rapid and novel accessibility to specimens' properties, we can only hazard guesses at possible uses of specimens in the future. So it is unwise to categorize specimens' values solely on the basis of current uses.
2. *Historical information preserved in collections ramifies through biology*.– The individual constitution, together with a singular origin in time and space, confers a unique historicity on each specimen and makes its replacement impossible. Different groups of specimens, originally studied within their respective subdisciplines, are equally essential in many other life sciences. For example, uses of mammal specimens originally collected primarily for a biogeographic survey (summarized in Smithers, 1971 for example) extend beyond these published compendiums. The specimens continue to operate as sources (in the form of refutable vouchers) for biogeographical, taxonomic, ecological and biochemical information which interrelate with numerous other domains of biological knowledge.
3. *Information derived from natural science specimens maintains biological knowledge*.– In addition to their myriad of uses throughout the life sciences, specimen preservation maintains data quality. This is critical. For biologists to disseminate knowledge about organisms, such as specific plants, taxonomies allow disparate facts to be collated, compared, synthesized, and also refuted. In epistemological terms, taxonomies maintain consensibility (see Ziman, 1978) across the life sciences, and wherever else biological knowledge is applied. Type specimens vouch for Linnaean binomials to allow universal communication of disparately derived data. Underpinning the construction and maintenance of taxonomies, preserved specimens are fundamental to authenticate independently derived facets of information — whether an identity, relationship or other property published about an organism and circumstances of its existence. These epistemological functions, where specimens are sources of historical information and underpin a web of consensible knowledge about the living world, firmly establishes the unique role of specimens in science (Table IV).

Continued existence of specimens confers reliability to information communicated through electronic and printed media. Further explication of the role of preserved specimens is in order. The information preserved in specimens I term tentelic; such that a preserved, correctly documented specimen preserves tokens of tentelic information; and so contributes a unique detail of reliable information to a web of knowledge assembled by biologists about life. Such tokens of tentelic information include its occurrence, identity, and age. The neologism, scientela, describes this composite web of authentic knowledge about biodiversity, built of tentelic information. Singular properties of the scientela are consensibility and authenticity, where authenticity is built from reliable and representative tokens of tentelic information. Literally, the scientela is the “web of knowledge”, while the verb, tentela means “to hold together the web of knowledge”. The most critical epistemological contribution in biology of preserved specimens is their operation as tentelic tokens of reliable information.

Considerable natural history research can be done, and indeed is done, outside natural history museums. Nevertheless, a consideration of the discipline in its entirety (encompassing systematics, taxonomy, and the various subdisciplines of comparative and organismal biology) emphasizes the criticality of collections. Equally, if not more importantly, the scientific and thus economic and social impacts of continuing losses of specimens, and failures to preserve specimens, perpetuates the 2nd Alexandrian Tragedy (Cotterill, 1997; Cotterill & Dangerfield, 1997). This constitutes a crisis in science.

PART II

GROWTH AND DECAY: PARADOXICAL TRAJECTORIES OF MUSEUMS THROUGH THE 20TH CENTURY

While museums have indeed contributed a huge wealth of knowledge to science and society, there are disturbing signs of a slowing down, and even reversal of the growth of collections and generation of knowledge. (Paradoxically, these collections are only beginning to be tapped for knowledge, when one considers the potentials of their preserved information).

Declines in Afrotropical Herpetology

Attention is repeatedly drawn to declines in productivity - if not the lack of a very existence - of museum science (e.g Froese, 1999; Knox & Walters, 1992). «As a final aside, I was intrigued by an interesting graph that compares the rates of description of amphibians from South America and Africa. The rates are comparable until the 1960s, when they begin to diverge sharply following an explosive growth in knowledge of the Neotropical herpetofauna. Knowledge of its amphibian diversity now far exceeds that of Africa, and as Schiøtz notes this reflects the emergence of local South American herpetologists. In contrast, herpetology posts at African national and provincial museums continue to disappear, and we still await the first taxonomic revision of an amphibian taxon by an Afro-African. If we are to successfully document and protect the unique African biological heritage it is essential for a new generation of local herpetologists to emerge. This requires an urgent metamorphosis in attitudes and priorities» (Branch, 1999a: 72). This decline in taxonomic output is widespread, and not just limited to a single subdiscipline such as herpetology (Branch, 1999b), where:

"Herpetological manpower in southern Africa is declining, with the recent loss of senior herpetological posts at South African Museum (1991), State Museum, Windhoek (1990), National Museum, Bloemfontein (1997), Transvaal Museum (1999), Transvaal Nature Conservation (1996), Eastern Cape Nature Conservation (1997) and Kwazulu-Natal Parks Board (1997). No new appointments at these, or other national museums or nature conservation bodies have filled these vacated posts. Technical assistant posts at other institutions, e.g. Port Elizabeth Museum, have also been frozen for many years. Aside from the direct problem of curtailed curation and research on these existing collections, the lack of manpower also has longer term consequences. There is a critical lack of training for the next generation of herpetological curators.» (W. R. Branch, 1999: *in litt*.).

Additional Examples

A noteworthy example of corporate weakness is the proverbial apology to society for being a museum, such that natural history museums are rebadged with trendy names. This, the Transvaal Museum in Pretoria was recently renamed the "Great Northern Institution", while the Port Elizabeth Museum is now subsumed under the epithet of 'Bay World'. These are not trite changes. The label of Bay World might well market the educational attributes of an aquarium, but it places the institution's natural science in an even weaker position to assert its international relevance and secure support. It appears such changes glean some of their motivation from the controversial, if not notorious, corporate plan of London's Natural History Museum. This may be a sensitive subject for some individuals - especially museum administrators, but it's a mere smokescreen to try and counter criticism by pretending that these phenomena (homespun wisdom of management plans and corporate decisions) should be sacrosanct, and immune from criticism. These are most definitely not sacred cows. In this respect, criticisms of the NHM's corporate changes (Erzinclioglu, 1994) still await objective evaluation after being inadequately countered by Chalmers (1994). As I will argue in detail below, it is unrealistic to pretend that public entertainment and natural history research (let alone maintenance of an historic building) can each achieve its full potential under a single corporate "plan". In research alone, considerable scientific and technical expertise was forcibly reduced in the NHM (Gee, 1990).

Angst over radical depredations on museum science in the BM (NH) peaked in 1990. Latterly, the Los Angeles County Museum (LACM) underwent stringent scientific cuts. This prompted the executive controlling body of the LACM to request a detailed exposition on the scientific values of the institution's collections (Davis, 1996); and the latter is a noteworthy treatise for all museum scientists and administrators to study in depth. Most recently, the Smithsonian Institution has been hit adversely by cuts in research funding and thus scientific capacity, with threats to shut down core academic operations (Kennedy, 2001; Pennisi, 2001). This is an especially disturbing development, because the National Museum of Natural History is the global powerhouse of taxonomy and systematics (Miller, 2001). One could continue citing more examples of the 2nd Alexandrian Tragedy , in addition to these highlighted above. Lamentably, a decade post-Rio, with rare exceptions, the museum community has still to clearly face up to its responsibilities in developing natural history toward unprecedented demands and opportunities. Most museums continue to flounder under the pervading obsession with corporate plans pandering to parochial threats and markets.

