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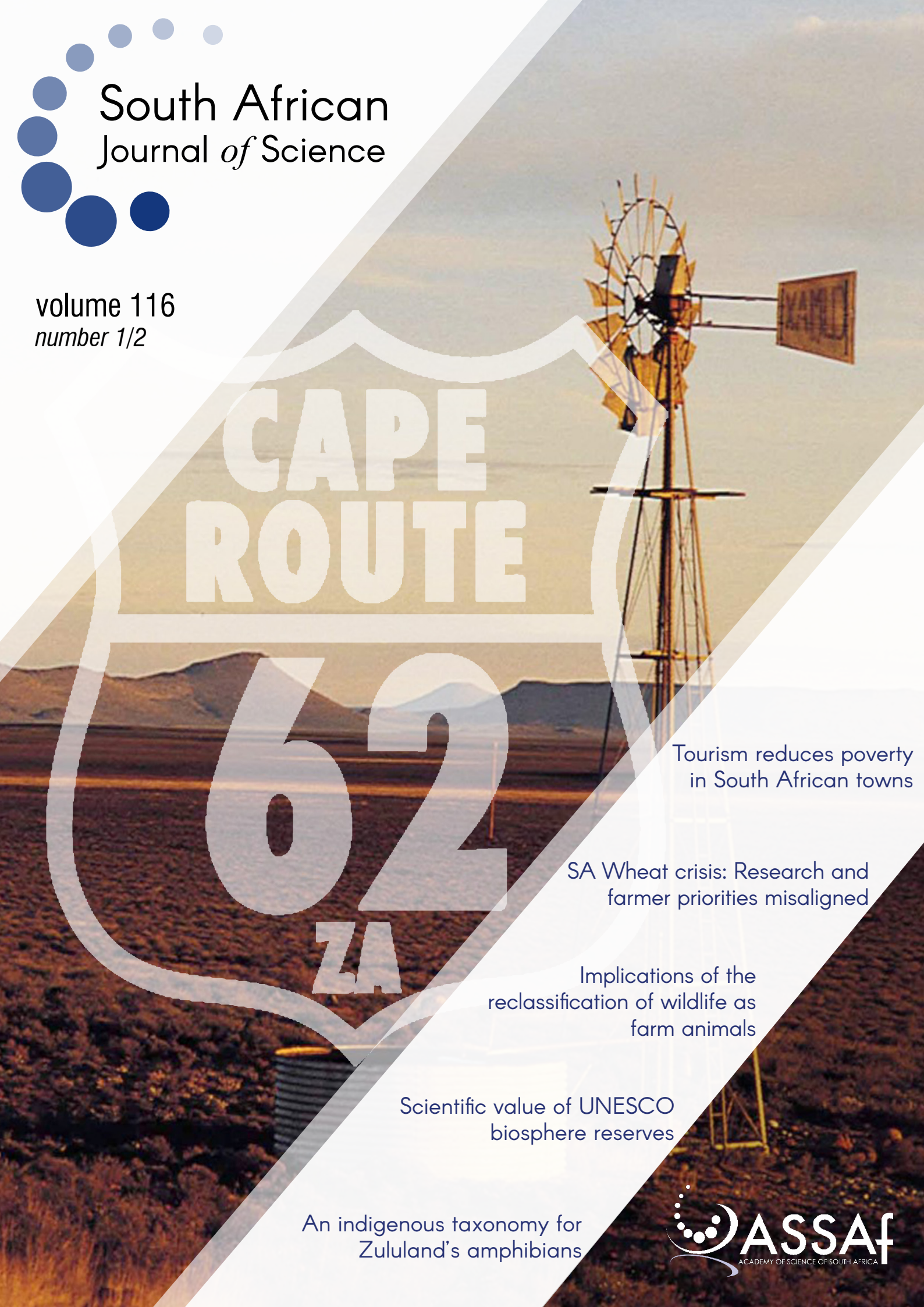

Tourism reduces poverty in South African towns

SA Wheat crisis: Research and farmer priorities misaligned

Implications of the reclassification of wildlife as farm animals

Scientific value of UNESCO biosphere reserves

An indigenous taxonomy for Zululand's amphibians

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Invited Commentary

Commentary

Review Article

Research Article

Cover caption
A windmill in the Karoo, South Africa (image CC-BY 2.0: South African Tourism). In an article on page 72, Toerien explores the link between tourism and poverty in rural South African towns located on Route 62, the N1 and N9.

Conservation science and UNESCO Biosphere Reserves

The front section of this issue of SAJS foregrounds a number of items relating to the science of environmental and biological conservation.

We feature an important overview of South Africa's UNESCO Biosphere Reserves by Ruida Pool-Stanvliet and Kaera Coetzer. Many readers may not be familiar with the concept of Biosphere Reserves, nor be aware that they can make an almost unparalleled contribution to sustainability science in South Africa. Although the Man and the Biosphere Programme was launched in 1971, South Africa's first biosphere reserve was declared only in 1998 after the country had been readmitted to UNESCO, consequent upon our becoming a democracy.

Biosphere reserves, of which South Africa currently has 10 – located in six provinces and collectively covering almost one-tenth of the total land area – are eminently appropriate landscape management areas for our age of the Anthropocene. Their purpose is to facilitate, in the most flexible and inclusive manner of governance, many of the global Sustainable Development Goals. In doing so, they ensure long-term conservation and appropriate land use in designated socio-ecological systems that encompass and include many forms of landholding and livelihoods.

Unlike other institutions in South Africa's protected area estate, biosphere reserves are not enforced through legislation, but rely on their success through collaboration, education and interaction with local partners. Our country has a long history of strict forms of nature and wildlife conservation, dating from proscribed hunting areas in the pre-colonial era, to the colonial game reserves of the 19th century in the Cape and Natal colonies and in the Transvaal Republic. The 20th century saw the international acceptance of the idea of national parks and during that century South Africa's national parks proliferated, as did the provincial game reserves. All these, however, have stringent legislation to monitor their activities, and their organisational structures are hierarchical and bureaucratic. The distinction is clear between top-down control of state-protected areas and bottom-up collaboration among all biosphere reserve stakeholders who can introduce appropriate and flexible socio-economic environmental management.

Biosphere reserves are ideal localities for studies in, and of, indigenous knowledge. An Invited Commentary in this issue by environmental scientist Fortunate Phaka, highlights the value of applying indigenous names and taxonomies to South Africa's biota. A co-author of *A Bilingual Field Guide to the Frogs of Zululand*[1] and a PhD student at North-West University and the University of Hasselt, Phaka is taking a molecular approach in his doctoral research to determine the amphibian species used in the South African traditional medicine (*muthi*) trade. In his contribution in SAJS, Phaka emphasises indigenous taxonomy and explains its scientific merit. In doing so, he underscores the importance of the organising principles of any taxonomic system and the linkages between biological and cultural diversity. He hopes that his work will lead to environmental policy that is socially and ecologically justified. It is worth noting that Phaka will be networking with Professor Peter Taylor, a mammologist with expertise on bats, who holds the South African Research Chair in 'Biodiversity and Change in the Vhembe Biosphere Reserve' at the University of Venda, thus demonstrating the opportunities for scientific research and collaboration in biosphere reserves, particularly with local communities.

Phaka's work on nomenclature resonates with that of Adrian Koopman, Emeritus Professor of Zulu Studies at the University of KwaZulu-Natal, whose book *Zulu Bird Names and Bird Lore* is reviewed in this issue by Richard Aitken. Using oral tradition, praise poetry, riddles and games, Koopman links the names and habits of birds to Zulu culture in interesting ways. Sue Nicolson reviews another innovative book on southern African fauna, *Dance of the Dung Beetles: Their Role in our Changing World,* authored by the unusual disciplinary partnership of Marcus Byrne, an entomologist, and Helen Lunn, a literature and music scholar.[2] Brian Reilly assesses the multi-authored *Livestock Predation and its Management in South Africa: A Scientific Assessment*, an exercise to evaluate the state of science around pastoralism and predators[3], while the large tome that comprehensively, expertly, and beautifully, includes all *The Amaryllidaceae of Southern Africa*[4] by Graham Duncan, Barbara Jeppe and Leigh Voigt is reviewed by Brian van Wilgen. The history of natural history in South Africa finds a place with a new biography of early naturalist and explorer, François Levaillant: *The First Safari: Searching for François Levaillant* by Ian Glenn[5] that is reviewed by Richard Dean.

On the subject of significant books, it would be remiss not to draw your attention to *A Fossil History of Southern African Land Mammals*.[6] Written by Margaret Avery, currently Honorary Associate of the Iziko South African Museum in Cape Town – and an Associate Editor of the *South African Journal of Science* – this is a work that has been long awaited and is destined to become an immediate classic. It is reviewed by Richard Klein, an internationally acclaimed palaeoanthropologist at Stanford University.

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The implications of the reclassification of South African wildlife species as farm animals

The Government Gazette No. 42464 dated 17 May 2019[1] amended Table 7 of the *Animal Improvement Act (Act no. 62 of 1998)*, which lists breeds of animals, to include at least 32 new wild animal species, including 24 indigenous mammals. The list includes threatened and rare species such as cheetah, white and black rhinoceros, and suni. Some alien species such as lechwe, various deer species and rabbits are also included. The cornerstone of the original Act is 'To provide for the breeding, identification and utilisation of genetically superior animals to improve the production and performance of animals in the interest of the Republic; and to provide for matters connected therewith.'

By declaring these wild animals as landrace breeds (in Table 7 of the regulations), the Act implies that they are locally developed breeds. The Act typically provides for landrace breeds to be bred and 'genetically improved' to obtain superior domesticated animals with enhanced production and performance. Similarly, provision is made for the Breeders Association to lay claim to the breed and to establish specific breed standards for animals to be included in stud books. Animals declared as landrace breeds can also be used for genetic manipulation, embryo harvesting, in-vitro fertilisation and embryo transfers. As indigenous species of wildlife are included in the recent amendment to the Act, the amendment is flawed.

Here we point out numerous concerns in the new legislation, including the process of consultation, and argue that the law will not improve the genetics of the species mentioned but will have considerable negative genetic consequences and pose ecological and economic risks. We also suggest that this new law is in direct conflict with other biodiversity laws in South Africa.

The consultation process

This amendment was seemingly processed without any public (including industry user groups or the scientific community) participation or consultation, and without the knowledge of the national and provincial conservation organisations which, together with the Department of Environment, Forestry and Fisheries, are responsible for the protection of all wildlife/game species in South Africa.

Legislation implications

The listed species are also covered by other legislation that potentially clashes with the new legislation (Supplementary table 1). As there are spelling mistakes and scientific names are not given, there is confusion over which species are being referred to (Supplementary table 1). However, as pointed out by Ezemvelo KZN Wildlife (EKZNW)[2], the new legislation does not repeal or replace existing laws: NEM:BA (including ToPS Regulations and the Alien and Invasive Species Regulations) and KZN Nature Conservation Ordinance 15 of 1974 all still apply. However, even in KwaZulu-Natal, where there is close cooperation between game breeders and the provincial conservation organisation (EKZNW), EKZNW still has difficulty in keeping track of what happens on game farms and in enforcing legislation.[3] This new law will add to this difficulty, and will likely be less controlled in some other provinces.

What are the genetic implications?

The genetic consequences of intensive or semi-intensive breeding (farming) of wildlife species are negative, and considerable.

Genetic diversity is the fundamental basis of diversity within species and determines the underlying health and long-term survival of a population.[4] Populations with higher genetic diversity have more options (different alleles) for adapting to ever-changing environmental conditions. Genetic diversity is, therefore, essential for the evolutionary process of natural selection to occur. However, if only the so-called 'best' alleles (from a game breeders' perspective) are passed on to each successive generation, it would eventually lead to a population with reduced genetic diversity.[5] Thus, selection by itself does not maintain genetic diversity in any given population. Long-term population viability, and evolutionary potential, depend more on processes such as genetic drift and gene flow, not only selection. Genetic drift is the random change in population allele frequency. The process of genetic drift does not account for fitness or 'superiority' of an allele and will often keep alleles in a population by chance, despite heavy selection for or against that allele. However, when populations become small, genetic drift has a corrosive effect on genetic diversity, and can quickly remove alleles from a population within a few generations.[6]

The current NEM:BA ToPS Regulations *(Act 10 of 2004)* regulates breeding of the listed species to protect their gene pool for the long-term conservation of wild populations. However, intensive breeding through artificial (non-random) selection of individuals for commercially valuable traits (e.g. horn size/shape, coat colour) represents humans taking over this natural process. Such artificial selection by humans is even more powerful than natural selection in creating distinct phenotypes within very short timeframes. Although domesticated animal species have been around for thousands of years, most of our modern domestic animal breeds developed through a marked increase in intensive animal breeding within the last century or two.[7]

The major difficulty with artificial selection is its focus on obtaining a desired or genetically superior phenotype, but without the built-in safety net of natural processes, which allow genetic drift and gene flow to maintain population genetic diversity in the background. Intensive and semi-intensive breeding invariably leads to small isolated (closed) populations because it is the quickest way to produce a desired phenotype. These populations lose genetic diversity through artificial selection for the so-called superior traits, as well as through genetic drift (a consequence of small populations) and lack of gene flow (a consequence of isolation).

The full negative impact of reduced population genetic diversity then becomes clear as most individuals in the population become so closely related that they all possess the same lethal or deleterious allele copies for the same genes. This then increases the chance that an individual will receive harmful copies of a gene from both parents in a phenomenon known as inbreeding depression.[8] In the wild, natural selection purifies or purges populations of these harmful alleles on the rare occasion when a homozygote emerges. The domestication of traditional farm animals was, therefore, necessarily a lengthy process because it had to allow time for natural selection to purge populations of harmful alleles before they became a burden (load) to the population. However, modern-day breeding practices require the establishment of the desired phenotype as quickly as possible. In these populations, lethal homozygotes increase and, with the population usually being small, will soon be unable to bear the accumulated genetic load of all the 'bad genes'.[9]

Finally, intensive and semi-intensive breeding often leads to hybridisation because individuals from other parts of the species range (other subspecies), or other closely related species, are also present on the same land. This is a common occurrence in South Africa. Although hybridisation is the opposite of low genetic diversity and inbreeding, as it leads to increased genetic diversity, its negative consequences for long-term population survival should not be understated.[10] Attempting to increase population genetic diversity on wildlife reserves in this way is unethical for the following reasons. Populations of wide-ranging species are often adapted to local conditions, especially if local conditions can be markedly different from the rest of the species' range, as is the case in temperate South Africa relative to the rest of tropical Africa. While managed gene flow may be required, and even essential, to maintain long-term genetic diversity of many wild large mammals, gene flow between evolutionary divergent populations can disrupt local adaptability and lead to the loss of unique alleles in receiving populations. It is, therefore, disingenuous to claim that genetic diversity of intensively managed populations can be maintained through translocations if, in reality, the translocations are undermining locally evolved adaptive traits. Hybridisation between species, or very distantly related subspecies, compounds this effect even more because the hybrid will not be adapted to either parental environment, which leads to reduced fitness and survival.[11]

What are the ecological and industry considerations?