While declines and deficiencies in taxonomic resources and knowledge differ relatively, they afflict our knowledge of all biodiversity everywhere, even of vertebrates. This includes African antelopes (Cotterill, 2002a,b) and European herpetofauna and Chiroptera (Dubois, 1998; Mayer & Von Helversen, 2001) and birds in North America (Winker, 1996). As briefly reviewed (Box 1), knowledge of all other less apparent organisms is far worse (Wilson, 1992; Donoghue & Alverson, 2000; Miller & Rogo, 2001).

The reasons for the tragic declines of science in natural history museums is comparatively straightforward. The reason why the real obstacles to scientific advancement have not been tackled is because they are in most cases too politically sensitive to be tackled by those responsible or incoherently argued. The major, rarely acknowledged reason for these collapses of museum science is "that if government does not recognize the importance of museum research, it is because it does not understand it. If it does not understand, it can only be because no-one has taken the trouble to explain it in language it can understand. The responsibility lies with the scientific community, not the government." (Halstead, 1990: 406). Furthermore, the higher authorities to which museums answer largely fail to recognize significant international, scientific and environmental implications of the crisis. These consequences are extreme, and failure by governments to respond provides ample evidence of rampant scientific illiteracy. Barely hidden behind the corporate propaganda and smoke screens (such as new age display galleries) in contemporary museums, and primary reason is either or both phenomena:

1. Preservation of an administration, which given the failure (and/or unrealized potential) to support natural history science, is parasitic on the corporation;

2. Pandering to parochial forces of the visiting public, and/or local authorities. Here lies a fundamental tension (Cotterill, 1995a), where the opportunities for natural history are by definition international in scope, but sources of prevailing support are perceived to be mainly local.

The proverbial response to criticisms of weaknesses of administrations in academia (and/or corporate structures, master plans, or whatever their epithets) is to label the critic a defender of the academic Ivory Tower syndrome; or (depending on the gravity of perceived threat to the establishment) as seditious and bent on treasonable disruption of administrative procedures - often because correct reporting channels have not been respected. I cannot even begin to apologise if I should offend such entities; simply because the preservation of personalities is peripheral and superfluous to scientific imperatives that are my primary concern. It is well worth acknowledging - in the words of the late Richard Feynman - "that science takes precedence over public relations, for nature cannot be fooled". Developing this argument, it is time to focus on the corporate status of institutions housing collections. Here, the term 'corporate status' addresses their relative performance in the creation of new knowledge and preservation of the legacies that are the natural science collections in their care.

PSEUDOSCIENCE AND MANAGEMENT SCIENCE: AN ERA OF DARKNESS FOR NATURAL HISTORY AND MUSEUM SCIENCE

Management Science

The embracement of management "science" by museum administrations follows museums' attempts to justify their existence, and turn their operations into a cost recovery exercise. The reason for my focus on this subject is precipitated by museums increasing embrace of the tenets of contemporary management theory, fads and jargon. Some museums re-engineer themselves as they pander to local public and political pressures.

There is some interesting evidence on the exposure to and impact of management psuedoscience on academia in Britain. Recent developments in certain African museums (with attempts at cost-recovery management) is perhaps belated when we consider Thatcherite depredations on science in the UK, for which an apt example is Keith Devlin's poignant experience in pure mathematical research (see Devlin, 1991). Devlin's career was terminated, and he was expunged from the University of Lancaster in the 1980s; this was followed by government cutbacks, such that his research was then discriminated against because it was not sufficiently applied - ".....'Pure' research was looked upon with disdain as a luxury bought at others' expense." (Devlin, 1991: vii). He sought refuge in the USA, where his work on information and logic (extending situation theory) subsequently blossomed - such that it provides a most promising avenue in artificial intelligence: I quote - "I would hope that this book [Devlin, 1991] serves as a testament to the stupidity, *even in those very terms of 'usefulness' that were foisted on the British university system*, of judging any intellectual pursuit in terms of its immediate cash value." (Devlin, 1991: viii, italics his). This is a pertinent example of how attempts to distinguish "applied" from "pure" research invariably makes a fool of the forecaster. Serendipity rules in scientific, and indeed all intellectual pursuits; this renders mute bureaucratic and political attempts to turn science into a cost recovery exercise.

The administrations of museums attracts a spectrum of human personalities, who defy unequivocal classification. It is not unusual for a person with a scientific background to migrate laterally into museum management - either to avoid science, and /or to secure better material rewards. In fairness, such career moves may be taken with all the good intentions of improving and enhancing scientific performance at a corporate scale (Loehle, 1996). One should also acknowledge that certain museums have been known to provide a refuge for administrators who have fared poorly in the cut and thrust of mainstream commerce, or universities. Certain other personalities who secure administrative responsibility in museums relish the petty political power, and so satisfy simple goals in life. The attempts by these individuals and the refugees to regulate and "support" science can verge on the moronic. A common reason for these problems is that too few people understand what science is (Wolpert, 1992; Feynman, 1998).

Against this background, what actually defines management science? Its credentials might appear superior when we acknowledge that it underlies a billion dollar industry, whereby commercial corporations sustain management consultancies and gurus. The cases described above involving cost cuts and associated corporate restructuring provide ample and sinister examples of how management "science" is construed administratively and impacts on museum science. Before the future of collections can be discussed further, we need to scrutinize the arena of management "science" and especially the criteria for its celebrated credibility (Boxes 2 & 3). Its manifestos increasingly influence science, with disastrous consequences for museum science.

The Foibles of Management Science

A disturbing predicament in all these examples of declining support for science and collections is that museums grasp at straws in a struggle to survive - a struggle driven by dwindling funds, allied with the familiar threat that academia wean itself of public funding. Considerable emphasis is placed on cost-recovery and becoming financially independent of public funding. This enacts a pattern of downward causation. Science in natural history museums (specifically research based on collections) is often an easy target for corporate cost-cutting, as it is poorly appreciated, and many of its practioneers are insufficiently prepared, and positioned to defend their activities against the rhetoric of corporate re-engineering. Invariably, these changes to a museum are introduced in the shape of a corporate plan where public galleries and entertainment are developed at acute cost to the academic scholarship represented in natural history research, and impact negatively on the scientific libraries and collections management which define a museum's *raison d'être*. Every credible natural scientist employed in a museum (in the Neartic, Neotropics, Palaearctic, Australasia as well as the Afrotropics) with whom I have discussed these tensions between museum science and management share a scepticism for management theory, and that support for museum science is inadequate and declining. Yet, the supposed invincibility, and indeed the credibility of management "science" is too rarely questioned.

A familiar key to growth in management science is to adopt or coin a catchy message purported to improve corporate performance; then market it intensively and persuasively. It has all the credentials to inaugurate yet another fad in management science (if it has not already happened), where a simple riddle will be disguised in obtuse prose by a spindoctor and peddled to gullible employees of threatened corporations. Perhaps, some readers subscribe to academic strengths in management "science". I do not. At best, the core concepts and dictums obscured by the antics and writings of management gurus and management fads are at best commonsensical notions, or worse New Age baloney. If their repercussions were not so extreme, and did not consume so much paper, and above all disrupt peoples' lives, this evangelism might be so dismissed as so much amateur comedy. I refer the reader to Micklethwait & Wooldridge (1996) *The Witchdoctors* - a lucid critique of a counter development in 20th century civilization: the management bandwagon has few matches in its sales and support by a huge assemblage of sycophants, who readily purchase the burgeoning titles churned out by management gurus. One of the benefits of *The Witchdoctors* is that it spares the reader the agonizing experience of wading through screes of "management speak" searching for underlying principles. Another way to avoid wading through screes of such watery or obtuse prose; to rapidly get to grips with the truth of management "science" is through a few hours of critical scrutiny of the topic in back issues of *The Economist* published over the past five years (Wooldridge, 1997).

At least 70% of the re-engineering efforts that have torn down and rebuilt companies have failed to achieve the hoped for corporate objective (Anon., 1995). It is worth noting "that Germany's best companies have been thriving by eschewing complexity, avoiding diversification and focusing on their core skills. The rest of the world is only beginning to catch up." (Anon., 1996: 61). Allied principles devolve to solving specific problems detracting from corporate performances. Among many, I single out an entertaining, but also sad, example where an entire production line for a range of vehicles in Chrysler was to be re-engineered to solve a product fault: sun visors on some vehicles were splitting, which obviously irked automobile customers. The problem was solved simply by the replacement of a supplier's worn tool - a commonsensical solution that obviously obviated a bizarrely motivated re-engineering (Anon., 1997).

Box 2. The Singular Reason Why Management "Science" Is Not Science: Corporate Paranoia and the Misconception of the Human Machine

Can the radical personalities who often carry out scientific discoveries and the serendipitous nature whereby scientific knowledge increases, be encapsulated by management theory, and so managed for efficiency? It is important to admit that the term "scientist" is an apt example of an essentialistic epithet - it lumps together a vast assemblage of humans whose personalities, performance and beliefs are each unique. This highlights a gaping weakness, characteristic of management theories, often so conveniently overlooked. This is that human operators are seen as cogs in a machine, and as machines in their own right. Traditionally, the setting for such ideas has centered on the factory. Latterly, the term "knowledge worker" has become the increasing vogue. This is the proverbial complex processor who accrues knowledge in an Information Age; conquering challenges in the acquisition of profits in the unpredictable marketplace (Toffler, 1990); where as Andy Grove, the CEO of Intel maintained, "only the paranoid survive" (Grove, 1995). In the extreme, this culture of Hollywood style paranoia has been caricatured by one management guru, Tom Peters, who states that "crazy times call for crazy institutions". Judging by the growth and market for such embroidered sales talk about a hypothetical situation, such statements and "spindoctoring" fuel a feeding frenzy for re-engineering "knowledge-generating" corporations. Here, threatened corporate leaders do not appear to recognize, or ignore, inherent weaknesses in the purchase so long as it helps placate immediate threats and visceral fears.Museums increasingly embrace, or are flung, bewildered into this corporate circus. The management structures that I have been exposed to - notably in the NMZB - are similar in treating a corporation as a mechanically inanimate, but still alive, entity. Humans and material resources interact along the linear dimensions of Gant charts in the context of goals formulated through Log-frame analyses. When developed (or rather "re-engineered") into the extreme, such situations degenerate into comic tragedies. Their credibility is best classified with that not so hypothetical parody of Monty Python's "Ministry of Silly Walks". The popular ubiquitousness of the engineering analogy is a glaring weakness in management theory which is also encountered elsewhere in the social sciences. (Wilson, 1997, has criticized the scientific immaturity of the social sciences - identifying deficiencies that are too rarely acknowledged.)

These engineering parodies of humans in the workplace attribute a common property to a human (or subsets of humans) for which there is no material evidence. This means these constructions are just so much mythology. Tattersall (1998) has eloquently described the frustration encountered - among each of us, and in palaeoanthropology - when we try to define the essence of being human. Evolutionary epistemologists have tried to distill an essence into genetic determination - such that a stream of wrangles allied with sociobiology is riven with nature-nurture debates. Strangely, perhaps surreptitiously, management science has blundered around this debate, such that it now is subsidized by widespread reverence in first world society. It increasingly influences many of the corporate domains where science goes about (or should go about) its activities: this is especially in medicine, and latterly in museums and universities. The huge collection of management treaties and self help literature (not to mention a massive consultancy industry) might have some value to help people work more efficiently and corporations return bigger profits to shareholders. All well and good, they may indeed calm fears and cultivate confidence and egos. The latter does not constitute science. It would be nice if management theory could deliver the same for science - unequivocal guarantees for unparalleled scientific performance liberally lubricated by commerce. But science does not work that way. Its discoveries are so often serendipitous. The problem is that management theory misconstrues the properties of the living world, and especially humans.

This is essentialism in all its woeful weaknesses. At one extreme radical essentialism has structured theories such as national socialism and eugenics which seek to pigeonhole human individuals into races or other categories. Equally essentialistic is the doctrine that the intellectual performance, and potential for intellectual performance (how ever this property can be said to exist) can be encapsulated in a single measurement. The notion of an intelligence quotient (IQ) is most infamous (see Gould, 1983). In a similar vein, Hull (1989) argued that the notion of a human nature has no credibility. This rubbishes not only social engineering agendas such as eugenics but the greater part of management "science", whose theories and facts are structured on essentialistic treatments of its study animal - *Homo sapiens*. (See Hull & Ruse (1998) for a collation of essays, which rubbish, in unequivocal and unforgiving arguments, essentialism in its applications in human biology and sociology.)

Analogous to the historicism of Marxism (annihilated by Popper, 1961), essentialism is the Achilles' heel of management "science". We might excuse some of the weaknesses in a fledgling discipline like management theory in its struggle toward an objective ontology that can characterize the performance of individual humans and the firms and corporations in which they work and behave in other very unpredictable ways. Unfortunately, this quest is futile so long as it rests on an essentialistic treatment of its subjects. This ranks it alongside the plethora of dogmas characterizing other sociological and political works - the credibility of whose arguments boil down to a belief in a mythological essence attributed to humans and any sub classes and populations they may supposedly comprise. Thus, the notion of the "Jew", "Gay", the "bourgeoise", or the appellation of being "working class" are examples of artificial constructs allied to a belief in a human "nature". Mistaken characterizations of "human nature" based on essentialistic misconstrual have shattered the lives of countless humans throughout our species' turbulent history. The examples of Apartheid and Fascism, the on going troubles in Kosovo and the Middle East through the 20th century are grim reminders of nasty mistakes in social engineering; while human genocide perpetuated across Africa provides sobering and more immediate lessons. Unfortunately, humans too rarely learn from these mistakes; but Africa, especially, has suffered severely from the brunt of political and management agendas structured by essentialistic notions. Rationale for human engineering enjoys the same "credentials" as eugenics.