Extralimital or exotic species can have benefits such as ecotourism.[12] However, the ecological implications of moving some of these species are potentially large. For instance, rabbits can cause massive environmental impacts.[13] Due to the lack of transparency and details, we do not know how these species will be managed and, therefore, what the ecological implications will be. A logical endpoint of this legislation is that we will have two populations of each species: one wild and one domesticated. We suggest that maintaining this distinction will be expensive, if it is actually possible. Thus, domesticated varieties of wildlife will represent a novel, genetic pollution threat to South Africa's indigenous wildlife that will be virtually impossible to prevent or reverse.[14]

In conclusion

We provide concerns and threats which arise from the amended Table 7 of the *Animal Improvement Act* (*Act no. 62 of 1998*). Most importantly, we point out that the main aim of the law, which is 'To provide for the breeding, identification and utilisation of genetically superior animals to improve the production and performance of animals in the interest of the Republic…' is fundamentally flawed when applied to wild animals on this amended table. The genetic consequences of the law are likely to be severe for some of the listed species. We, therefore, believe the process and reasons given for the addition of indigenous wild game species as landraces is a risk to South Africa's biodiversity heritage, as enshrined in the Constitution.

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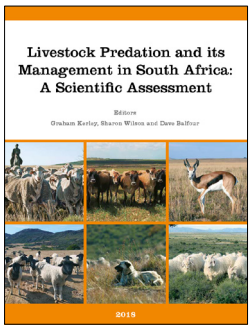
Livestock predation and its management in South Africa: A scientific assessment



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Assessing the jackals among the sheep

It is now well established that modern humans evolved in Africa and that this process was in large part a co-evolution with other species. It was entirely inevitable that livestock domestication brought pastoralists into direct conflict with other predators and this, combined with increasing human populations, has created what is termed 'human–wildlife' conflict and raised issues about how best to mitigate it.

This book on livestock husbandry and predation by wild animals incorporates the work of nearly 40 authors in a transdisciplinary magnum opus that provides perspectives from agricultural, biological, ecological, ethical, historical, legal, economic and philosophical fields. The co-authors together represent a staggering array of knowledge and expertise on the subject and represent government, NGOs, academics and producers from across the spectrum. This compendium is ably edited by Graham Kerley, Sharon Wilson and Dave Balfour, respected scientists in their own right, and this publication should help us take a step in the direction of what have been defined as 'living landscapes' by Brown[1], among others, because livestock predation is likely to remain a problem into the foreseeable future.

The work was strongly underwritten by both the Department of Environment Affairs and the Department of Agriculture, Forestry and Fisheries with the foreword penned by both ministers. Start-up funding was provided by a well-known and respected retail chain and the production of the book was supported throughout by a number of livestock producer organisations.

Chapter 1 covers the basics of the history of predator management, the essence of a scientific assessment[2], as well as the economic realities of predator impact. Included is a summary of the current legal framework and management, using the black-backed jackal and the caracal as central case studies. Chapter 2 discusses the history of predator livestock conflict in South Africa by reviewing different periods in our history, and clearly establishes the complexity of the problem. There is a useful timeline giving key dates of interest – be it legal, political, economic or wildlife management key developments. Chapter 3 analyses the socio-economic impacts of livestock predation and, in a particularly data-rich chapter, the financial impacts are clearly spelled out with a number of comparisons with other livestock-producing regions of the world.

Chapter 4 deals with ethical issues – essential in the modern approach to complex problems. With so many interested and affected parties involved, it is inevitable that opinions and therefore approaches will differ. Here, the ethical issues are articulately unbundled and examined in terms of moral grounding. The rise of 'animal rights' is also included as well as an examination of control methods and the moral obligations to both animals (predator and livestock) and sectors of society and our human social contract. Chapter 5 presents a comprehensive current legal framework in South Africa, tracking legislation cascading downwards from the Constitution to provincial regulations and responsibilities. The authors conclude that metapopulation management plans for damage-causing animals and norms and standards for their control are required in order to lessen the burden on authorities and allow for role players to adhere to more universal standards.

Chapter 6 reviews past and current management of predation on livestock, including a comprehensive review of accepted methodologies from around the world. This chapter will force any livestock or wildlife manager comprehensively to review the spectrum of available options to their particular problem. Indeed, it is surprising how many non-lethal methods of control exist. However, while many methods have been trialled in South Africa, the authors conclude that there are little data on their success.

Chapter 7 departs from the template above, summarising our knowledge about the biology and ecology of the black-backed jackal and caracal. These two species have dominated discussion on damage-causing animals for decades, and they are universally blamed and persecuted in every possible way when it comes to small livestock predation. The authors agree that most studies have been biased towards the species' biology rather than focusing on their ecology, particularly as it pertains to how they operate in the areas where they overlap with stock farming. In terms of identifying knowledge gaps (the point of a scientific assessment), it is evident that this problem has not been researched and that, once again, the theoretical research trumps the applied – the latter being more difficult to conduct and much more difficult to publish.

Chapter 8 discusses the ecological role of meso-predators in ecosystems and the potential effect of managing their populations. Once again, as in Chapter 7, there are knowledge gaps on a large number of ecological parameters. The Chapter summarises the who's who of research on black-backed jackals and caracal, again suggesting that what we know is of little use to stock farmers. Chapter 9 draws attention to the many other species responsible for livestock predation, including baboons and raptors. Major aspects of the ecology and behaviour of these species provide useful reading. What is surprising is the impact of baboons on small stock and one wonders if this has anything to do with the relaxation of natural controls on baboons and their increasing populations and how this may develop into the future.

The work in general presents a high-quality narrative, as is to be expected from esteemed academics and scientists, but its major value lies in the comprehensive literature cited. At the end of each chapter, knowledge gaps are identified and suggestions raised as to where optimal scientific and financial investments in the future should lie. In general, however, the book will be useful in many areas of research and could also help change attitudes to land and wildlife management, reinforcing many underlying principles but also acting as an engine for shifting attitudes to wildlife, its management and our human ethical dilemma. I would certainly wish to have this publication on my shelf for personal and academic use. This is a wonderful example of newer transdisciplinary approaches to problems facing humanity and its interactions with the environment and wildlife.

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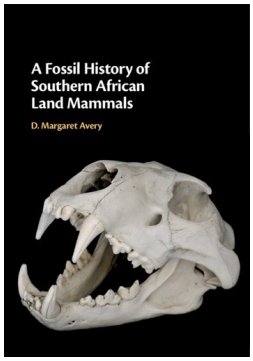
A fossil history of southern African land mammals



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Southern African land mammals through space and time

In 1839, Andrew Geddes Bain initiated the study of mammalian fossils in southern Africa when he published the skull of a large extinct buffalo found on the banks of the Modder River in what is now the Limpopo Province of South Africa. In this book, Margaret Avery notes that the field received a significant boost in 1925, when Raymond Dart reported *Australopithecus africanus* and associated fossils from a cave at Taung in the present-day North West Province, and another in 1936, when Robert Broom and others began to accumulate australopith and accompanying mammalian fossils from caves within what is now the Cradle of Humankind, Gauteng. It matured in the 1960s, led by C.K. ('Bob') Brain, who analysed entire fossil bone assemblages to reconstruct the behaviour and ecology of the bone accumulators. Avery entered the field in the 1970s and subsequently became the leading authority on micromammals – small rodents, insectivores and bats – from southern African fossil sites.

In the research for this book, Avery identified more than 600 fossil mammal localities in southern Africa, defined as the subcontinent south of the Kunene and Zambezi Rivers, roughly Africa below 15°S. In geopolitical terms, southern Africa means Botswana, Lesotho, Mozambique (southern half), Namibia, South Africa, Swaziland and Zimbabwe. Most known localities are in South Africa, because that is where the commercial activity that exposes sites has been most intense and because it is where palaeontologists and archaeologists have been most numerous. The sites date mainly from the later Pleistocene and Holocene, between about 130 000 years ago and the near-present. However, some, most notably Langebaanweg in the Western Cape Province, Makapansgat in the Limpopo Province, and the Gauteng australopith caves, document mammalian species during the Pliocene and early Pleistocene, between roughly 5.5 and 1 million years ago, while Arrisdrift, Berg Aukas, and other localities mostly in western Namibia, have revealed species that lived in the early-to-middle Miocene, between perhaps 23 and 14 million years ago. A handful of especially old sites, clustered on a short stretch of coastal Namibia, record mostly micromammal species of later Eocene age, broadly between 45 and 34 million years ago. Considered irrespective of age, the sites have produced specimens from about 650 species.

Information on the sites and their fossils is widely scattered and often difficult to access, even for specialists. To remedy this, Avery has gathered into a single volume lists of all the known mammalian species and sites by geologic epoch, from the Eocene through to the Holocene. For each species, she presents its classification within the Linnaean hierarchy from the level of Order down, and she locates the sites where the species occurs within a grid of 350 contiguous squares covering all of southern Africa. Each square is one degree of latitude and one degree of longitude on a side. She presents a cross-cutting list of sites with the species each contains and their locations by epoch within the same 350-square grid; 153 squares contain at least one site. For each species and site, she provides basic references and, where relevant, notes on species or age ambiguity and on species synonyms. Readers can locate information on a particular species or site from a full index or, in keeping with publication in 2019, they can search for it in the open access ebook.

Avery has worked hard to ensure that the text is both comprehensive and accurate. Specialists can use it to investigate variation in species composition through time and space, and many will surely use it to gather the background they need to place new fossils or sites in context. Avery and Cambridge University Press are to be thanked for making such an invaluable research tool freely available.

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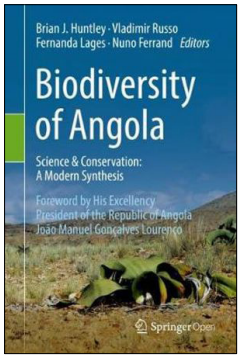
Biodiversity of Angola. Science and conservation: A modern synthesis



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Updated account of Angola's remarkable biodiversity

Angola is one of the most biologically diverse countries in the world, yet relatively little is known about the species that occur there, or the ecosystems in which they live. There were, compared to southern and eastern Africa, relatively few naturalists who documented the biota of the country, and much of what they published is difficult to access or is now out of print. Just when the world started to take ecological research seriously in the mid-1970s, Angola was plunged into a devastating civil war that was to last for more than a quarter of a century. A peace settlement was finally reached in 2002, but in the intervening years almost no scientific activity was possible. The situation has changed for the better since then, and scientific exploration and research have resumed, albeit under challenging circumstances. This book provides a modern synthesis of what is known about Angola's biodiversity from early work that was published in 'extinct journals and inaccessible official reports' as well as more recent findings, and outlines opportunities for further work and collaboration in an exciting and relatively unexplored part of the world. The book has 20 chapters by 45 contributing authors, and is divided into five parts: an introductory part that sets the scene; chapters dealing with flora, vegetation and landscape change; two parts on invertebrate (two chapters) and vertebrate (seven chapters) diversity respectively; and a concluding part examining research and conservation opportunities. The book is well illustrated, with many colour photographs and maps.

Angola is a large country (1.2 million km^2), and its ecosystems range from deserts receiving less than 60 mm rainfall annually, to rainforests with mean annual rainfall exceeding 1600 mm. It has seven of Africa's nine recognised biomes and 15 of the continent's ecoregions – placing it second only after South Africa for its diversity of African ecoregions. Starting with the flora, approximately 6850 native species are known, of which about 14.8% are endemic. However, these numbers are based on a very patchy level of exploration, particularly in the eastern half of the country. There are a further 230 alien plant species that have naturalised in Angola, 4 of which are highly invasive. One of the most peculiar vegetation types is a grassland dominated by geoxylic suffrutices, where there has been an 'astonishing radiation' of species (there is a separate chapter on this). These low shrubs are characterised by large, extensive underground root systems, sometimes referred to as 'underground trees' or 'underground forests' which persist almost in perpetuity in the face of severe disturbances. Another conundrum is posed by the phenomenon of 'fairy forests', possibly akin to the 'fairy circles' of the Namib. Illustrations show markedly rounded blocks of miombo forest that appear to have been isolated by fire, and for which no explanation yet exists. Rates of clearing of natural vegetation – harvesting for fuel or timber, clearing for crops, or conversion of woodlands to grasslands by frequent fires – are very high, which places many unique areas at risk.

The coverage of invertebrate fauna is of necessity restricted to those groups for which information is readily available. These include the dragonflies, damselflies, butterflies and skippers, and complete checklists for these groups are included as appendices. Each class of vertebrates has its own chapter, and marine and terrestrial mammals are treated separately. As for the invertebrates, there are complete checklists for each group (except birds, for which other modern lists can presumably be found elsewhere). Interestingly, the chapter on birds provides the usual list of sources cited in the text, but also includes a list of 'publications post-1975 *not* cited in the text' – a useful resource. Angola is home to 940 bird species, with 29 endemics, and the country has in recent years become a favoured destination of bird enthusiasts, both professional and amateur. The longest chapter by far is an exhaustive assessment of the status of Angola's 291 mammal species, and a rather sorry tale it is. While the small mammals presumably persist, Angola's civil war resulted in the almost complete annihilation of large mammals. We read, for example, that the near-endemic black-faced impala 'is likely on the verge of extinction', that wildebeest are 'likely extinct in the western areas of their Angolan range', and that plains zebras that used to be 'relatively common and widespread in Angola' in the 1970s, are now reduced to 'only a few animals [that] may still linger in Bicuar National Park'. Other examples include the national extirpation of *inter alia* black rhinos, forest elephants, western gorillas, chimpanzees, giraffes and forest buffaloes. Angola's iconic national symbol – the giant sable antelope – has fortunately been relocated, and about 200 survive today. In a separate chapter devoted to this species, Pedro Vaz Pinto recounts how an isolated group of surviving female giant sables hybridised with a roan antelope bull in the absence of a conspecific mate. This hybridisation has contributed further to conservation problems, which are being addressed by translocations, the sterilisation of hybrids, and the constitution of a breeding nucleus.

Despite decades of enforced neglect with regard to biodiversity conservation, there is now cause for optimism, and the book concludes by examining the opportunities for further exploration, research, and conservation initiatives under a new and strengthened administration. The system of protected areas was greatly expanded in 2011, and increasing resources are being directed towards improved management. A concluding chapter points to many opportunities for fundamental research, including for example genetic studies of Angola's two elephant species, or distinct baobab phenotypes, unravelling to population dynamics and resilience of the once vast populations of the unique desert conifer *Welwitschia miribalis*, solving the puzzle of fairy forests, and understanding the ecological role of fog along the coast. Many of these questions may appear academic, but it is pointed out that 'every element of applied science and technology rests on the fundamentals of curiosity-driven enquiry'.

The coverage in this book is as good as the available information allows, and Brian Huntley, his co-editors and the authors are to be congratulated on producing this volume. What is not in this book is almost certainly not yet known, as the coverage is comprehensive. For anyone wanting to embark on research or biological exploration in Angola, this book will be an indispensable resource.

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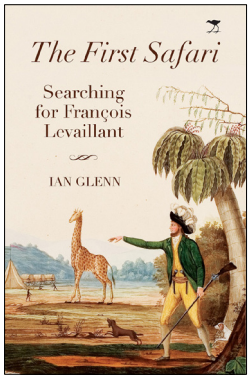
BOOK TITLE:
The first safari: Searching for François Levaillant



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François Levaillant: Explorer and biologist

Reputed to be the most famous ornithologist of the 1700s, François Levaillant (1753–1828) made a large contribution to the study of avifauna in South Africa. Levaillant's name is frequently repeated in any African bird list, not only because he discovered 'new' species, but also because he carefully noted his observations on a wide range of birds and other animals.

In this very readable account by Ian Glenn, Levaillant the man, not only the traveller and ornithologist, is revealed. Glenn takes us through Levaillant's early life and passions – his obsession with birds generated and fostered by his early formative years in the tropical wilderness in Suriname where he was exposed to a diversity of nature. Levaillant's parents returned to France in 1763 and his life there was somewhat turbulent and varied, with interests in hunting and taxidermy, enlisting in the cavalry, and his marriage. By 1774, Levaillant's prospects were, apparently, bleak, with nothing much to offer except his strong interest in natural history. The latter, ultimately to the benefit of South African ornithology, fortuitously landed him a sponsorship and an expedition to the Cape. The sponsor was Jacob Temminck, himself a bird collector, who used his position as treasurer-general of the Dutch East India Company to send Levaillant to the Cape to collect material.