To repeat, Hull (1989) has argued on philosophical grounds, that a human "nature" does not exist, and his conclusions are bolstered by a central tenet of modern evolutionary theory. This acknowledges that the variation of populations is real. This recognition that the uniqueness of the individual organism and the emergent property of populational variation comprised Charles Darwin's revolutionary breakthrough on the 28^{th} September 1838 (Mayr, 1991). Mayr (1959) labeled this perspective population thinking, and it is a tenet of modern biology (O'Hara, 1997). And *Homo sapiens* is one of the more variable vertebrates known. This continuous variation within our species is multidimensional with respect to height, body mass, hair colour, and pigmentation of the epidermis. This variation exhibited amongst humans is especially extreme in the multifaceted attributes of our idiosyncratic behaviours and intellectual attributes (Lewontin, 1995). Now how well do we understand those traits responsible for our relative abilities to perform in politics, wealth creation and management, and especially science? Any attempt to categorize humans into artificial categories that mirror work "processes" rests on the mythology of essentialism, and opens itself to skeptical ridicule. It is especially dubious when such mismeasures of human beings provide the platform on which to restructure scientific institutions; and try and judge the performance and future of science, in museums, other academic institutions, and elsewhere.

At least 70% of the re-engineering efforts that have torn down and rebuilt companies have failed to achieve the hoped for corporate objective (Anon., 1995). It is worth noting "that Germany's best companies have been thriving by eschewing complexity, avoiding diversification and focusing on their core skills. The rest of the world is only beginning to catch up." (Anon., 1996: 61). Allied principles devolve to solving specific problems detracting from corporate performances. Among many, I single out an entertaining, but also sad, example where an entire production line for a range of vehicles in Chrysler was to be re-engineered to solve a product fault: sun visors on some vehicles were splitting, which obviously irked automobile customers. The problem was solved simply by the replacement of a supplier's worn tool - a commonsensical solution that obviously obviated a bizarrely motivated re-engineering (Anon., 1997).

A forgiving apology is to excuse management "science" as immature science (Micklethwait & Wooldridge, 1996). If this is true, it is more pertinent to identify the actual scientific foundations of the discipline, and then try and establish how its theories can be improved and consolidated. The inauguration of a "science" of management can be traced back to Sloan's best selling book, endorsed by business tycoons such as W. H. Gates, of software giant Microsoft. Although Sloan's maps of organizational structures were apparently the first known in commerce, they were no doubt predated by the organizational charts used by military logicians for millennia. Rather analogous to the statement that all western philosophy is a series of footnotes to Plato, I suspect, perhaps maliciously, that little progress has been made toward a science of management since Drucker (1946). I further hypothesize that the eventual maturity of management "science" must await revolutionary advances in the brain sciences - developments that will radically improve understanding of human behaviour. Until then, our attempts to manage each other's behaviour will remain very much an art, and will remain an art for some time to come. This conclusion is reinforced when we acknowledge the core weakness of management "science" (Boxes 2 & 3).

Why Is Management Pseudoscience So Adulated?

Clearly, management science has little credibility. To be blunt, the emperor has no clothes. But perhaps it possesses a few, albeit scanty, garments of relevance, some of which it has even yet to wear in public. Its entreatment by commerce and amongst a gullible public is perhaps understandable, but its uncritical adoption by individuals who profess to be trained and active academics is not. The adoption of management psuedoscience by administrations and governing bodies of scientific institutions (including but not limited to natural history museums) is dangerous in its impacts on all science and critical thinking stands for (Boxes 2 & 3).

Against the background of the biodiversity crisis, it is ridiculous that pure taxonomy should be so neglected (Miller, 1993; Cotterill, 1995a, 1997, 1999; AMNH, 1999). One is led to conclude that science in many of the museums in which I have been privileged to work persists despite remarkable odds. In more extreme cases, the administration exacts huge overheads on scientific performance, instead of enhancing it. Frustrations resulting from bureaucratic constipation are compounded by diversions of scarce resources to pseudoscientific activities. These natural history museums where science declines are remarkably analogous to a parasitized host organism, struggling to exist against depredations of hyperparasitism. A bizarre situation indeed. It is indeed lamentable that at the time when natural history museums are sorely needed; their core activities, and thus *raison d'être* should be so threatened.

Is there a need and/role for management "science" in museums? - Or can a Pseudoscience manage Science?

The short, surprising and paradoxical answer is, 'Yes'. This affirmation must place caveats to the fore. This is simply because management is either an art, or merely a series of procedural operations. Each situation is unique, and may well require a peculiar solution. Much of these procedures involve movements and treatments of material objects and resources. This is just so much routine paperwork, spreadsheet work and databasing. Certain aspects of the descriptive stages of any of the sciences somewhat lend themselves to comparatively goal orientated management. But this cannot be applied to synthetic developments of scientific theory; and especially profound breakthroughs and advances. A characteristic of many managers is their singular misunderstanding, and in extreme cases arrogant disregard, for science. In most cases the latter attitude results from ignorance. There is clearly a need, and this is paramount, for administrators of institutions where natural history is to be done to have direct experience in this research; experience and uppermost support for science of museum leadership is critical if museums are to grow or die.

One role for improved efficiency in the core business of natural history museums is to streamline collections management. This is already commonplace for information technology in museums to replace formerly manual procedures. It is important here to distinguish between the management practices involved and prescribed in collections management from those involved in research. The former can be methodologized, whilst the attempts by bureaucrats to straightjacket scientific activities are persistently confounded and often ridiculed. This runs against the grain in which considerable successes have been achieved in research in museums focused entirely on natural history (Table I). In this respect, it is worth noting that "The bulk of good taxonomists today are spending only 0-20% of their time actually doing taxonomy, but would be quite happy to have the opportunity to invest their lives full-time in taxonomy" (Janzen, 1993: 108).

Box 3. Science, Mythology and Management Pseudoscience

The crisis in museums is a symptom of a larger problem - the vogue to turn science into a cost recovery exercise. It appears that science in most countries is withering under a brownlash from society unmatched since the Dark Ages when such noted luminaries and pioneers of scientific discovery as Galileo were persecuted. Although no one in the modern scientific fraternity (to my knowledge) has been burnt at the stake or forced to recant their conclusions under persecution (at least not in the western World), the pervasive extent of the modern backlash against science is unprecedented in its zealotry and subtlety (Zimmerman, 1995). This sees its penetration into the formerly hallowed ground of academia. Here, postmodernism can be singled out in its tacit adoption by supposedly learned institutions, those held up as bastions of critical thinking (Dawkins, 1998; Attwell & Cotterill, 2000). In its extreme, postmodernism is the antithesis of science (Wilson, 1997). Free thinking and constructive criticism is to be encouraged, displacement of reasoned knowledge by obfuscatory dogma is not. It is equally undesirable that an obsession with mythology retards on scientific activities; and especially alarming when the education of society is impacted. At first encounter, management pseudoscience appears to focus on financial austerity and corporate streamlining - accolades that seduce cost conscious politicians and administrators. Yet, besides the core weakness of essentialism, its gurus routinely endorse mental attitudes and processes which lack any material evidence let alone scientific credibility. Although my evidence is circumstantial, management psuedoscience forms a continuum with New Age personal improvement treatises. It appears that all share a commonality with postmodernism in being bereft of critical reasoning, ignorance or downright dismissal of the scientific method; and a belief that mythical entities hold precedence over material realities.

The global corporate acclaim paid to management "science" has much to do with the existence of a nourishing sycophantic audience. Why is their snake oil so willingly bought? The obvious, proximate reason has already been acknowledged - the complexities of the modern commercial environment, especially its unpredictability, fuel fears of failure with ensuing financial and material deprivation. Paucity of critical thinking is the ultimate reason. Uncritical adoration of management science recalls the late Sir Peter Medawar's review of Pere Teilhard's *The Phenomenon of Man* - that: "...the greater part of it.... is nonsense, tricked out with a variety of metaphysical conceits, and its author can be excused of dishonesty only on the grounds that before deceiving others he has taken great pains to deceive himself...." (Medawar, 1996: 1). "How have people come to be taken in by *The Phenomenon of Man*? We must not underestimate the size of the market for works of this kind, for philosophy-fiction. Just as compulsory primary education created a market catered for by cheap dailies and weeklies, so the spread of secondary and latterly of tertiary education has created a large population of people, often with well developed literary and scholarly tastes, who have been educated far beyond their ability to undertake analytical thought" (Medawar, 1996: 9). It is ironic that essentialism is especially anathema in these core institutions (namely museums) of comparative and evolutionary biology (see Mayr, 1982), institutions where management science is increasingly misapplied.

The automation of data capture and management, preliminary identifications, and curatorial procedures are a given. The impacts of information technology on the curation of preserved organisms over the past two decades have provided revolutionary advances. The automation of sorting and cataloguing of specimens now involves electronic databasing as a routine. Management of digital images of specimens (for example Biotrack® developed by the Biodiversity Centre, Macquarie University, Sydney, Australia) has proved immensely useful to automating activities and data processing procedures that have formed until very lately, important barriers in the Taxonomic Impediment (Oliver *et al.*, 2000). There are clearly opportunities to judiciously apply management approaches to develop and improve such processes in museum research.

Obviously, it is easy to poke fun at management "science", and eviscerate its shaky academic credentials. It is indeed a target ripe for annihilation given a modicum of critical thought, but it cannot be dismissed entirely. By this, I do not mean that some management guru should write a scholarly treatise on the management of natural history museums proselytizing trendy fads. The serious consideration for management "science" with its impacts on science needs to apply far greater scepticism to the problem than has been the case so far. The threats posed by the cults of the management gurus is sidelined by imperative needs for biodiversity knowledge. These demands deserve detailed consideration.

PART III

THE FUTURE OF NATURAL SCIENCE COLLECTIONS INTO THE 3RD MILLENNIUM

The Corporate Goal is the Crux

I conclude that museums, as for any firm or corporation, have to be managed. Their management remains an art, such that Snow's two cultures might be better realigned to contrast management with science, rather than art and science (Snow, 1959). This needs to be acknowledged and respected by its practioneers and acolytes (that management is no more than an art). Until the brain and behavioural sciences provide a far reaching explanation for human behaviours in and out of the work place (accounting for the quirks of motivation, aggression, and other such typological labels on states of mind); adherents of management "science" risk perpetuating mistakes with grave impacts on science and society (Boxes 2 & 3). It is obvious that a museum needs a management plan, structure, mission statement, and various operational plans. But these lose their relevance to the real world, when they denigrate the central role of museum science, and/or collections decay.

This means that, like it or not, collections have to be managed; and like it even less, and above a critical population of personal, so must certain humans manage scientists in museums. Nevertheless, it is a truism to emphasize, against the preceding presentation, that management of these biosystematic resources has to articulate and achieve clear goals. I do not advocate that an institution should be left to anarchic control, stripped of hierarchical management structures and strictures. Far from it. The corporate goal is the crux. The following opportunities and demands for knowledge of the natural world dictate what these priority goals are.

What Knowledge do we Need?

Museums are uniquely poised to dominate the business of knowledge generation in biology, and interface with a huge spectrum of users of this information (AMNH, 1999; Brooks & Hoberg, 2000; Cotterill, 1995a, 1997, 1999; Cracraft, 1995; Janzen, 1993, 1996, 1999). The underlying reason for this opportunity are the reasons for conserving biodiversity (Table V). One example is understanding the complex interface between ecosystem performance and composition - a rapidly expanding research agenda in ecology, focusing on monitoring of target taxa in intensively studied communities. These studies are fueled by the urgent and encompassing need to understand and predict how human modifications of biodiverse landscapes will change properties of ecosystems, and their ability to sustain essential "services" (Western, 1977; Cotterill, 1999). Biosystematic resources hold a critical but poorly supported role in this research. The relevance of biosystematic resources to managing ecosystems at a landscape scale (the nub of terrestrial biodiversity conservation) requires elucidation and consensus if zoologists, botanists and microbiologists are to build a scientific knowledge of biodiversity which is of practicable use to society, and the biodiversity we seek to maintain.

The focus of such knowledge must be on organisms and how they maintain and modify ecosystems at the landscape scale; which requires a representative understanding of a multitude of interacting populations - the composition and function of biodiversity. Biosystematic resources build and sustain our knowledge of this composition, while investigations of organisms' interactions involves many ecological subdisciplines.

Existing information is inadequate to provide a reliable knowledge of the scope of biodiversity (Box 1). The world's biological collections contain inadequate samples of biodiversity - especially at large spatial scales - extending from landscapes to national and regional domains. These collections not only fall short of objectively representing the composition of biodiversity, but this information has limited application to elucidating the ecological properties of biodiverse landscapes. Biodiversity inventories need to address, as the fundamental objective, the properties of ecological complexes.

Standardized collecting methods are essential if such data are to be compared, and generate a knowledge of practicable use to biodiversity conservation. Such a grandiose research agenda will require unprecedented commitments, particularly in collaboration at regional and international scales. This is where involving biosystematic resources is fundamental and critical to success. This priority is unfortunately not widely known within the scientific community, and is very poorly appreciated by decision makers. One solution is to market the values of taxonomic resources to society. The strategy likely to practically support biodiversity, and society in the longer term, urgently needs immediate action. This is to inventory biosystematic resources at a global scale and consolidate their unique information. This must be done as rapidly, efficiently and professionally as possible.