In all, Levaillant made three expeditions in South Africa. The first from April 1781 to December 1781, was localised to the area around Cape Town. The second, from December 1781 to March 1783, consisted of an anticlockwise loop eastward along the coast to about Port Elizabeth, then inland to the Cradock area, and the return via the Karoo. The final exploration from June 1783 was north along the west coast to the Orange River for which the dates and destinations are unreliable. Glenn notes that trying to retrace Levaillant's travels has been difficult for anyone who has tried to follow the details of the expeditions.

It is the second expedition that gives the book its title, for it left Levaillant, as Ian Glenn tells us, not only 'transformed' through searching for new specimens, and encountering the landscape and its people, but was also highly profitable in terms of specimens and field notes. Incidentally, many bird species collected by Levaillant and described as 'new' were obtained on this expedition, with their descriptions and names published in *Histoire Naturelle des Oiseaux d'Afrique*, printed in 51 parts over a period of 17 years. Not explained in *The First Safari* is that Levaillant's published names and descriptions were in French not Latin, and thus did not constitute formal descriptions of holotypes. However, the holotypes were published by later taxonomists using Levaillant's illustrations as well as his names. The Narina Trogon *Apaloderma narina*, for example, was formally described by Stephens in 1815, although the name and description had been published earlier by Levaillant.[1]

Levaillant was a man of many parts. He was concerned about many sociological aspects of the indigenous peoples whose land had been invaded by settlers. His views on Dutch colonial expansion, his insights into the loss of Khoikhoi land – he insists on their 'sacred and respectable rights of property' – and his comments on the treatment of local people by the white settlers were perceptive. Glenn deals with 'Levaillant as social and cultural observer' very well, concluding that Levaillant's impression of the Cape was that of a 'detached outsider' who had an influence on later writing and thought.

In 1784, Levaillant returned to the Netherlands with his bird collection, some of which was shared with Jacob Temminck, Joan Raye, L.F. Holtshuyzen and W.S. Boers. The fate of Levaillant's insect collection is not known, but the botanical specimens, according to Gunn and Codd, were largely lost at sea, although the species survive as plates in Levaillant's books.[2]

Glenn devotes a large part of the book to Levaillant's life in France after returning from Africa. This part is particularly well done, with persistent, thorough research, exploring every avenue of Levaillant's life while he was, in the author's words, writing his 'highly ambitious, highly successful [book] leading to the encouragement of some of the most beautiful ornithological books of the time'. Glenn also explains the discovery of Levaillant's bird collection, which was incorrectly listed in the register of the Paris Natural History Museum, and the important 'map', prepared for Louis XVI by several major artists, with its annotations referring to Levaillant's travels.

Some of Levaillant's observations of birds are summarised in a general section on Levaillant as naturalist and ornithologist. His insights into certain aspects of bird behaviour, calls, and nest building have, in many cases, been supported by subsequent studies. Some of his hypotheses, however, have not been upheld by recent research, but it is to Levaillant's credit that he tested his ideas and raised questions to be addressed by later generations of ornithologists.

In his final years, Levaillant endeavoured to link exploration with commercial gain, as have many others, and Glenn deals with Levaillant's complex personal life. The book also details Glenn's own unsuccessful attempts to find Levaillant's travel notebooks but, sadly, they are probably lost forever.

Colonial scientific endeavour is generally not well covered in South Africa. *The First Safari*, while not the first book on Levaillant, is a useful addition to the literature and complements other texts about him. The life of this interesting man is well worth reading.

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2. Gunn M, Codd LE. Botanical exploration of southern Africa. Cape Town: A.A. Balkema; 1981.

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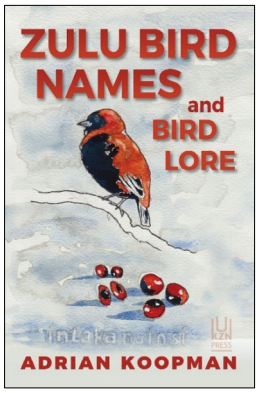
BOOK TITLE:
Zulu bird names and bird lore



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Naming birds accurately is part of being passionate about defending nature

To frame this review of Adrian Koopman's most recent remarkable book, I make two general points. First, it is a philosophical commonplace of our contemporary understanding of how our minds apprehend the world that language precedes perception. What we see and understand depends on the language we inherit through enculturation: if you are not given words to describe the world, you cannot and do not see it in any consequential way. Second, to be intellectually alive in our contemporary world entails knowing some of the fundamental scientific features of climate change, and perhaps more importantly, being aware of the growing clamour about the extinction of species that climate change threatens. This awareness comes burdened with moral imperatives: we are enjoined to do something about the loss of nature, but we pall at the prospect of change on this scale. These two framing threads will be brought together in why I consider Koopman's book to be important.

Zulu Bird Names and Bird Lore is fundamentally autobiographical. Koopman mines his lifelong engagement of collecting folklore, myths, and the multitude of folkloric narratives from eastern southern Africa. As a professional scholar of language, he explores the morphology of linguistic structures, and the multitude of ways inherited observation, through countless generations, has attributed semantic and relational properties to naming birds. There is therefore considerable consonance between Koopman's interest in linguistic morphology – the form, change and inflection of words – and the morphology of birds. Reading about the complexity of Zulu bird names is to be immersed in an extended dialogue between culturally embedded forms of description, as one shuttles constantly between English common names of birds, the universalising and culturally invariable scientific binomial nomenclature, and Zulu words drawn from a multitude of descriptive experiences, both of living people and archival semantic sources. The latter includes the dictionaries of Bishop John Colenso, the Reverend Arthur Bryant, the records of James Stuart, the mid-20th century lexicography of Clement Doke and Benedict Vilakazi, and a host of others. Included among these multiple sources are the rich traditions of praise poetry, proverbs and riddles, mythological beliefs and the verbalisation of birdsong.

There is also reference to the Zulu and other regional vernacular words that various published English bird guides have provided over the decades (often erroneously), most notably in the successive editions of the canonical Roberts field guides. In an implicit yet real sense, this book is a highly developed exploration of cultural mediation, and the author is scrupulous not to give precedence to one classificatory scheme over another. Koopman is not explicit on the matter of cultural relativism, but in a significant way the book immerses the reader in the competing legitimacy of incommensurable rational and descriptive systems as different people with different pasts have looked in wonder and veneration at the fauna of their worlds; as a cardinal principle of cultural mediation, this is virtue indeed.

Koopman gathers his harvest of Zulu bird names to provide a descriptive context of linguistic structural principles of Zulu, including the morphology of bird names and, particularly, the use of prefixes and suffixes. He shows how naming birds has informed, and is referenced to, many other uses in the metaphorical evolution of Zulu, as is the case also in naming the different properties and patterns of cattle, or even historical military regiments.

The book illuminates the personal relationships between the author and a number of his important informants. Fascinatingly, he explains how they offered their insights in a series of bird-naming workshops between 2013 and 2017. Here we catch a glimpse of a vibrant exchange between people that suggests a social and living form of scholarship, including giving names to birds that previously had none.

Koopman has included some of his own watercolour sketches of birds that seem to yearn to illustrate the symbolic, metaphorical and morphological connections to which his academic study points. His paintings join the immense, and highly regarded, genre of South African bird illustration. Look at birds in an informed way by means of a vocabulary of description, the author seems to suggest, and you will begin to understand the miracle of the creation and the myriad functional and descriptive relationships of nature which bird watching, if genuinely informed by observational accuracy, will lead you into. Seeing bird species precisely has language at its core in any account of evaluative cognition.

Zulu Bird Names is not an easy book to read but it will unquestionably become a standard reference for biologists, taxonomists, and ecologists insofar as their work impinges on the social and political world – most assuredly as professionals devise persuasive programmes in defending regional biomes as essential habitats upon which the survival of species depend. This book offers the richest experience for those fluent in Zulu and English. Thus, within southern Africa, the readership is a very large one indeed – part of the extraordinary privilege of living in a multilingual society. The work amply underscores the point that the cognitive and cultural tools of veneration and wonder at nature's richness reach deeply into the archaeology of our own minds, but most of all, are part of a fertile dialogue of cultures. This is the book's real strength.

Koopman's study may well undergo some change in later editions. Although it has a bird-name index, it is not an easy reference tool. For example, when speaking with a friend about the call of the Cinnamon dove, more often called the Lemon dove, or *Aplopelia larvata*, neither of us could think of the Zulu name, *isagqukwe*. The index of *Zulu Bird Names* has 30 page references to 'dove', and 8 to 'Cinnamon dove', but it did not yield instantly to the Zulu name for the bird. Future editions might correct this, and a simple solution would be to include a table that showed English common names, scientific names, regional Zulu variations, and references to birds so named in the body of the text.

For recreational birders and scientific ornithologists alike, all protesting loudly about what we, as a human species, are doing to our environment, an immensely valuable book has arrived.

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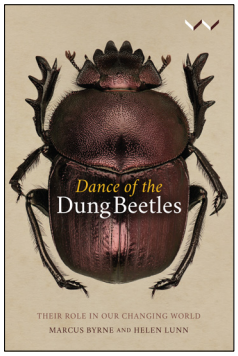
BOOK TITLE:
Dance of the dung beetles: Their role in our changing world



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Dung beetles do the dirty work for the planet with style and charisma

The 6000 species of dung beetles form a large and successful subfamily of the Scarabaeidae. They make a living from dung as rollers, dung dwellers or tunnellers: most are tunnellers but it is the rollers that catch our attention. They are most diverse in Africa and South America, and South African scientists have been active in research on these insects. Broad in scope, this book weaves together dung beetle mythology, ecology, behaviour and evolution in a most entertaining and readable way.

We follow the fortunes of dung beetles in human history, beginning in Chapter 1 with ancient Egypt. While dung beetles have featured in various human belief systems, best known is the sacred scarab (*Scarabaeus sacer*). Dung beetles bury their balls in the ground and the larva develops inside the ball. In the Egyptian world view, the re-emergence of the beetle was a symbol of the daily death and rebirth of the sun; also a symbol of resurrection. Later, the French entomologist Cambefort compared the pupa in its chamber to a mummified body, the chambers and tunnels to pyramid interiors.

The following two chapters describe the role of dung beetles in the history of science. Their subterranean nests were first described in 1602, and an early microscope enabled Swammerdam to describe a scarab and its immature stages. International trade and exploration led to the discovery of new fauna and flora. As collections from around the world expanded, it became important to explain the similarities and differences between the newly named species. Darwin's notes made during the second voyage of the *Beagle* show he was thinking about the links between dung beetles and herbivores, and about how beetles might adapt to new dung types in new places (Appendix A). Detailed observations by the French naturalist Fabre led to a delightful description of the life cycle in 1918.

The book then moves to the ecological roles of dung beetles. Chapter 4, about colonising insects, focuses on the fascinating story of how dung beetles were introduced as a form of biological control, first to Hawai'i and later to Australia. Unlike Australian dung beetles which are adapted to marsupial dung, introduced beetles such as *Onthophagus gazella* (a small tunneller) were spectacularly successful in burying cow pats and reducing bush fly numbers. When it was realised that different beetles were needed for different soil types and rainfall patterns throughout Australia, the Dung Beetle Research Unit was established in Pretoria. This was a great impetus for research on their taxonomy and biology, and extensive collections were made (now in the National Collection of Insects). Strangely, there is an appendix listing introduced species that became established in Hawai'i, but no similar list for the 23 out of 50 species that were introduced into quarantine in Australia. The Australian dung beetle project is being revived, with a new AUD13 million grant aimed at quantifying the ecosystem services rendered by exotic dung beetles across Australia.

Early ecological studies on the relationships between dung beetles and large herbivores such as elephants, mainly in Africa, are covered in Chapter 5. The establishment of game parks, initially in areas made uninhabitable by tsetse flies, led to the new profession of wildlife management, although it took a while for dung beetles to be noticed. Malcolm Coe was first to examine the interactions between elephants and dung beetles in Kenya, and to publicise the value of their recycling activities.

Chapter 6 celebrates the value of dung beetles for research on ecological and behavioural questions. Multiple species, attracted by scent, converge in large numbers on fresh dung. Ball rollers are intent on rolling their balls – backwards – away from the dung pile, and are undeterred by experimental interventions. They roll to avoid competition for space under the dung, and to avoid having the valuable resource stolen. In fights, the hotter beetle wins. Conversely, beetles cool down on the hottest days by standing on their balls; demonstrating this involved fitting them with silicone bootees (the colour photos are helpful).

The 'dance' in the book's title refers to the beetle standing on top of its ball and rotating to get its bearings. Ball rollers need to get away from the dung pile quickly and efficiently, i.e. in a straight line, and Byrne and his colleagues have carried out a series of ingenious and fun experiments showing how beetles use celestial cues for orientation. Apart from the sun, dung beetles use polarised light from the sun or moon, and even the Milky Way – the only animals known to do this. Beetles wandered in circles when caps were put on their heads, or changed direction when what they could see of the sky in the field or in a planetarium was modified.

The final chapter is about the value of dung beetles for evolutionary studies. Astonishingly, more than 250 papers are written every year on the bull-horned beetle *Onthophagus taurus*. Male beetles come in different sizes with large or small horns or none. Large individuals win fights, guard females in tunnels, and help with parental care; while smaller males engage in sneaky copulations and have bigger testes, useful for sperm competition. Body size and whether the genes for horns are switched on are determined by the amount of larval provisions. The species is valued for allometric studies as well as its flexible breeding system.

This book is not the first text on dung beetles from South Africa: surprisingly, the select bibliography does not list the substantial academic volume by Scholtz et al.[1] These books differ greatly in approach and content, and complement each other.

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1. Scholtz CS, Davis ALV, Kryger U. Evolutionary biology and conservation of dung beetles. Sofia: Pensoft Publishers; 2009.

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Doubling the age and size of the universe at the IAU in Rome in 1952: Contributions by David Thackeray, Walter Baade and Harlow Shapley

In September 1952, the International Astronomical Union (IAU) met in Rome. The meeting was attended by 430 astronomers from 34 countries.[1] The inaugural ceremony took place in the historic palace at the Campidoglio on the Capitoline hill, and sessions were held in the building of the National Research Council near the Cittá Universitaria. The Vatican Observatory at Castel Gondolfo was visited in the course of the conference, and the degates were addressed by Pope Pius XII.

Commission 28 was convened to discuss extra-galactic nebulae. It was attended by, among others, Georges Lemaître (proposer of the concept of the Big Bang), Fred Hoyle (proponent of a 'steady state' universe) and Jan Oort (after whom the Oort Clouds are named). Without doubt, the most remarkable event at the meeting of this Commission was the recognition that the perceived age and size of the universe had to be doubled. Douglas[1] described the session as 'intensely interesting'. Three astronomers were central in this connection (Figure 1): Walter Baade (a German, based at the Mount Wilson Observatory in California, USA); my late father, David Thackeray (trained in Cambridge in the UK, and subsequently based in Pretoria, South Africa); and Harlow Shapley (trained at Princeton and based at Harvard, Massachusetts, USA).