Williams & Humphries (1996) have acknowledged that the complexity of biodiversity, *sensu lato* cannot be encapsulated in a single measurement—part of the impetus for partitioning organismal from ecological biodiversity (Tables II & III). In inventories of the organisms (forming ecological complexes) which are members of metapopulations, species diversity is the most commonly employed (and perhaps most easily used) surrogate measure of organismal biodiversity. Species diversity measures in extensive landscapes may camouflage important differences among metapopulations. For example, such surrogate measurements across large biogeograp-

Table V

Category of biodiversity	Category		Role of Biodiversity Collections	Economic and Other Benefits
Organismal	1	Biodiversity industry	Discovering biological history in the composition and interrelationships of organismal biodiversity	Wealth and alleviation of human suffering
Organismal	2	Human health	Knowledge and control of diseases	Wealth and alleviation of human suffering
Organismal	3	Agriculture	Discovery and domestication of new crops and livestock	Food and wealth
Organismal/Ecological	4	Aesthetic and economic benefits	Knowledge and maintenance of biodiversity and especially ecological goods and services	Wealth and economic efficiency (through providing rest and recuperation)
Ecological	5	Ecosystem services	Ecological monitoring and measuring, and especially ecological goods and services	Stable atmosphere, potable water, fertile soils
Ecological	6	Ecosystem integrity and economic stability	Linking knowledge of organismal and ecological biodiversity	Minimise impacts of disturbances on ecosystems and economies

Table V. The values and influences of biodiversity on humans and the roles of biodiversity collections in realising these benefits.

hical realms of sets of species typically lump subspecies together. Inventories of organismal biodiversity must carefully evaluate the surrogacy of measurements used and quantify how representative are the samples of the organismal biodiversity we seek to quantify.

All-Biota-Taxa-Inventories - ABTI's

Any attempt to representatively chart global biodiversity requires very careful planning. In an important distinction, Wheeler (1995) argued for taxon focussed inventories (rather than site specific inventories) termed All-Biota-Taxa-Inventories (ABTI's) in place of All-Taxa-Biological-Inventories (ATBI's). ABTI's raise three issues: an ABTI is not an inventory; but rather an ambitious revision of a taxon by a team of systematists classifying the products of national biological surveys. ABTI will generate a taxonomy of hitherto unavailable thoroughness and representativeness; and ABTI's appear to be the best means available to optimally and efficiently share a scarce resource - the world's biosystematic skills. This apparent conflict of interests (between ABTI's and ATBI's) indicates how little ecologists and biosystematists have thought about how best to sample biodiversity according to a coherent plan which optimally deploys available resources over the next few decades. Charting the biosphere (SA2000, 1994; Cracraft, 1995; AMNH, 1999; Brooks & Hoberg, 2000) arising from the simultaneous progression of many ABTI's, will flood the world's natural science collections with specimens, demanding careful forward planning. Compared to museums' previous activities, the planning and execution of these inventories (especially their location and extent) requires preparations unparalleled in their scope and resource demands.

Global taxonomic reviews (performed as ABTI's, Wheeler, 1995) cannot proceed without synoptic collections (comprising recent and historical specimens) to provide thorough phylogenetic classifications of focal groups. We have to prioritise which taxa will receive the undivided attention of ABTI's. These categories might be similar to the Taxonomic Inventory Working Groups (TWIGs) of an ATBI (see Stork & Samways, 1995; Cotterill, 1995b for details). Based on these priorities, within the next two decades, it may be feasible to compile cladistic classifications of some invertebrates and all vertebrates, but not detailed phylogenies of huge clades of bacteria. Tensions between ABTI versus ATBI need not degenerate into a territorial tiff between biosystematics and ecologists. Both disciplines seek to elucidate the origins and determinants of biological complexity - a goal to which both parties provide mutually supporting knowledge. As central channels and nodes of the Taxasphere, I see these ABTI's interfacing tightly with those intensively studied landscapes where ATBI's are being carried out (Janzen, 1993, 1996; Brooks & Hoberg, 2000).

Future Opportunities and Realities

The impetus toward globalization in biodiversity studies and especially the development of biodiversity informatics (AMNH, 1999; Brooks & Hoberg, 2000) means that a museum faces two choices. One is to participate in this swelling arena - slot into the Taxasphere - with all the necessary adjustments in corporate structure and priorities (with concomitant resource developments) or openly abandon its biosystematics resources to institutions better suited and more committed to 21st century developments*.

*Two promising initiatives are the Global Biodiversity Information Facility, and the ALL Species Foundation: http:\\www.all-species.org

I am convinced that for museums to participate efficiently in the Taxasphere, then scientific leadership needs to secure the management of natural history research. The scientific study toward conservation of biodiversity is increasingly adopted as the corporate mandate of museums. If any such corporation has made this decision to maintain and expand its collections toward this goal, then they have to come to terms with certain truths. A singular truth is that science has to rank paramount in the operations and management of the institution. Anything less, and performance (and returns on funding and investment) will detract from achieving this corporate goal. It's that simple. There is also an important need to address the systems of reward structure, tenure, and the relative intellectual outputs of natural history researchers. Productivity of many taxonomists peaks late in their careers; this contrasts with the general trend in academia (as Loehle, 1996 has pointed out).

Brain (1991; 1998) emphasized that museum researchers are difficult creatures to manage. Here, the metaphor of trying to herd cats into a kennel springs to mind when one considers experiences and challenges in this vein! Those managers challenged to select and support the activities of museum scientists should never forget the ontogeny common to the majority of productive and successful researchers in museums. Their intellectual developments (if not their entire Lifelines, Fig. 2) can be traced back to a singular obsession with their chosen organisms. This overpowering devotion to biophilia (*sensu* Wilson, 1984) is a common strength of their intellects and personalities. Nearly all are strong minded individualists, though some may appear mild of manner and even reclusive, but fiercely devoted and defensive of their life's vocation. These infatuations with biodiversity (and allied natural phenomena) almost always began in early childhood; and then grows (not invariably against considerable odds) into a life's vocation in old age. Biographies of successful organismal biologists (for example Brain, 1998; Mayr, 1997; Wilson, 1994) reiterate this developmental pattern. It is one to recognize, nurture and mentor to develop museum science into the 3rd millennium. A common attribute of the museum-based scientist is one of high self motivation, which can be traced back to early ontogeny - exemplified by a childhood fascination with natural history (e.g Mayr, 1997; Wilson, 1994). These common traits of natural history researchers reinforces the arguments against the typologically based deficiencies of management "science" (Boxes 2 & 3).

The manager of a museum in need of consultation need only resort to Kepner and Tregoe's *The Rational Manager*, while Sloan's *My Years at General Motors* is ample secour for a bureaucrat challenged by management structures. To repeat, the need for radical management approaches are driven by certain individuals' fears and inability to cope with complex situations. The contemporary challenges facing museums will obviously overwhelm the average museum administrator, since many appear to be refugees from mainstream commerce and dynamic scientific research - areas which they find too challenging. The wise management decision when faced by such challenging corporate circumstances is to first and foremost recruit appropriate commanders. History has demonstrates the pivotal role of individuals of the calibre of Alexander the Great, Rommel, Montgomery, De la Boullière and Schwarzkopf in success in warfare. Perhaps the greatest weakness in many museums is their leadership - struggling to orientate to a larger, shifting canvas (which is difficult to understand, let alone manipulate) whilst dominated by allegiances to parochial circumstances. Most lack the scientific credentials (especially critical thinking) in a culture where disrespect for science has become the vogue. Consequently, the impacts on science in museums are appalling. The personalities and intellects of successful administrators of science are exceptional (see Wolpert, 1992 and Wolpert & Richards, 1997 for examples).

So Where Should Natural History Research Be Done?

It is clear that museums are poised to benefit from remarkable opportunities. These opportunities are driven by the urgent needs to understand the Earth and biodiversity in unprecedented detail and scope; and these demands for scientific knowledge derived from tentelic specimens will grow. Such funding opportunities and demand for scientific knowledge for museums could scarcely have been dreamed of by 19th century architects of natural history, such as Agassiz, T. H. Huxley or Lord Rothschild. It is incredible, therefore, (with very few exceptions) that museums routinely fail to unequivocally reorientate their missions toward getting on with the job. At an international level, the museum community continues to dither. I suspect this collective failure can be traced to a lack of scientific leadership.

Natural history museums would do well to get over their infatuations with the pseudoscience that masquerades as an academic discipline, namely management science. Not only does it detract from a healthy tradition of unparalleled scholarship in natural history, but such flirtations with questionable quarters will degenerate to corporate death from the contagious disease; whose common symptom is an obsession with cost recovery (Cotterill, 2001). Their improvements of operational performance across a spectrum of corporate activities (ranging from education to environmental impact assessments, and more) and whilst the cultivation of new age management structures are a corporate *cul de sac*. A singular deficiency in many threatened museums is there lack of leadership to grasp the challenge of unprecedented research opportunities at an international scale and reap the rewards.

We should not ignore that the many connections between academic institutions and society are complex (Kenward, 1986). As Dunbar (1995) has reasoned, modern society has become and will remain utterly dependent on science. This behooves governments and bureaucracies, where even if they do not understand it, to acknowledge this dependence; ultimately for their own benefit. A scientifically literate, and/or critical society may grow to judge the failed mutualism between science and governments, with negative impacts for the latter. In reality, such accommodation is unlikely as distrust and misunderstanding tend to flourish in political circles (Gross *et al.*, 1996).

The sceptical ridicule I have heaped on management pseudoscience is obviously relevant to other realms of academia, where the ogre of cost-recovery strictures threatens academic performance. Certain politicians and bureaucrats appear happy to live with the reality that their understanding and respect for science and scholarship differs little from that of medieval peasants. Nevertheless, the revelation that management theory scarcely differs in its aspirations and practices from the more sinister aspects of human engineering and apartheid classification (bedevilled in eugenics and fascism) might rattle the egos of politician or administrator, especially those sensitive to disruption of politically correct careers (Boxes 2 & 3).

The Future Corporation?

To reiterate: The major, rarely acknowledged reason for these collapses is “that if government does not recognize the importance of museum research, it is because it does not understand it. If it does not understand, it can only be because no-one has taken the trouble to explain it in language it can understand. The responsibility lies with the scientific community, not the government.” (Halstead, 1990: 406).

Toward this development, more professional biologists need to endorse Wheeler's (1995: 485) urging that "...Fundamental scientific questions about biodiversity can only be asked and answered given great collections. Any institution holding such collections and not supporting scientists qualified to undertake such research is behaving irresponsibly and unethically and deserves any diminished prestige in which it is held. Museums are not universities and they are not theme parks. They must rediscover their unique mission among the biological sciences and strive for unapologetic excellence...let taxonomists be taxonomists...Meeting the biodiversity challenge means rebuilding taxonomy. This requires a clear vision of taxonomy and its aims." I can reiterate a similar message "We patently cannot afford to allow taxonomic resources, as the foundations of biological knowledge, to decline any further. Their international value reaches way beyond the myopic and parochial policies typical of many herbaria and museums, which invariably sway to the tune of national politics and in groping for survival, create or adapt corporate policies as an answer to climates of dwindling support...Museums which cling to national strictures will become even more vulnerable if they continue to ignore international demands for biological knowledge, the needs for which at least equal that of physics and medicine, which routinely receive considerable funding." (Cotterill, 1995a: 195).

It is clear that the institutions where biosystematics resources currently reside have to change radically. Until this happens, I do not see how surveys and monitoring of biodiversity can coexist with the numerous other more local mandates in museums as they currently struggle to coexist. The preemptive remedy for recalcitrant museums is simple. The requisite legal and political instruments need to train their sights on a radical re-engineering. The alternative is to concentrate on public entertainment and education but relinquish responsibility for biosystematic resources. Ultimately, the only recourse is for recalcitrant institutions to surrender biosystematic resources to institutions with the expressive mandate to get on with natural history research. There is abundant evidence that the prevailing situation to serve as public institutions with expensive galleries of displays with closeted, poorly supported research departments is unsustainable.

The thrust of this change is straightforward. Museums must place natural science to the fore and reorganize to perform national inventories of biodiversity in the countries where they exist. Equal emphasis needs to be placed on palaeontology. It is worth acknowledging that the end result - in the shape of the new institution - might not even be called a natural history museum, but assume new epithets of the order of a Palaearctic Biodiversity Institute, International Nematode Research and Database Centre, or Afrotropical Fungi Research Centre. The activities of field inventories, alpha taxonomy, phylogenetic systematics, and comparative biology will be their core operations. No others can be accommodated. Their necessary focus must be on the whole organism - with molecular techniques out sourced to appropriate laboratories as is already routinely done. Here, post graduate education will be an integrated ingredient in the "new" museum for continuity of science and thus achievement of corporate objectives in the longer term.

The corporate mission of such a new museum will be the survey and monitoring of biodiversity at a predetermined national, regional or global scale. The scale of geographical and taxonomic focus will depend on a number of factors. One is the historical legacy of adopted collections. For example, the particular research legacy in Zimbabwe bequeathed the most comprehensive collections of vertebrates, Hymenoptera, Lepidoptera, Isoptera, certain Arachnida and Odonata for south-central Africa preserved in the NMZB. A complementary representation of molluscs is held in the Natal Museum - Pietermaritzburg, South Africa. It is logical to expand on these traditions as it is to found new initiatives to explore uncharted terrain and taxa, and so account for other less well known taxa.

All reorientated museums will have to operate at international levels - simply to overcome the Taxonomic Impediment (see Hoagland, 1996). Mature leadership of these institutions cannot be overemphasized, especially in Africa where so often a local recruited administrator tends to be inwardly focussed, invariably exacerbates bureaucratic strictures, and fosters nepotism, instead of focussing on facilitation and support of science without frontiers. The regional and continental operations of larger institutions that have traditionally worked across international borders must obviously expand. They have an important role in fostering fledgling natural history museums in countries which do not yet possess them. Biodiversity collections occupy the focus of this work, while the biosystematics community are the means (Janzen, 1993, 1996; Wheeler, 1995).

Some may view this scenario as radical if not heretical. I do not see anything extraordinary in the reorientation of a science that has struggled with diminishing success to persist in institutions that currently masquerade as museums. The mandate I have sketched above is no more than a rational (and indeed the only) response to organize taxonomic skills and biodiversity collections toward a practicable response to the biodiversity crisis. The key ingredients for success of the new biodiversity centre is strong, committed leadership based on a platform of political support and international collaboration. Otherwise success is very remote and existing museums will continue their decline into scientific infirmity. I would be among the first to welcome the unequivocal evidence demonstrating beyond reasonable doubt that reports of the death of the natural history museum are greatly exaggerated. Unfortunately, my intimate experience with several museums for nearly twenty years, and especially recent catastrophic declines (despite opportunities presented post Rio) reinforce my belief that the situation and conclusions I present in this paper are the reality. For how much longer will we continue to deny it?