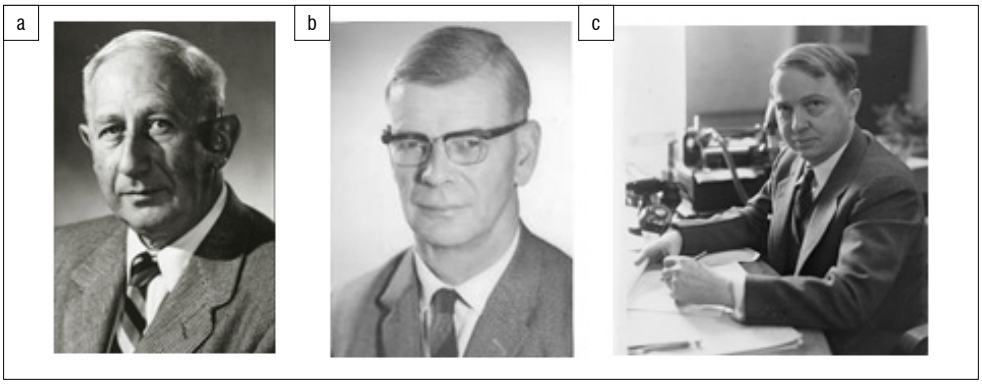

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Figure 1: (a) Walter Baade, (b) David Thackeray and (c) Harlow Shapley.

Prior to 1952, Shapley had been able to calibrate a period-luminosity relationship which could be used in efforts to determine distances on the basis of observations of stars of variable brightness, including Cepheids ('standard candles') visible in the northern hemisphere.[2] For southern hemisphere observations, Shapley made use of the 24-inch Bruce refractor telescope at the Boyden Station on 'Harvard Koppie' near Bloemfontein in South Africa. Since 1931 (with Edwin Hubble), Baade had been using the 100-inch reflector telescope on Mount Wilson, and in particular attempted to determine the distance of the Andromeda Nebula (M31) using Cepheid variables. After 1948, Thackeray used the 74-inch reflector telescope that had just begun operations in Pretoria on 'Oxford Koppie' at the Radcliffe Observatory which, at that time, was the largest telescope in the southern hemisphere. (This telescope was moved to Sutherland in 1974 on account of light pollution in Pretoria).

Baade had written to Thackeray in 1949, encouraging him to look for RR Lyrae variable stars in the Magellanic Clouds. The two men had known each other in 1934 when a 24-year-old Thackeray was based at Mount Wilson, and just embarking on an astronomical career in the stimulating presence of Hubble.

Feast[3] and Glass[4] refer to the following correspondence from Baade to Thackeray in 1949:

> *Both Hubble and I hope that Shapley's tendency to consider the Magellanic Clouds as his personal property will not deter you from attacking this problem [of searching for RR Lyrae variables]. He has monopolised the clouds all too long and it is high time that the barbed wire fences and the warning signs 'Keep out. This means you!' are taken down. Monopolies in science are intolerable and should never be respected… The whole situation has become intolerable and a good fresh breeze is most desirable.*

That 'fresh breeze' did indeed blow at the IAU in Rome in September 1952. Baade himself reported that RR Lyrae variables could not be detected in the Andromeda Nebula, even when using the 200-inch telescope at Mount Palomar in California. This by itself was a notable fact. Baade suggested that the distance of M31 might be greater than previously thought, with conjectural implications for an increase in the perceived size of the universe. Glass[4] refers to an instantaneous sequel:

> *Immediately afterwards Thackeray made the dramatic and unexpected announcement that he had already found RR Lyraes in the Small Magellanic Clouds and could thus confirm Baade's suggestions. This had the consequence that the true Cepheids had to be more luminous than Shapley had thought, and that therefore he had underestimated their distances. One consequence was that the universe had to be twice as large as previously believed.*

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In 1952, Shapley said that he could no longer be regarded as 'Mr Magellanic Clouds', in deference to David Thackeray and his Dutch colleague Adriaan Wesselink based at the Radcliffe Observatory.[4] Subsequently, Shapley appears to have claimed credit for doubling the perceived size of the universe. At a meeting of the American Astronomical Society he presented the 'distance scale' based on variable stars in the Magellanic Clouds and the Andromeda Nebula. The sensational but unpublicised conclusions that had initially been announced quietly at the IAU in Rome in 1952 were presented (in Shapley's name) in *The New York Times* and elsewhere. Baade took umbrage and stated that it was 'simply shameless' for Shapley to claim credit; Bart Bok stated that he 'did not like it'; and 'a concerted effort was made by leading American astronomers to make sure that the true facts became known'[4].

Dubow[5] has recently published an article on the history of astronomy in South Africa. He writes:

> *Professor David Thackeray's astronomical research extended back to 1952, when he announced at the International Astronomical Union meeting in Rome that he and Wesselink had found evidence of RR Lyrae variables in the Magellanic Clouds. This dramatic discovery revealed that the universe was double the size of current estimates – thus resolving a puzzle whereby the earth seemed to be older than the universe itself. Much of the credit for the discovery went to internationally renowned astrophysicist Walter Baade, in part because Thackeray was overly diffident in publicising his findings. It may well be that the international world of astronomy* [in 1952] *was not yet prepared to accept that fundamental scientific findings could emanate from distant South Africa. Michael Feast, whose career as an astronomer in South Africa extends over half a century of active work, summarises the overall contribution of the Radcliffe Observatory thus: 'It enabled astronomers to begin to place the study of the southern hemisphere (with its exceptional globular clusters, the Magellanic Clouds, the Galactic Centre, etc.) on a par with that of the north.'*

In 1953 and 1954, Thackeray and Wesselink[6,7] formally published the results of their combined research on RR Lyrae variables, notably in NGC 121 in the Small Magellanic Cloud (Figure 2) which had been studied by Henrietta Leavitt in 1912 in the context of period-luminosity relationships. NGC 121 is now estimated as being about 200 000 light years away, and about 10 billion years old. Even older stars are known in the Large Magellanic Cloud.

In his Bruce Medal address in Pasadena in 1955, Baade reflects the excitement of the moment at the IAU meeting in Rome[8,9], when Thackeray 'rose to announce data obtained at the Radcliffe Observatory'.

Trimble[10] refers to the contribution by both Baade and Thackeray in re-estimating the Hubble constant, relating to the expansion of the universe. Whereas Lemaitre and Hubble had initially suggested a H_0 value of between 500 and 600 km/s.Mpc in about 1925, this was essentially halved in 1952 to 280±30 km/s.Mpc by Thackeray and Baade.[10] Since then, its determination has been improved to circa 74 km/s.Mpc.

Thackeray was very modest in his accomplishments, but he is known to have said in private that he considered his announcement in Rome to have been his greatest achievement in his entire career, when he contributed to the doubling of the perceived size and age of the universe on the basis of meticulous observations of RR Lyrae variables in the Magellanic Clouds, under challenging circumstances. In 1952 at the Radcliffe Observatory in Pretoria, the precise orientation of the telescope in the direction of a star was controlled visually through the eyepiece, and glass photographic plates were developed in a dark room, prior to the advent of computerisation and digitisation. The modernised telescope continues to be used, adjacent the Southern African Large Telescope (SALT) at Sutherland in the Karoo where Thackeray was tragically killed in a road accident in 1978 at a time when he was still actively involved with research.

Image CC-BY: ESA/Hubble & NASA, Stefano Campani, 2014

Figure 2: NGC 121, a globular cluster in the Small Magellanic Cloud discovered by John Herschel in South Africa in 1835. It is now recognised as being about 200 000 light years away and about 10 billion years old. Thackeray and Wesselink[6,7] used RR Lyrae variable stars in this globular cluster to double the size and age of the universe as perceived in 1952, when results obtained from the Radcliffe Observatory in Pretoria were announced at a conference of the International Astronomical Union in Rome, supplementing data obtained by Walter Baade and Edwin Hubble who studied the Andromeda Nebula (M31) at the Mount Wilson Observatory in California. Variable stars in NGC 121 had been studied by Henrietta Leavitt in 1912 to determine a period-luminosity relationship. Harlow Shapley was able to calibrate the relationship to estimate distances of stars of variable brightness.

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Contrasting conifer versus angiosperm xylem strategies to explain the domination of the boreal forests by conifers

While angiosperm trees dominate woody floras worldwide in most ecological contexts, there is a swathe of coniferous dominated forests across northern Europe. In this short note I make the argument that this dominance is largely to do with the different xylem strategies of conifers versus angiosperms.

The general advantage of angiosperm wood is that it can increase the diameter of its vessels. However, quantitative analysis of xylem from the Great Karoo shows that when the size of vessels is constrained by cold, the wood of angiosperms begins to resemble that of conifers.

Many of these plants are described as 'root splitters', i.e. plants with wood that is prone to shear in the vertical plane. I speculate that this tendency is to do with the relative weakness of the vessel wall/fibre wall bond in angiosperms, compared to the tracheid wall/tracheid wall bond of conifer wood.

A second factor is how the xylem strategy results in a structure that is optimised to transport sap. With a few exceptions (plants growing near water for example), angiosperms dedicate only about 14% of their cross-sectional area to vessels. This fact, together with the decreasing size of vessels whose development has been constrained by cold, results in a point being reached at which the conifer, whose sap transporting elements – the tracheids which occupy close to 70% of the area in conifers – will transport more sap per unit area than the wood of angiosperms.

I speculate that, in the higher latitudes of the northern hemisphere, conifers in the cold boreal forests are outperforming angiosperms in two ways:

1. by transporting more sap per unit area and,
2. because their wood shears less in the vertical plane, they are able to grow taller and catch the lower rays of the sun.

A coniferous forest

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Basal stem area is a better measure of woodiness than canopy cover in the savannas of the Kruger National Park

Water availability, soil nutrient availability, fire and herbivory are all known to affect the abundance of trees in savannas; yet the strength of each factor is often puzzlingly variable between sites.[1-3] Woody cover in African savannas, for example, varies from <1% to >80% under similar rainfall regimes.[4] We hypothesised that part of the problem in determining how environmental factors affect woodiness in savannas relates to the difficulty of quantifying woodiness effectively.

One of the most common ways of measuring woodiness is by estimating the extent to which the canopy of woody plants covers the ground in a plot.[5] We have found, however, that canopy cover estimates frequently differ by up to 25% amongst observers in the same plot. Another method of measuring woodiness is allometry. This method is also, unfortunately, fraught with difficulty, mainly because obtaining a sufficient sample size to develop accurate allometric equations for all woody plant species in a landscape is usually not practical.[6]

In a recent study on the effects of soil nutrients on woodiness in the savannas of the Kruger National Park of South Africa, we examined two ways of measuring woodiness in 10 m by 10 m plots: firstly by visual estimation of canopy cover (%), and secondly by measuring the basal stem diameter (cm) of each woody stem. Basal stem diameter measurements were used to calculate basal stem area (πr^2) and then summed for each plot to provide a cumulative measure of total woody area (cm^2). The methods of soil sampling and analysis are described in Mills et al.[7]. All data were analysed using R statistical software.[8]

Relationships between the two different methods of quantifying woodiness and soil nutrients are shown in Figure 1 and Table 1. Both measures of woodiness were positively correlated with a wide range of soil nutrients, with the strength of correlations varying between sampling sites. Such positive correlations have been attributed to effects of nutrient availability on the growth rate, and therefore establishment, of trees.[9,10] Where growth rates are faster, it is more likely that trees will establish and not succumb to pressures such as fire or herbivory. Assuming that such causal mechanisms are taking place, it is noteworthy that there were more, as well as stronger, correlations between basal stem area and soil nutrients than between canopy cover and soil nutrients. This finding suggests that basal stem area is more appropriate than canopy cover as an index of woodiness at our study sites in the Kruger National Park. If the same applies in other savannas, measurements of basal stem diameter could be of considerable value for isolating which environmental factors have the greatest influence on tree abundance. Such information is likely to be of practical value for land managers wanting to alter the ratio of trees versus grass in a savanna environment.

Table 1: Correlation coefficients (S), *p*-values and rho estimates for relationships between basal stem area (cm^2) and soil nutrients, and canopy cover (%) and soil nutrients at the Phalaborwa ($n=32$) and Skukuza ($n=20$) study sites in the Kruger National Park, South Africa

		Basal stem area (cm^2)			Canopy cover (%)		
Nutrient	**Site**	**S**	***p***	**Estimate (rho)**	**S**	***p***	**Estimate (rho)**
Ca	Phalaborwa	3041	0.011	0.44	3484	0.042	0.36
	Skukuza	848	0.117	0.36	915	0.181	0.31
Mg	Phalaborwa	2397	0.001	0.56	3166	0.017	0.42
	Skukuza	671	0.027	0.49	1340	0.974	-0.01
Na	Phalaborwa	4698	0.448	0.14	6653	0.227	-0.22
	Skukuza	645	0.02	0.51	1550	0.484	-0.17
K	Phalaborwa	3212	0.02	0.41	4088	0.167	0.25
	Skukuza	736	0.05	0.45	1537	0.511	-0.16
P	Phalaborwa	2805	0.005	0.49	2907	0.007	0.47
	Skukuza	1063	0.396	0.20	1061	0.394	0.20
Cu	Phalaborwa	2681	0.003	0.51	2565	0.002	0.53
	Skukuza	591	0.011	0.56	1192	0.665	0.10
Zn	Phalaborwa	2779	0.004	0.49	3969	0.131	0.27
	Skukuza	882	0.147	0.34	1100	0.467	0.17
Mn	Phalaborwa	3474	0.042	0.36	3694	0.072	0.32
	Skukuza	564	0.009	0.58	1027	0.334	0.23
B	Phalaborwa	3604	0.057	0.34	4125	0.179	0.24
	Skukuza	652	0.022	0.51	1353	0.941	-0.02
S	Phalaborwa	4589	0.385	0.16	4326	0.256	0.21
	Skukuza	631	0.018	0.52	1839	0.096	-0.38
C	Phalaborwa	3299	0.025	0.40	4687	0.442	0.14
	Skukuza	840	0.11	0.37	1314	0.962	0.01

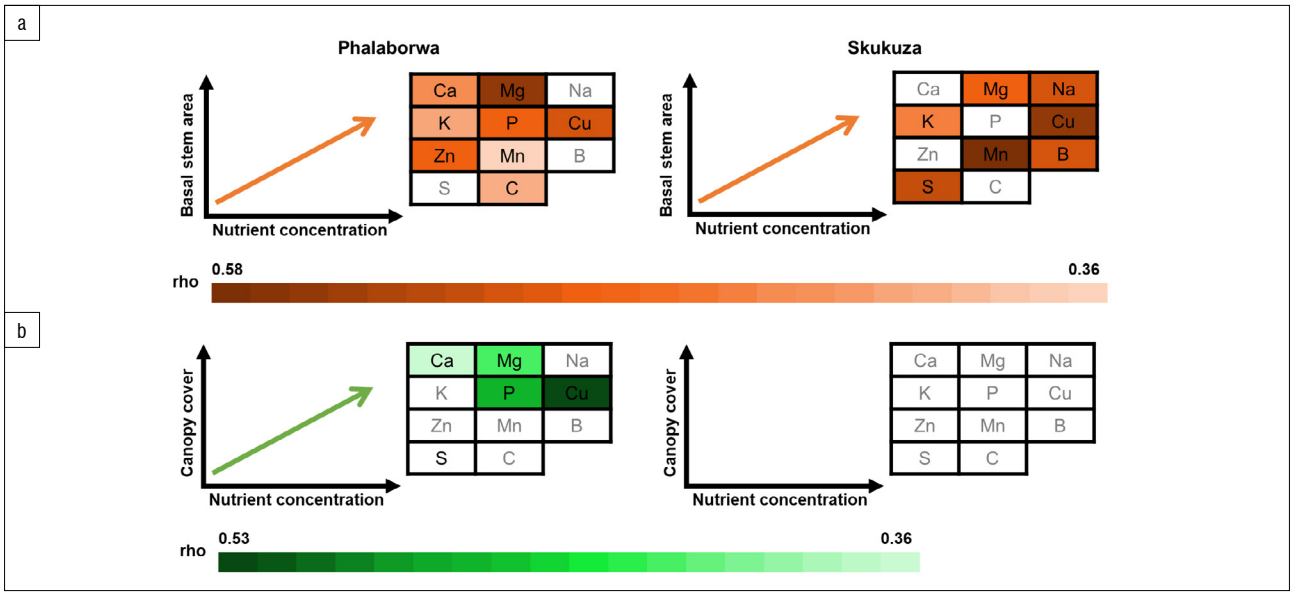

Figure 1: Significant correlations between (a) basal stem area and soil nutrients and (b) canopy cover and soil nutrients at the Phalaborwa ($n=32$) and Skukuza ($n=20$) study sites in the Kruger National Park, South Africa. Colour intensity reflects the relative strengths of the significant correlations as per the rho values.

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Proposed adaptation of the $KMnO_4$ oxidation method for determining active carbon for South African soils

One of the most widely acknowledged indicators of soil quality is soil organic matter and its elemental constituents, like soil organic carbon (SOC) and nitrogen.[1,2] However, due to the fact that soil organic matter has no definite chemical composition, SOC is more commonly estimated and reported in scientific literature.

With an ever-increasing interest in sustainability and the subsequent quality of soils, it is of utmost importance to measure sensitive indicators of soil quality. One of these indicators is active or labile carbon. This portion of the SOC is a small but relatively labile fraction and acts as fuel for the soil food web.[2] Thus the active carbon fraction could be used as an early indicator of changes in soil quality because of the influence of agricultural management practices.[3] Various methods have been published whereby active carbon can be measured. A review[4] on the then current methods was published in 2006, listing the advantages and disadvantages of each method.

A major advantage of the $KMnO_4$ oxidation method is that it is easy to perform and does not use hazardous chemicals in large amounts. There are, however, many different versions of the same method in which aspects like incubation time, amount of soil used, shaking time and manner, differ.[2,3,5-8]

The aim of this contribution was to adapt the $KMnO_4$ oxidation method for soils from different South African localities, because it was found that strictly following the protocol, especially with low carbon soils, resulted in low repeatability. The method described by Culman et al.[7] was used and adapted as deemed necessary.

Four soils from different localities in South Africa were chosen and analysed for particle size as well as organic carbon.[9] The general characteristics of these soils as analysed by the Elsenburg Analytical Laboratories are depicted in Table 1. The organic carbon varied widely between the four soil types, with Clanwilliam having the lowest (0.2%) and George the highest (4.84%).

Table 1: Characteristics of the surface soils (0–10 cm) from four locations in South Africa

Location	GPS co-ordinates	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Clay (%)	Silt (%)	Organic carbon (%)
Bethlehem	-28.1557 28.29095	2	4	68	12	14	2.22
Clanwilliam	-32.114162 18.703532	37	20	19	2	22	0.20
George	-33.978533 22.420484	4	5	67	6	18	4.84
Riviersonderend	-34.16047222 19.90427778	27	8	41	16	8	1.79

Because it was difficult to get comparable and positive results in soils with low carbon content, such as with Clanwilliam, both 5 g of soil, as was originally suggested[2], as well as 2.5 g as suggested by some other authors[7,8], were tested. Most of the methods studied were unclear as to the required positon of the tubes during shaking. The tubes with the soil samples and $KMNO_4$ were therefore shaken either in an upright or flat position on an orbital shaker at 120 rpm for 2 min as suggested by Culman et al.[7] Shaking the centrifuge tube in the flat position should result in better mixing of the $KMnO_4$ with the soil sample, thus potentially extracting more active carbon.

Each soil sample was tested, with five repeats, with both amounts of soil (2.5 vs 5 g) in both positions (flat vs upright).

The data were subjected to a three-way factorial ANOVA (soil type (4) x amount (2) x position (2) x 5 replications) using the software program Genstat 18.[10] The dependent variable (active carbon, mg/kg) was not transformed because residuals were neither skewed nor heteroscedastic.

Soils differed markedly ($p<0.001$) in their average active carbon content (Tables 1 and 2), ranging from almost 800 g/kg for carbon-rich George soil to very low carbon sandy soil from Clanwilliam (7.4 mg/kg), with Riviersonderend (221.4 mg/kg) and Bethlehem (136.8 mg/kg) soils being of intermediate active carbon content. Generally, more active carbon ($p<0.001$) was extracted in the flat than the upright tube shaking position (377.6 vs 204.1 mg/kg) and when using 2.5 g rather than 5 g of soil (301.5 vs 280.2 mg/kg). However, because all two-way interactions as well as the soil x amount x position interaction were significant ($p<0.001$), the most effective combination of position and soil amount depended on soil type (Table 2).

For Bethlehem soil, the flat shaking position produced a similar result for both amounts of soil whereas in the flat position, 2.5 g of soil yielded 435.1 mg/kg more carbon than 5 g of soil for George soil (Table 3). Flat shaking with 5 g of soil gave better results (by 80 mg/kg) than 2.5 g for Riviersonderend soil (Table 3), although this increase was not significant. Clanwilliam's sandy soil produced very low, variable and often negative results for active carbon and no method seemed to achieve acceptable results (Table 3).

Table 2: Results of an ANOVA for active carbon in different soils extracted using different methods (amount of soil and tube shaking position)

Source of variation	d.f.	*F*-value	*p*-value
Soil	3	2075.15	<0.001
Amount	1	7.75	0.007
Position	1	512.10	<0.001
Soil x Amount	3	86.88	<0.001
Soil x Position	3	30.60	<0.001
Amount x Position	1	46.43	<0.001
Soil x Amount x Position	3	46.42	<0.001
Residual	64		
Total	79		

Table 3: Means for active soil carbon content compared with post-hoc Tukey tests (means with letters in common are not different; $p=0.05$)

Location of soil sample	Amount of soil (g)	Shake position	Mean active carbon (mg/kg)	s.d.
Bethlehem	2.5	Flat	245.71^{d}	23.275
Bethlehem	2.5	Upright	2.51^{ab}	50.503
Bethlehem	5.0	Flat	223.21^{d}	19.116
Bethlehem	5.0	Upright	75.79^{bc}	18.549
Clanwilliam	2.5	Flat	-6.64^{a}	21.683
Clanwilliam	2.5	Upright	-48.48^{a}	26.394
Clanwilliam	5.0	Flat	75.46^{bc}	40.074
Clanwilliam	5.0	Upright	9.10^{ab}	2.969
George	2.5	Flat	1142.59^{g}	29.034
George	2.5	Upright	686.88^{f}	65.787
George	5.0	Flat	707.55^{f}	1.798
George	5.0	Upright	654.03^{f}	31.861
Riviersonderend	2.5	Flat	275.79^{d}	12.361
Riviersonderend	2.5	Upright	113.65^{c}	72.41
Riviersonderend	5.0	Flat	356.9^{e}	24.01
Riviersonderend	5.0	Upright	139.20^{c}	7.872

From these results, it is recommended that the tubes should preferably be shaken in the flat position in order to allow the $KMnO_4$ to properly mix with the soil sample, using 2.5 g of soil as most of the published protocols suggested. In case of negative values obtained for a certain soil, the experiment should be redone using 5 g of soil, because it was found that increasing the amount of soil resulted in more detectable values in the low carbon soils, although not significantly so.

The final protocol that gave the best repeatable results is consistent with that of Culman et al.[7], but with the tubes lying flat while being shaken. Additionally, if negative absorbance values are obtained at 550 nm, it is advised that the procedure should be repeated, using 5 g of soil and adapting the equation accordingly.

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Environmental science investigations of folk taxonomy and other forms of indigenous knowledge

The strides made in standardising English and Afrikaans frog names created a gap to achieve the same for the other South African languages spoken by the majority of the country's population. This gap hints at an exclusion of indigenous languages and associated cultures from wildlife-related matters. Frog names in indigenous languages are part of mostly undocumented cultural/indigenous knowledge systems and they are subject to indigenous naming and classification guidelines. Indigenous names often have localised use due to cultural specificity.

Indigenous taxonomy is part of a pre-scientific knowledge system which is often considered a pseudoscience. However, a recent study was able to show that indigenous amphibian taxonomy from the Zululand region of South Africa's KwaZulu-Natal Province has scientific merit.[1] Furthermore, the investigated indigenous naming and classification guidelines have similarities to those used when formulating Afrikaans, English and scientific names. A comparison with other indigenous taxonomy research shows that similarities also exist between Zululand's taxonomy and indigenous taxonomies of other parts of the world. Researchers also found indigenous names to be condensed forms of knowledge rather than abstract words.[2] Information about species' behaviour and ecology is often contained within indigenous names.[3] Linnaean taxonomy's basic structure is inspired by indigenous taxonomy's fundamental organising principles.[4]

Other investigations have shown that some traditional medicinal and gastronomic uses of organisms purported in South African indigenous knowledge systems have scientific validity.[5,6] Conversely, overexploitation of natural resources under the guise of indigenous knowledge systems has also been reported.[7,8] Cross-disciplinary research that investigates the scientific merit of indigenous knowledge systems is not meant to justify culturally motivated overexploitation. This research seeks to explore an under-investigated knowledge base while also increasing social inclusion in environmental matters. Studies of this nature are spurred on by the recent research focus on the interactions between biological and cultural biodiversity[9], and the environmental science sector's acknowledgement of the coupling of ecological and social systems[10]. Zululand's rural setting is steeped in culture and high in amphibian diversity, and thus presented the region as an ideal area to pilot a study investigating interactions between South Africa's herpetofaunal and cultural diversity.

This pilot was completed with two major outcomes. Firstly, there is merit in researching how South African cultures interact with local biodiversity (in this case herpetofauna). Secondly, it is possible to standardise the indigenous names of South Africa's amphibians and bridge the gap left by the standardisation of names in two of the country's 11 official languages. The outcomes fulfil scientific curiosity (as this is a relatively novel research field) and also contribute to social inclusion. The social inclusion begins before the actual research takes place as one has to sufficiently integrate into the community whose culture they are researching in order to understand their ways and also introduce them to the type of wildlife research being undertaken. This integration helps with being welcomed into the community and enables discussions about potential benefits to be obtained in return for allowing the survey of elements of their culture that interact with biodiversity. Social inclusion is a clear benefit from the researcher's point of view, but for the community it may be perceived as being intangible. More tangible benefits are likely to appeal to research participants. For the Zululand community, a tangible benefit was an educational publication (a handbook) based on their knowledge of amphibians in their area. The publication was translated to their own language (isiZulu) and thus presented the additional benefit of an indigenous language being developed. Indigenous knowledge relating to amphibians has also been preserved in the process.

Employing purposive sampling to collect cultural data has a greater chance of yielding results when there is minimal negativity towards the research project. The purposive sampling of 13 Zululand community members using a semi-structured questionnaire technique allowed documentation of naming and classification guidelines used for amphibians in the area. The study's sample consisted of 3 female and 10 male native isiZulu speakers whose socio-economic status varied from unemployed to full-time students and the permanently employed. The participants were from five different parts of Zululand with similar environmental conditions. Analysis of the documented guidelines revealed that Zululand's indigenous taxonomy groups amphibian species according to their habits, habitats or appearance. Scientific taxonomy conventions also group species in a similar way. Species with similar traits are placed under uninomial isiZulu names. These single word isiZulu names correspond to either scientific genera or families (Figure 1) that are also represented by uninomial names. Zululand taxonomy's use of single word names to group species based on their biology is in line with the International Code of Zoological Nomenclature.[12]

The similarities between indigenous and scientific taxonomy have enabled supplementation of indigenous taxonomy guidelines with their modern knowledge counterparts. These supplemented guidelines were then used to assign individual isiZulu names to Zululand's amphibian species (Table 1). The newly formulated isiZulu species names have a meaning that is similar to English and/or scientific names and they also retain their relevance to isiZulu speakers as they are modified from existing indigenous names. When the newly formulated names are subjected to the rigour of the International Code of Zoological Nomenclature[12], 55% conform to the principles of binomial nomenclature as each name is composed of two words with the first word being a generic name. Due to the isiZulu language's descriptive nature, the remaining 45% of names could not conform to the principles of binomial nomenclature without their meaning being altered.

[a]*IsiZulu names modified from Tarrant[11] with the assistance of Mr Bongani Mkhize.*

[b]*Name borrowed from existing English generic and common name.*

Figure 1: Zululand's indigenous amphibian taxa and their corresponding scientific taxonomy equivalents.[1]

The semi-structured interview technique fostered discussions among participants of the pilot study. Those discussions presented an opportunity to document folkloric elements of the cultural knowledge system in addition to indigenous taxonomy. There is an indication that some folklore is more than mere mythical beliefs and may constitute observations of amphibian behaviour coupled with attempts to explain the observed behaviour using available knowledge. For instance, members of the Zululand community believe that grass frogs (Ptychadenidae) bring rain as they are often seen moments before a rain event. Without knowledge of amphibian biology, the repeated observation of rainfall being preceded by the presence of grass frogs may reinforce this idea of them bringing rain. With an understanding of amphibian biology, increased activity of the grass frogs would be attributed to the humid and moderate conditions associated with rain. These favourable conditions precede rainfall and thus prompt frog activity to also precede rainfall. The indigenous taxonomy and folklore investigated in the pilot study represent a few of the many elements in the relationship between biological and cultural diversity.

Table 1: A comprehensive list of isiZulu names for frogs that occur in KwaZulu-Natal's Zululand region[1]

Isizulu name	Scientific name
Umanswininiza Onyawo Zingamafosholo	*Arthroleptis stenodactylus*
Umanswininiza Wasehlathini[a]	*Arthroleptis walhbergii*
Isele Lasezihlahleni Elinsundu[a]	*Leptopelis mossambicus*
Isele Lasezihlahleni LaseNatali	*Leptopelis natalensis*
Isinana Sasehlathini[a]	*Breviceps adspersus*
Isinana SikaBilbo[a]	*Breviceps bagginsi*
Isinana SakwaPhinda	*Breviceps carruthersi*
Isinana SaseMozambique	*Breviceps mossambicus*
Isinana SakwaNdumo	*Breviceps passmorei*
Isinana Sekhwela/Somtshingo	*Breviceps sopranus*
Ixoxo Elifishane	*Poyntonophrynus fenoulheti*
Ixoxo Elibomvu[a]	*Schismaderma carens*
Ixoxo Eliklabalasayo[a]	*Sclerophrys capensis*
Ixoxo Eliluhlaza Okotshani	*Sclerophrys garmani*
Ixoxo Lembodlomane[a]	*Sclerophrys gutturalis*
Ixoxo Lomhlane Oyisicaba	*Sclerophrys pusilla*
Isele Lasempophomeni	*Hadromophryne natalensis*
Isinana Esimabhadubhadu[a]	*Hemisus guttatus*
Isinana Esipendiwe	*Hemisus Marmoratus*
Umgqagqa Oyigolide	*Afrixalus aureus*
Umgqagqa Othambile	*Afrixalus delicatus*
Umgqagqa Omkhulu[a]	*Afrixalus fornasinii*
Umgqagqa i-Argus[a]	*Hyperolius argus*
Umgqagqa Opendiwe[a]	*Hyperolius marmoratus*
Umgqagqa Ka-Pickersgill	*Hyperolius pickersgilli*
Umgqagqa Omude	*Hyperolius poweri*
Umgqagqa Weminduze[a]	*Hyperolius pusillus*
Umgqagqa Wemigqa Ephuzi	*Hyperolius semidiscus*
Umgqagqa Oluhlaza Okotshani[a]	*Hyperolius tuberilinguis*
UKassina Wemilenze Ebomvu	*Phlyctimantis maculatus*
UKassina Obhadlayo[a]	*Kassina senegalensis*
Isele Elisanjoloba Elinemigqa[a]	*Phrynomantis bifasciatus*
Isele Lechibi Lasempumalanga Afrika	*Phrynobatrachus acridoides*
Isele Lechibi Elifishane[a]	*Phrynobatrachus mababiensis*
Isele Lechibi Elihonayo[a]	*Phrynobatrachus natalensis*
Ixoxo Elihlotshisiwe[a]	*Hildebrandtia ornata*
Uvete Olujwayelekile	*Ptychadena anchietae*
Uvete Olunomugqa Obanzi	*Ptychadena mossambica*
Uvete LwaseNile[c]	*Ptychadena nilotica*
Uvete Olunempumulo Ecijile[a]	*Ptychadena oxyrhynchus*
Uvete Olunemigqa[a]	*Ptychadena porosissima*
Uvete Olufishane	*Ptychadena taenioscelis*
Idwi Elijwayelekile[a]	*Xenopus laevis*
Idwi Lika-Müller	*Xenopus muelleri*
Isele Elithambile Elijwayelekile	*Cacosternum boettgeri*
Isele Elithambile LaKwaZulu	*Cacosternum nanogularum*
Isele Elithambile Elisathusi[a]	*Cacosternum nanum*
Isele Elithambile Elinemigqa	*Cacosternum striatum*
Isele Lase-Kloof	*Natalobatrachus bonebergi*
Isele Lasemfuleni Elijwayelekile[a]	*Amietia delalandii*
Inkunzi Yexoxo	*Pyxicephalus edulis*
Isele Lasemfuleni Elinemidwa[a]	*Strongylopus fasciatus*
Isele Lasemfuleni Eligqafazayo[a]	*Strongylopus grayii*
Isele Lasesihlabathini Elinemigqa	*Tomopterna cryptotis*
Isele Lasesihlabathini Elingqongqozayo[a]	*Tomopterna krugerensis*
Isele Lasesihlabathini LaseNatali[a]	*Tomopterna natalensis*
Isele Lasesihlabathini LikaTandy	*Tomopterna tandyi*
Usomagwebu Waseningizimu[a]	*Chiromantis xerampelina*