This agenda for rebuilding natural history is not far fetched. These requirements are endorsed and indeed enshrined in the Convention on Biological Diversity, the Global Taxonomic Initiative and allied international developments in biodiversity science (Loreau & Olivieri, 1999). Previously unimagined funding is available. Gutless and misguided mismanagement, which hustle pseudoscientific agendas at acute cost to science in museums, is the major reason for the lack of progress to date. The establishment of the nodes in the Taxasphere (Brooks & Hoberg, 2000; Janzen, 1993, 1996) that actually function is very long overdue. In closing, the reader may note that I not discussed the potentials of the futuristic institution that leads biological research in natural history in providing think tanks for theoretical advances. Biodiversity collections available to Darwin, Simpson, Mayr, Eldredge and Gould (to name a few examples), underpinned and catalysed the growth of biological thought into previously uncharted domains. I predict that unfettered attentions to collate and study samples of the multifarious dimensions of biodiversity across a spectrum of extinct and extant landscapes will drive fascinating and awesome advances in biological knowledge (see Donoghue & Alverson, 2000). We do indeed live in interesting times.

CONCLUSIONS

Principal Points

Natural science collections are the libraries of life; the tentelic information they preserve about planet Earth is unique, and obviously irreplaceable. The fundamental epistemological function of preserved specimens is very poorly understood by society. Unfortunately, even in museums, this singular corporate strength of museums is not sufficiently appreciated. This is because current leaderships in museums have yet to articulate and act on its worth with respect to its importance.

The ubiquity of uniqueness in the ontology of biodiversity and associated historical phenomena in the deep history of the earth is a under-appreciated law of the life and earth sciences. As it underpins the ontology of biodiversity, so it is the ultimate reason why natural science specimens are irreplaceable because each is unique. Recognition of this fundamental fact is the keystone of Darwin's unified philosophy of evolution.

There are immense opportunities to derive scientific knowledge from collections. Certain uses of collections are quite well appreciated, at least within the museum community. Nevertheless, as judged by the breakthroughs in studying novel properties (as revealed in genomics and developmental biology); there are undoubtedly presently unknown uses, many unimagined, for specimens awaiting discovery.

Unfortunately, the management of science is generally misguided in many museums; and not infrequently inept. The problem has been exacerbated by increasing infatuation with fads of management science and business marketing theory. These disciplines are commonly perceived to possess high academic credibility; and thus the obvious platform on which to risk the futures of science, natural science collections and a great deal of knowledge of the earth. It is strange that so many museums cannot identify with, and thus develop, their key corporate strength.

It needs to be acknowledged that the principles of management science and marketing theory are fundamentally flawed. They misconstrue human individuality, and disciples of these fads in management theory persistently fail to manage science efficiently and productively. Their impacts on scientific performances of museums are extremely disturbing, given urgent and unprecedented demands for reliable knowledge of biodiversity and the environment.

The corporate performance and integrity of nearly all museums needs to be rigorously assessed in terms of their contributions to natural science as their core *raison d'être*. Institutions housing natural science collections have reached a fork in the road; they either can be science education centres, and theme parks; or become international centres for natural history research, each a unique node in the Taxasphere.

Above all else, the future integrity of collections in those institutions that persist in sidelining investment and performance of scientific research and collections management is a priority issue of global concern demanding urgent response. It is high time to reconsider where such orphaned collections should be stored and researched. This may well require a revolution in traditional considerations of who really owns these objects collected from earth's habitats and geological formations.

These considerations should determine what resources are to be invested in which natural science collections. It will become very difficult to justify investment in collections and allied research in those institutions, which persistently ignore the core scientific values of collections, founded on the tentelic properties of natural science specimens.

A Final Word: Collections, Science and Natural History

Firstly, appreciation of this argument in its entirety emphasizes why museums are unique academic environments. It explains what they should be doing as scientific corporations; and why they deserve unprecedented public funding (no matter whether 1st or 3rd world). The underlying reason is to enhance their activities to deliver scientific understanding of the natural world to society. Secondly, the overriding impetus for paper's synthesis of topics is to foster development of natural history toward unfilled goals and opportunities. The plight of much of humanity, socioeconomies, and especially the biodiversity and ecosystems of which we are part and product (and utterly dependent upon) lends special weights to my arguments. Perhaps, all is not lost.

> "In the hundred or more years since Darwin's revolution began it has extended far beyond natural history, touching nearly every division of science and art. But the muse of history says here that when the future looks back through the lens of narrative, not only on Darwin's age, but also our own, it will see that the revolution of 1859 did not come to a close with us at the end of the Twentieth Century. It was not until the close of the Twentieth Century that the inertia of pre-evolutionary thought - of state questions and group-thinking - was at last overcome by the force of history - of change questions and tree-thinking - and Clio came down from the rafters of our museums, shook off the dust, and took her rightful place in the director's chair. A happy outcome of this, they will say, was the resurrection of the old term natural history: when the Darwinian revolution came to a close at the end of the Twentieth century, natural *history* became a discipline once again" (O'Hara, 1988: 153)

This quote takes us full circle to the philosophical foundations of biology - based on the ontology of biodiversity considered at the beginning of this presentation. Nothing in biology makes sense except in the light of history (Rose, 1997; Cotterill, 2002b). The ubiquitous[ness] of uniqueness of living entities underpins this radically different ontology and epistemology of the life sciences compared to any other branches of intellectual endeavour (Mayr, 1961, 1982, 1997; Cotterill, 1999, 2002b). These foundations of scientific natural history were elucidated by one of the greatest philosophers in the history of human thought - Charles Darwin (Ghiselin, 1984; Mayr, 1988). The Darwinian method has been improved on and consolidated through the 20th century, and refinements continue.

Structured by the Darwinian philosophy of biology, revolutionary advances continue to reshape 21st century biology and society too. It would be a global disaster of sinister and far reaching consequences if the very bricks and mortar of biological knowledge - natural science specimens - are allowed to crumble: because the cancer of short term greed and pseudoscientific agendas continues to parasitize the core scientific *raison d'être* of these institutions. In closing this polemical defence of the greatest of the life sciences, it is remarkable that the relationship between philosophy, preserved specimens and science renders natural science collections the foundations of the life sciences; and thus ultimately so central to nearly all facets of human welfare. It is therefore not just ironic, but an imploding disaster, that the corporate structures preserved in so many museums are terrified and bewildered by this key corporate strength of natural science museums.

Acknowledgements

I must first thank the organisers of this conference for their kind invitation and support to prepare this presentation. Unfortunately, I was unable to attend the conference in person due to the security situation following immediately on the events of September 11th 2001. The support of a Biodiversity Leadership Award to the author from the Bay Foundation, and the Josephine Bay Paul and C. Michael Paul Foundations, New York City, has been essential to gather literature and synthesize ideas for this review, and is gratefully acknowledged. I thank H. Whitham for her kind help in finishing the manuscript.

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