[a]*IsiZulu names modified from Tarrant[11] with the assistance of Mr Bongani Mkhize.*
[c]*This name was changed from uvete lwaseMaskarina to uvete lwaseNile to correspond with the scientific name change of this species in South Africa.[13]*

Other aspects of this relationship include medicinal usage, gastronomy, and traditional ecological knowledge. As a continuation from the pilot, investigations of the relationship between cultural and herpetofaunal diversity have been broadened to cover the entire country and also include reptiles. Upon conclusion of this research project it will be possible to make inferences about the state of the relationship between South African cultures and herpetofaunal diversity, and how this relationship can inform environmental policy that embraces the coupling of social and environmental systems.

Indigenous knowledge's place in science

The interaction of traditional knowledge with nature has generally been viewed to have negative environmental consequences. This view is justified by reports of environmental abuses informed by traditional knowledge.[7,8] Furthermore, the view was pervasive in environmental science as evidence of less destructive interactions was limited, but it started changing when research into the relationship between biological and cultural diversity started generating evidence to the contrary. Research solely focused on understanding the relationship between the two diversities started gaining prominence in the 1990s as a concept called biocultural diversity.[9] A systematic review of scientific literature on South Africa's biocultural diversity research shows that focus over a period of 28 years has collectively transcended more than 10 disciplines or fields of study. Some of this literature presents evidence of indigenous knowledge's applicability in human health science[5], veterinary science[14] and ecology[15]. The research presented is transdisciplinary as questions stemming from one discipline are answered using methods from another field of study. Transdisciplinarity is a critical, self-reflexive research approach relating societal with scientific problems and producing new knowledge through integration of different scientific and extra-scientific insights with the aim of contributing to both societal and scientific progress.[16] The consideration of extra-scientific insights translates to inclusion of indigenous knowledge practitioners as well as their perspectives. This inclusion is especially vital for conservation planning which often focuses on intrinsic value of wildlife protection while disregarding people who are the ultimate beneficiaries of conservation initiatives. People's perspectives have become integral to conservation planning, and failing to integrate people lessens the effectiveness of this planning.[17] In a culturally rich country such as South Africa, people's perspectives are often linked to their culture. Biodiversity is especially important to the culture of many South Africans as it features in their names, praises, folklore, art and traditional medicine. The country has a rich heritage of nature-based cultural traditions and this reiterates the importance of wildlife to the country's cultures.[18] Conservation planning that embraces the complex link between biological and cultural diversity is more likely to succeed in reducing biological and cultural diversity loss, and could potentially provide effective and just conservation outcomes across different socio-ecological contexts.[19] Socio-ecologically just conservation planning requires the knowledge pool from which it draws evidence to also embrace the link between biological and cultural diversity. The pilot study and its follow-up project as mentioned above aim to contribute to this knowledge pool through focusing on languages/cultures and taxa that are often marginalised from environmental science research.

Studying the relationship between South African biological and cultural diversity

The research required to inform appropriate environmental planning for the unique South African biological and cultural landscape should adequately embrace local contexts. A systematic review of 263 peer-reviewed articles shows this required research is succeeding in providing a greater understanding of the South African culture and biodiversity relationship, but the local context is not fully embraced due to knowledge gaps that still exist. Research focus is biased towards four of the country's nine provinces. Within provinces, research tends to concentrate on certain localities (Figure 2).

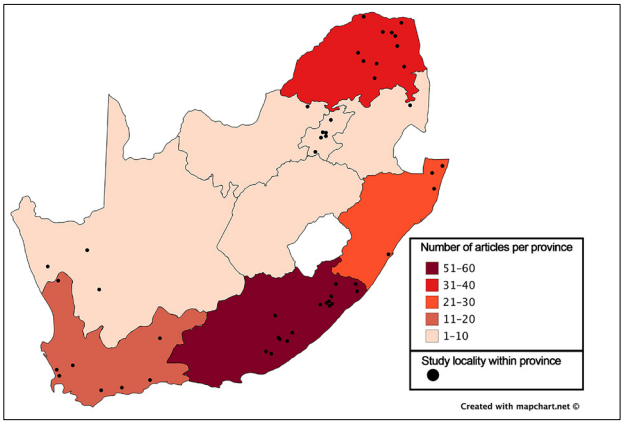

Figure 2: Distribution of biocultural diversity research within South Africa. The map plots spatial research focus (grouped by province) of 142 of 263 peer-reviewed articles published between 1990 and 2018. The remaining 121 articles have a national research focus.

Investigations of South African biocultural diversity have steadily increased from 1990, when the biocultural diversity concept gained prominence, to 2018, when the follow-up project commenced (Figure 3). Ethical consideration or the reporting thereof was only present in 74 of the 263 articles in the review sample. Without this ethical consideration

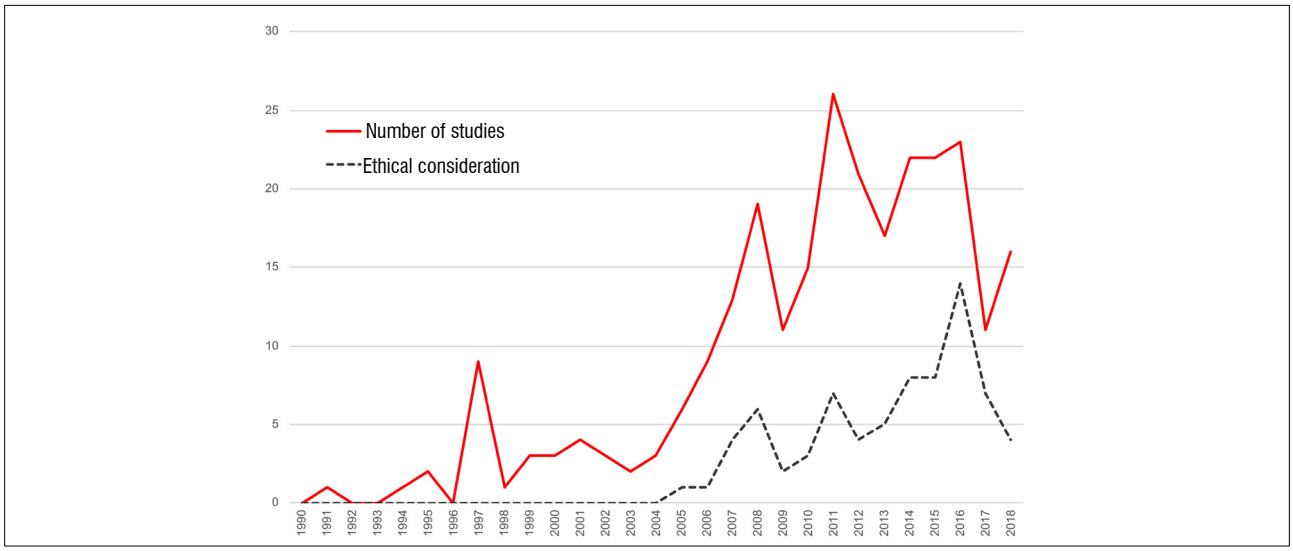

Figure 3: South African biocultural diversity literature published in 1990–2018 and the ethical considerations of these studies. The studies were searched on the Scopus database and the ethical consideration data were extracted using a pre-determined review protocol.

there is no assurance that researchers did not exploit human participants or subject non-human organisms to undue stress. The consideration of ethics began in 2005, the year before adoption of the International Society of Ethnobiology's code of ethics following deliberations that began in 1996.[20] Ethical consideration is not extended to plants which feature prominently in this research niche as they have a weaker moral standing than humans and non-human animal research subjects. Plants dominate the focus of South African biocultural diversity investigations (Figure 4). This taxonomic bias misrepresents the proportion of taxa which interact with culture. The dominance of plants is due to their importance in traditional medicine, and this results in a bias in the field of study within which investigations are carried out. Of the 14 fields of study explored in the review sample, human health science was explored in 84% of the articles. The taxonomic bias provides motivation to increase representation of herpetofauna (along with other non-plant taxa) in research so as to make the South African biocultural diversity knowledge pool more contextually appropriate and suited to informing socio-ecologically just environmental policy.

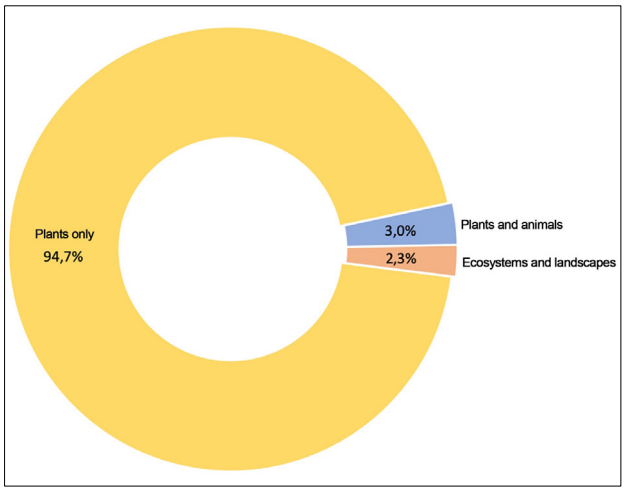

Figure 4: Taxonomic focus of South African biocultural diversity research from 1990 to 2018.

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The scientific value of UNESCO biosphere reserves

The United Nations Educational, Scientific and Cultural Organization (UNESCO) launched its Man and the Biosphere (MAB) Programme in 1971, with its 'biosphere reserve' concept instituted 5 years thereafter. The aim of the MAB Programme is to improve the relationship between people and their natural environment, and provides an explicitly people-centred conservation approach that emphasises the synergies and trade-offs between environmental 'preservation' and environmental 'use'. These synergies, i.e. linking people and nature in pursuit of development goals, are being executed in landscapes designated as biosphere reserves. Sites are listed in the World Network of Biosphere Reserves (WNBR) and organised into regional networks in order to improve networking and collaboration. South Africa is a member of AfriMAB (regional MAB network for sub-Saharan Africa) and is the current coordinator of the southern Africa sub-regional network.

The WNBR currently numbers 701 in 124 countries. All sites enable three complementary functions: conservation (of landscapes, ecosystems, species and genetic variation), sustainable development (fostering economic development which is ecologically and socio-culturally sustainable), and logistic support (promoting research, monitoring, education and training), achieved through a graduated spatial zonation of permissible use (Figure 1). Biosphere reserves have been established across a wide range of landscapes and habitats, from the largest, North-east Greenland Biosphere Reserve of 97 200 000 ha, to the diminutive 905 ha coverage of And Atoll Biosphere Reserve, part of the Federated States of Micronesia. Despite differing in size and location, all sites are operationalised according to UNESCO's global policy objectives, and therefore constitute a very valuable resource of similarly managed sites that can be used to conduct scientific research.

The Director-General of UNESCO, Audrey Azoulay, recently noted:

> *The vitality of the WNBR gives us cause for hope. Each UNESCO biosphere reserve is an open sky laboratory for sustainable development, for concrete and lasting solutions, for innovation and good practices.*

Her statement underscores the value of the international biosphere reserve network, especially in places where sustainability science could be practised and showcased.

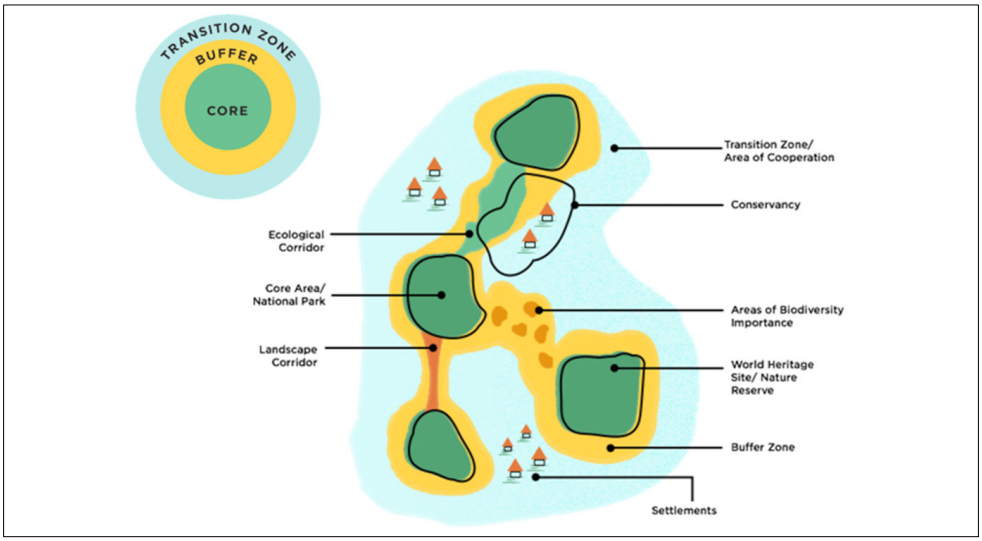

Figure 1: Schematic spatial layout of a typical biosphere reserve

UNESCO Guidelines for biosphere reserves

All biosphere reserves are directed by dedicated UNESCO guidelines, the first of which was the Seville Strategy and Statutory Framework of the WNBR in 1996.[1] New guidelines were released in 2017, namely the new global MAB Strategy and associated Lima Action Plan (LAP).[2] With the LAP's entry into MAB's policy space, the contribution of biosphere reserves to implementing the global Sustainable Development Goals (SDGs) as well as other multilateral environmental agreements including the Aichi Biodiversity Targets, was emphasised. Specifically, MAB's mission highlights the role of research

> *to help member states to urgently meet the SDGs through experiences from the WNBR, in particular through exploring and testing policies, technologies and innovations for the sustainable management of biodiversity* [...] *and adaptation to climate change.*[2(p.16)]

In line with Strategic Objective 3 of the global MAB Strategy, each biosphere reserve is expected to have an active research programme based on sustainability science,[2(p.19)] and in the LAP, member states and individual biosphere reserves are encouraged to use the sites as observatories for climate change research, monitoring, mitigation and adaptation. Specific mention is made of research in terms of biosphere reserves as social-ecological systems. Action A1.6 of the LAP specifically notes that member states should 'undertake research and ensure the long-term conservation of the socio-ecological systems of biosphere reserves'[2(p.36)]. Research to support the

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management of biosphere reserves is addressed in detail in Outcome A4 and emphasises good practices for sustainable development and partnerships with tertiary institutions.[2(p.38)] Joint research agendas and collaborative research in general is mentioned as actions of regional networks such as AfriMAB.

Clearly, research and innovation is required in order to assist countries in meeting the requirements of the SDGs. However, Nakamura et al.'s[3] recent analysis of research activities related to the SDGs indicates that Africa is a small participant in SDG-related research, despite the fact that achieving the SDGs is of critical concern on the continent. Biosphere reserves specifically contribute towards SDGs 1 (No Poverty), 4 (Quality Education), 5 (Gender Equality), 8 (Decent Work and Economic Growth), 10 (Reduced Inequality), 13 (Climate Action) and 15 (Life on Land). This suggests a pressing research opportunity across the AfriMAB network to contribute to sustainability science as per requirements of the global MAB Strategy.

South African biosphere reserves

South Africa has 10 designated biosphere reserves (Kogelberg, Cape West Coast, Waterberg, Kruger to Canyons, Cape Winelands, Vhembe, Gouritz Cluster, Magaliesberg, Garden Route and Marico), with the first designated in 1998 and the most recent in 2018 (Table 1). They are located in six of South Africa's provinces (Limpopo, Mpumalanga, Gauteng, North West, Eastern Cape and Western Cape) and collectively cover 115 732 km^2, approximately 9.5% of South Africa's total land area. Although this figure includes statutory conservation areas as biosphere reserve core areas, it is clearly not insignificant in the greater national system of landscape protection.

Table 1: Biosphere reserves of South Africa

Biosphere reserve	Province(s)	Year of designation	Total size (ha)
Kogelberg	Western Cape	December 1998	103 629
Cape West Coast	Western Cape	November 2000	387 000
Waterberg	Limpopo	March 2001	417 406
Kruger to Canyons	Limpopo and Mpumalanga	September 2001	2 608 000
Cape Winelands	Western Cape	September 2007	322 032
Vhembe	Limpopo	May 2009	3 044 163
Gouritz Cluster	Western and Eastern Cape	June 2015	3 187 893
Magaliesberg	North West and Gauteng	June 2015	357 437
Garden Route	Western Cape and Eastern Cape	June 2017	698 363
Marico	North West	July 2018	447 269

Unlike statutory protected areas, biosphere reserves in South Africa are not enforced through legislation, but instead implemented in a 'soft law' spirit through collaboration between the biosphere reserve management entities and major stakeholders and role players.[4] By establishing these relationships, biosphere reserves enable more defensible socio-political decision-making. In a country where the concept of 'conservation' is often associated with enduring resentment due to a socio-political history of marginalisation, exclusion, and ethical injustices,[5] the MAB model's values of collaborative thinking and decentralised decision-making have additional relevance.

South Africa's biosphere reserves are currently guided by the Strategy for the Biosphere Reserve Programme (2016–2020).[6] This specifically notes the value of partnerships at multiple scales, as the strength of a biosphere reserve lies in its ability to interact with local actors – of which research institutions are considered key – around a shared vision for landscape management. The Implementation Plan and Monitoring and Evaluation Framework associated with the Strategy, list specific criteria for the designation and evaluation of biosphere reserves that inter alia refer to the value of having biosphere reserves, especially core areas, listed as long-term study sites for climate change research and monitoring.[7] The Strategy also emphasises the general research role of biosphere reserves and the value of joint research agendas with tertiary institutions. The intention is that, coordinated effectively, biosphere reserves have the potential to assist the country towards meeting its international commitments in terms of the SDGs and the Aichi Biodiversity Targets, as well as the implementation of national priorities such as the National Development Plan.

Scientific value of biosphere reserves

People's lives are intertwined with natural ecosystems and this interconnectedness plays out in landscapes realised as social-ecological systems. The complex dynamics between humans and environmental systems are studied in the relatively new field of sustainability science.[8,9] However, the MAB Programme has been the embodiment of sustainability science from the onset,[10] arguably decades before this discipline gained prominence in the academic scholarship. One of the founding directions noted by the Seville Strategy was to 'reinforce scientific research in biosphere reserves'[1(p.5)]. With time, the WNBR became a global network for interdisciplinary research – one that is albeit still underutilised – and thereby in effect, became the test case for applying sustainability science in different contexts.[10] Biosphere reserves by their nature are multi-use landscapes, managed as complex adaptive social-ecological systems.[4,11] They were initially positioned as a research network of permanent field sites[12] – sites at which the impacts of cross-scale social, economic and ecological interactions, and the consequences of ecological, social and political legacies of the broader landscapes can be assessed[11].

A literature review on research related to biosphere reserves[13] indicates a steady increase in scientific output since the mid-2000s. Although most of these research outputs took place in biosphere reserves, they were 'not *about* biosphere reserves'[13(p.46)]. Pool-Stanvliet and Coetzer[4] identified two types of research relating to South African biosphere reserves, namely focused research on the implementation of the MAB Programme, and then research on a very wide range of topics for which biosphere reserves are used as study sites. The strengthening of different forms of research, including empirical research on the MAB Programme in itself, is important within the network of biosphere reserves.

A few attempts have been initiated as platforms for exchanging biosphere reserve research and as a home for knowledge on research conducted in biosphere reserves, e.g. BiosphereSmart, an online, global observatory created to share ideas and knowledge; the Biosphere Research Platform facilitated by C-BRA[14]; BRInfo, the Biosphere Reserve Information-sharing Portal; the database hosted by the *International Journal of UNESCO Biosphere Reserves*; and the Western Cape UNESCO Biosphere Reserves Research Portal. However, these platforms have yet to gain widespread traction as knowledge-sharing implements. Regardless, these attempts are in line with Strategic Action Area D of the LAP which emphasises transparent information and data sharing.

To illustrate the scientific value of South African biosphere reserves, we present two examples: Kruger to Canyons Biosphere Region and Vhembe Biosphere Reserve.

Kruger to Canyons Biosphere Region

Kruger to Canyons Biosphere Region (K2C) straddles Limpopo and Mpumalanga Provinces, covers 2 608 000 ha and was designated by UNESCO MAB in 2001. Scientific research is embedded in K2C, with the inclusion of the SAEON Ndlovu node that focuses on the Savanna Biome. The K2C team has identified 'sound research' as one of the responsibilities of the biosphere reserve. The Board of Directors is supported by a Representatives Council that hosts, amongst others, a task team on research.

A basic literature search for published papers specifically mentioning K2C as a study site reveals a long list of tertiary institutions from numerous countries, including (but not limited to) Australia, Canada, France,

Germany, Hungary, South Africa, the United Kingdom, and the United States of America. The fields of research are broad and cover climate change, biodiversity, and ecosystems, to social systems and resilience.

Being active in the research field, K2C has numerous connections to tertiary institutions and it benefits greatly from these collaborations through being exposed to alternative funding sources. Postgraduate students produce research that could be used to inform adaptive management in the K2C to improve effectiveness of the biosphere reserve.

Vhembe Biosphere Reserve

Vhembe Biosphere Reserve (VBR) in Limpopo Province comprises 3 044 163 ha and was designated in 2009. VBR is a vibrant landscape for scientific research and hosts a number of private research centres as well as the University of Venda.

The University of Venda is home to the South African Research Chair on Biodiversity Value and Change in the Vhembe Biosphere Reserve, and provides scientific support to administrators, politicians and biosphere reserve managers through applied research related to the challenges facing the biosphere reserve. The Research Chair is co-hosted by the Centre for Invasion Biology at Stellenbosch University which is a hub for biodiversity science, training and conservation application in the Southern African Development Community.

Work of the Research Chair contributed inter alia towards an effective environmental management plan for VBR. Collaborations of the Research Chair with VBR and the Limpopo Department of Economic Development, Environment and Tourism, have ensured that biodiversity and its ecosystem services have been adequately mapped and integrated into conservation planning at local and provincial levels.

Here, a basic literature search for published papers specifically mentioning VBR as a study site revealed an equally long list of tertiary institutions being involved with scientific research. Similarly, the fields of research were very broad, including insects, spiders, mammals, vegetation, conservation planning and social studies.

VBR reaps benefits from these valuable collaborations. Research outputs increase the visibility of the biosphere reserve and also contribute to greater awareness of the VBR and its work within the respective social-ecological landscape.

Other South African biosphere reserves

All South African biosphere reserves support and promote scientific and transdisciplinary research collaborations with tertiary institutions. The Gouritz Cluster Biosphere Reserve (GCBR) in the Western Cape Province is another example. The collaborative Jobs for Carbon project (J4C) is an innovative, flagship initiative combining job creation with biodiversity conservation. J4C has been included as a case study in a paper on climate change mitigation and ecosystem restoration.[15] GCBR greatly benefits from exposure through the J4C. The project is resulting in job creation, skills development, landscape restoration, alternative funding streams and an increase in the quality of life of local communities. Toerien[16] uses the GCBR as a case study that, for the first time in South Africa, has provided a quantitative picture of enterprise development and dynamics in a biosphere reserve.

Garden Route Biosphere Reserve (GRBR) in the southern Cape straddles the Western Cape and Eastern Cape Provinces. The George Campus of the Nelson Mandela University is located within the biosphere reserve. GRBR is being studied as a complex social-ecological system and used as a site for sustainability research, driven by the Sustainability Research Unit. This unit has conducted considerable research on topics such as biodiversity inventories, ecosystem services, management regime shits, resource governance, stewardship and systemic change, to name but a few.

Conclusion

From the time of its inception, scientific research has been intrinsic to the MAB Programme. Biosphere reserves have a responsibility to promote and support interdisciplinary and transdisciplinary research that is relevant to society. The complex interaction between people and the natural environment is embedded in biosphere reserves and it is this interconnectedness that drives sustainability science. Biosphere reserves are therefore ideal, scientifically sound platforms that can be used for understanding social-ecological systems,[17] with Strategic Action Area A of the LAP placing biosphere reserves firmly at the interface between science, policy and society.

Biosphere reserves are 'learning sites for sustainable development', where the security associated with the UNESCO designation and the domestic political support that accompanies a nomination is of considerable importance.[18] The LAP specifically acknowledges the WNBR as 'an integrated global network of learning and demonstration sites for innovation in sustainable development'[2(p.22)]. Yet despite this acknowledgement, biosphere reserves are still very much underutilised as global transdisciplinary study sites.

Critically important to biosphere reserves is the international affiliation with UNESCO. Being part of the WNBR carries a wealth of international recognition and access to expertise, thereby facilitating the process of requesting funding from international institutions. Given the increased competition for an increasingly limited number of research grants,[19] such endorsement from UNESCO, *and* the public–private partnerships that the biosphere reserves management entities curate, has considerable added value.

We have presented a brief overview of South African biosphere reserves, emphasising their value as scientific research arenas. They are ecological and cultural depositories where the interconnectedness between humans and the natural environment is evident, and where scientific research focusing on this human–environment interface should be promoted and supported.[10,20]

We foresee a future where biosphere reserves individually and the WNBR collectively would be fully utilised as a valuable platform for interdisciplinary and transdisciplinary research. Doing so would contribute to realising the vision of UNESCO's Director-General that they be acknowledged as open sky laboratories for sustainable development.

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The emergence of green bonds as an integral component of climate finance in South Africa

One of the greatest challenges facing the global community is climate change.[1] Over many years, global leaders have embarked on various platforms in a concerted effort to combat climate change.[2] One of the key platforms has been the annual Conference of the Parties (COP) – a regular meeting in which climate negotiations and high-level political discussions have taken place.[2] In 2015, the 21st COP was the most important because 195 countries agreed to ensure that rising global temperatures do not exceed the safe zone of 1.5 °C, as it is forecasted that temperatures will continue beyond this value between 2030 and 2050 if no action is taken to combat climate change.[3] The parties further agreed that climate investments for countries are critical to make enormous transformational changes to reduce their greenhouse gases by scaling up climate adaptation and mitigation strategies.[3]

Developing countries are at a crossroad because they are the most vulnerable to the impacts of climate change and they are highly dependent on climate finance from developed countries in order to finance climate adaptation and mitigation projects.[4] The Climate Funds Update is one of the largest databases on multilateral climate finance initiatives and the Green Climate Fund set up by the United Nations Framework Convention on Climate Change (UNFCCC) in 2010 has now become the largest climate fund for developing regions such as sub-Saharan Africa, Asia and the Middle East.[4,5] However, there have been challenges facing many developing countries that have tried to access this finance. These challenges arise because developing countries have difficulties in the design and co-ordination of projects due to a lack of effective institutions and expertise.[5] This also creates challenges in the planning and coordination of projects.[5]

Furthermore, a 2018 report by the World Bank on climate finance, estimated that more than USD200 million per annum will be required for each developing country to have proper strategies and capacity-building frameworks to build resilience against climate change.[6] It is therefore important that, in order to meet their commitments to the Paris Agreement, developing countries explore other finance opportunities for climate mitigation or adaptation strategies, of which green bonds are one.[6]

The emergence of green bonds has been explosive over the years as an innovative manner in which to mobilise private capital towards investing in 'green' projects.[7] Green bonds have been considered an integral component of climate finance because they appeal to investors who can reap financial benefits whilst also playing a role in investing in environmental and climate-related projects.[7] Green bonds have also appealed to the public sector, where governments and municipalities have begun to issue green bonds to meet their climate-change commitments by implementing their adaptation and mitigation strategies.[7] To date, South Africa is one of only a few African countries that have been active in the green bond sphere.[8] Both the public and private sectors have issued green bonds – the proceeds of which have gone into renewable energy such as wind and solar projects, energy-efficient buildings as well as low-carbon infrastructure, e.g. low-emission vehicles and electric buses.[8]

In view of the above, green bonds are analysed here as being an integral component of climate finance in South Africa, with both the public and private sectors involved.

Green bonds: A new source of climate finance

Green bonds have emerged as one of the most innovative and promising climate finance mechanisms internationally.[8] The green bond market has had exponential growth of 92% over little more than a decade with a few green bonds purchased from its establishment in 2007 to more than USD200 billion worth of green bonds purchased in 2018.[8] Owing to increasing awareness of the benefits of green investments, the first green bonds to be issued were by international development institutions such as the World Bank, the International Finance Corporation, and the European Investment Bank.[8] Since then several commercial banks, municipalities, governments as well as large investment companies have issued green bonds to support and enable the transition towards a low-carbon society.[8,9] This is because green bonds fund projects that contribute to reducing carbon emissions such as renewable energy, sustainable agriculture like eco-farming, as well as climate-resilient infrastructure.[9]

Green bonds have been defined in various ways. Banga has argued that there is 'no universal definition of green bonds, although a growing consensus has emerged on what they are intended to do'[10(p.18)]. Here we use the World Bank's definition of a green bond: 'a debt security that is issued to raise capital specifically to support climate-related environmental projects'[11(p.23)]. The unique feature of green bonds is that, for the first time in capital markets, there is an actual bond in which proceeds are invested in projects that will bring environmental benefits.[11] The Climate Bonds Initiative is a non-governmental organisation located in London that assists governments and investors internationally to issue green bonds and assists in certifying eligible green projects.[9] The Climate Bonds Initiative has a selected taxonomy of the range of projects supported by green bonds.[9] This is very diverse and can cover renewable energy, low-carbon transport, green buildings and infrastructure, as well as improved water efficiency.[12] However, it is unlikely that this taxonomy is exhaustive and inclusive because it is anticipated that, as the green bond space grows, more eligible green projects will be included.[13]

Ameliorating climate change is now considered a huge investment opportunity and investor appetite for green bonds has grown rapidly.[14] In the developed region of the world, the growth of green bonds is visible, with Europe and the USA leading the way.[10] This growth has been supported by governments and various investors to whom climate awareness and climatically responsible investments has become a priority in terms of international agreements.[8] By contrast, in developing regions, the green bond market has been relatively small, and there is certainly potential for growth.[8] In emerging markets, including countries in Asia, Africa and Latin America, the issuing of green bonds is increasing steadily.[14]

Climate finance systems and green bond opportunities in South Africa

The 2018 Intergovernmental Panel on Climate Change Special Report that came out of COP24 in Katowice, Poland, has projected that an increase in global temperatures will be detrimental for the sub-Saharan region.[15] In particular, South Africa is considered to be one of the hotspots of climate change[16], with increasing drought periods and resulting water shortages[17]. Climate change has affected broader South African society and the economy.[18] Figures are instructive: the prolonged drought from 2014 to 2017 resulted in a decrease in GDP because of the impact on agricultural production.[19] Moreover, and this remains to be seen in the policy arena, the consequences of climate change have accelerated the need to enforce national policies and consider strategies to build social, environmental and economic resilience. Climate adaptation and mitigation strategies are reflected in various policies and strategies, such as the Draft National Climate Change Adaptation Strategy (2019)[20] as well as the National Climate Change Response White Paper (2011)[21].

As part of the Nationally Determined Contributions, which are long-term climate plans to reduce emissions developed by each country at the Paris Agreement, South Africa has established various climate finance systems since 2011 for climate adaptation and mitigation projects.[22] These include climate finances from development agencies like the World Bank, the International Finance Corporation and the African Development Bank.[22] These climate funds have supported a range of renewable energy projects as well as climate-resilience projects such as developing community early warning systems for floods and droughts as well as climate-resilient agriculture such as multi-cropping and rainwater harvesting for crops.[22] It is only since 2014 that green bonds were implemented as a climate finance system in the country by municipalities and companies in the private sector.[23] The difference between these climate funds and green bonds is that the latter has a specific range of projects that would potentially be funded by investors from different sectors and allow investors an opportunity to benefit from these projects.

Furthermore, the Green Climate Fund (GCF) – which is a climate finance fund established under the UNFCCC designed to help developing countries reduce their greenhouse gas emissions – has been the largest source of climate finance.[24] This fund was set up in 2010 in which more than USD10 billion of climate finance has been committed for more than a 100 projects.[24] These projects include climate adaptation and mitigation projects from a local, national, regional and international level.[24] In partnership with the Development Bank of South Africa's (DBSA) Climate Finance Facility, the GCF has raised funding of over USD5 billion for adaptation and mitigation projects across the country including the GCF–DBSA Embedded Generation Investment Programme to support the implementation of renewable energy projects.[24] Other local projects include building capacity for the South African National Biodiversity Institute through the Ecological Infrastructure for Water Security Project.[25] This project is currently being piloted by the uMngeni Catchment in KwaZulu-Natal where local communities will be involved as a way to create employment and address current environmental issues.[25]

Despite some successes, there is increasing concern that these climate finances are not enough. The Department of Environmental Affairs[24] noted that over the years international climate finances have declined and developing countries have had to shift to using their own financial resources, thereby easing their reliance on outside aid. A further hurdle is the absence of political will and the unwillingness to implement policies and strategies that have discouraged outside investment.[25] In South Africa too, there is a lack of transparency and accountability as to how the money has been spent that has become of concern to the international community.[24,25]

Far too little attention in South Africa has been paid to other mechanisms within the country, including green bonds. These may well become integral to finance climate change projects and there are already numerous success stories. For example, the first South African green bonds were issued by the City of Johannesburg in 2014 (worth ZAR1.46 billion) and the City of Cape Town in 2017 (worth ZAR1 billion).[23] Green bonds have also given the two cities an opportunity to be up to date with the current world strategy on the implementation of green financing and green projects in cities.[23,26]

Green bonds differ from other climate finances such as those in the international arena in that they not only attract the private sector but also encourage environmental awareness. The Johannesburg Stock Exchange has set up a green bond segment which has been well received and companies such as Growthpoint Properties have issued green bonds for energy-efficient buildings.[27,28] Moreover, Nedbank is just one example of a commercial bank in South Africa that has issued green bonds for renewable energy investments.[28]

The green bond trajectory in South Africa

Climate finance mechanisms in South Africa need to be adapted to include new emerging mechanisms and this process seems to be occurring. Enabling transformative changes towards a low-carbon country will effectively require large financial resources. Green bonds have proven to be an effective climate finance mechanism globally, and their adoption within existing national financial structures looks promising, even for developing countries like South Africa. If provided with the opportunity to expand – given strong and effective institutions, multiple stakeholders involved as well as proper planning and coordination – green bonds may become an integral component of climate finance for South Africa and fund a range of environmental and climate-related projects.

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'Twelve Years Later: Second ASSAf report on Research Publishing in and from South Africa (2018)': Some issues arising

Responding to the extraordinary challenges facing publication in the digital age is the holistic view taken by the Academy of Science of South Africa (ASSAf) on threats and opportunities that characterise this conjuncture. *Twelve Years Later*, researched by Wieland Gevers, Robin Crewe and Susan Veldsman on national publishing strategies, provides the 'nuts 'n bolts' that every researcher should know in order to navigate the changing environment.[1]

The Report examines both past and present. The first chapter reviews ASSAf's 2006 report.[2] Chapter 2 revisits the 2009 report on books. Chapter 3 details ASSAf's Scholarly Publishing Programme between 2007 and 2018. How to enhance access of South African authors to global commercial publishers is discussed in Chapter 4. Chapter 5 deals with journal and book publishing, and Chapter 6 examines pitfalls and threats to good publishing practices. Outstanding problems are highlighted in Chapter 7. Chapter 8 offers recommendations. Appendices (45 pp) tabulate the hard data on which the study draws. These data showcase close correlations between the ASSAf qualitative evaluations and Department of Higher Education and Training (DHET) decisions. Significantly, ASSAf ratings and reviews of publishers closely align with the international Socio-economic and Natural Sciences of the Environment (SENSE) and the Norwegian Register for Scientific Journals, Series and Publishers ratings.

The 2018 Report offers a detailed history useful for individual university policy planning, and implementation of monitoring mechanisms, and explains accreditation decisions.

A basic cost–benefit analysis of the publication incentive system administered by DHET identifies residual problems. Notwithstanding these (see below), the statistics tabulated in Appendices by the Centre for Research, Evaluation, Science and Technology (CREST) at Stellenbosch University reveals that DHET has been very effective in encouraging publication. It has also acted as an inhibiting factor in author choice of predatory journals, although many thousands of articles still slipped through.[3]

A nuanced analysis of the usefulness or otherwise of impact factors, and the differences that exist between books and journals and high-citation and low-citation disciplines, is provided (pp 4, 18). This section cautions the current moves by some universities that apply impact factors to rank internal disbursements of publication incentives.

As the well-written Report is easily available, I now engage some of the Report's assumptions in the interests of further discussion. Thus, before moving to the Report's preference for SciELO, the Scientific Electronic Library Online, the pros and cons between traditional and open access (OA) routes are debated.

The traditional journal publishing route, managed by international firms, is questioned in the Report for high gatekeeping by a limited group of stable journals per subject field. This gatekeeping has, however, secured high-value benefits regarding academic quality, services, and widened author impact. The traditional publishing model helps to assure quality, but the Report observes that it also restricts output and raises price. In contrast, OA enables greater quantity and zero price for readers. The OA pay-to-publish approach, however, does generate information costs due to the high number of journals with varying levels of quality (p. 133). A recurring lament relates to unacceptably high subscription costs levied by the traditional route to libraries (with Elsevier being the exemplar). An additional cost that is often forgotten in criticisms of journal publishing companies, however, is the recent levying of VAT on digital materials, which contributes to precipitous cost escalations (p. 49).

The traditional model provides incentives for quality through scholarly associations that manage journals and own copyrights. The advent of OA created new possibilities for for-profit publishers and introduced the potential for imperfect information and fraud. A for-profit OA business incentivises the acceptance of articles without regard to quality or accuracy.[4] Not discussed by the Report, although buried within the statistics listed in the Appendices, are journals not linked to disciplinary associations or the corporate sector, but which are rather associated with universities and independent publishing collectives.

In comparison with the traditional model, less stability exists among OA journals in that they are 'free', lack a subscription base, and can move quickly in and out of the market, thus rendering them unstable as an information source. This pay-to-publish model places the cost burden on authors, while upfront payment may incentivise journals to publish more manuscripts, merely to attract increased income. This conflict leads to quality concerns and to the allure of predatory journals as is indicated in some local instances in the Report (Chapter 5).

In short, the traditional publishing model assures quality but restricts output and raises the price. The state-supported SciELO project, however, aims to maximise the net benefit of technological change by taking advantage of the efficiency offered by OA while preventing the market failures that result when shifting from the traditional model. This requires that journals minimise costs, provide optimal quantity (i.e. increase output and access to that output), and lower the price, while maintaining quality. Ultimately, all parties involved in scholarly publishing (e.g. associations, academia, publishers, accrediting bodies, libraries, authors) will need to respond to such transformations of the scholarly publishing market.

However, the SciELO platform is just one model – other OA models include institutional repositories, Open Journal Systems, and delayed open access (although the Report has its doubts on this front [p. 127]). The main challenge of a project like SciELO is to develop an internally sustainable business model – as implied in one passing remark (p. 40). SciELO is dependent on public funding and government priorities may change without long-term guarantees. To a large

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extent, SciELO is less a journal publisher than it is an aggregator – SciELO provides a platform for many journals. The question, then, is how much value is added when browsers are required to access articles through the journal's own website maintained at the journal's own expense? Publicly funded OA journals cannot easily compete with larger commercial publishing channels that continuously optimise metrics, redesign journal web pages for ease of access, and apply new technologies immediately they become available. Such firms also apply marketing strategies that leverage the full range of articles published.

The Report asserts that: 'global visibility of local journals can undoubtedly best be optimised by open access publication' (p. 132). While it is possible that an OA citation advantage exists over traditional publishing, its magnitude is (currently) small. Other benefits of publishing OA include increased downloads, especially by non-academic readers, but claiming a citation advantage for OA is not based on reliable evidence.[5] Many studies on OA are observational, and evidence a strong self-selection effect that is difficult to measure. Authors may choose to make their best work OA, and, if so, they are more likely to be located at well-funded institutions in the North Atlantic. This means that the population of OA articles observed may be more citable than the non-open access articles for reasons unrelated to their accessibility. For example, when newly accepted articles in 36 physiology journals were randomly assigned to a 'treatment' group and published open access, or a control group and published on a subscription basis, no OA citation advantage was found over a 3-year period, although the OA articles did receive significantly more downloads than did the non-OA articles. As Davis concludes, 'the real beneficiaries of open access publishing may not be the research community but communities of practice that consume, but rarely contribute to, the corpus of literature'[6]. That is, the likely readers – professionals – are not necessarily other researchers. Unlike university performance indicators that assume an incestuous hermeneutic in-group self-referentiality, the authors of the ASSAf Report sensibly argue that 'readers' are constituted as the key wider targets of publication. That is, readers and how they apply published studies in their respective professional sectors are actually more important than are citation listings.

The largest journals companies are adopting hybrid approaches by offering select OA options (delayed OA/embargo options, discounts for Africa, etc.). A cautious approach would adopt either a hybrid approach, or a criteria-specific approach and prefer OA journals publishing only. The SciELO platform is not yet an OA market leader, and an analysis of its metrics between 2007 and 2016 reveals that while Chile and South Africa's use of SciELO is on an upward curve, Brazil, Mexico, Argentina and Colombia's memberships curve downwards from 2014 onwards. Furthermore, SciELO is regionally/language-biased in terms of its impact and reach.

The issue is not whether SciELO is the only model to be supported, but rather that the principles and goals of wider access, better distribution, and visibility for African research are appropriately leveraged across all publishing models and sites.

Other models

Subvention presses, like author-pays OA publishers, consider their main customer to be the author rather than readers. The Report does list some subvention book presses and practices that might become a feature of publishing, but it does not discuss the implications of pay-to-publish over traditional publishing economics where the publisher invests capital and takes the risk.

The funding gap in the journals and book publishing value chains remains unaddressed, save for a few comments in the Report. Universities and authors are cash cows for under-funded journals and financially strapped presses. The weak link in the value chain is the lack of state funding for journals that enable the DHET system. Implicitly, the Report addresses rent-seeking activity on the part of authors but not by universities who put their staff under extreme pressure to publish.[7] The Report states that 'The financial viability of journals should be guaranteed through a reliable and sustainable set of revenue streams' (p. 3), but it does not explicitly tie the DHET incentive into one of these streams (which journals try to secure through article processing charges). The journals recognised but not funded by DHET carry the cost of the whole system, regardless of whether they are on SciELO. As a funded operation, digital development of the *South African Journal of Science*, for example, required expanded capacity in the form of a digital publishing administrator (p. 38). Also, the imposition of a tax on electronic services and worsening exchange rates have affected the journal (p. 39).

The UNISA Press – Taylor & Francis partnership model is assumed by ASSAf to be 'commercial'. This partnership arose during the mid-1990s as a developmental project initiated by the South African National Research Foundation and UNISA Press with the British predecessor to Taylor & Francis, Carfax, then a new specialist journal publisher. The objective was a viable business model that would integrate a selection of appropriate South African journals into the international scene while retaining their DHET accreditation; this collaboration has proven very successful across a range of journals and disciplines.

That said, many opportunistic commercial operations – whose modus operandi have been to rapaciously milk the DHET incentives – are identified in the Report. Perhaps – no matter the author or discipline – publication incentives might be capped to, say, 10, annually, thus putting a brake on the expansionary rent-seeking behaviour of the authors/editors (Section 2.3, p.33). A cap might also reduce opportunistic publishing, especially in the cash cow local journals identified by CREST's statistical surveys. Top researchers in high volume disciplines will continue to publish over and above this cap as there are intrinsic rewards to be gained over and above the DHET incentive.

Editorial misconduct

The ASSAf critique of misconduct largely relates to 'unacceptable publication intensity' (p. 93–96), involving editors who publish only or mainly and excessively in their own journals and who exhibit or engage in cartel behaviour in which two or more individuals (sometimes also members of the editorial board) co-author repeatedly in the same journal (p. 93–96). ASSAf has been flagging this concern for a number of years. However, there are instances when editors of trustworthy innovative journals aim to facilitate paradigm shifts, for which editor or guest edited theme issues are perfectly positioned. Bona fide journals can also function to shape entire fields, with work enabled by their editors and their boards over medium-to-long periods of time. Flexibility is suggested in assessing such situations on a case-by-case basis. In this regard, the Report observes that mega online journals like *PLoS ONE* 'have dispensed with the requirements for novelty and notability and retained only that of methodological soundness as judged by peers' (p. 119–120). While such cascading reiteration might be useful in the medical sciences, for the social sciences *PLoS ONE* type journals become a conveyer belt: the principle of 'novel plus notable' or repetition with difference does not necessarily apply and quantity prevails over quality and conceptual innovation.

Editorial, author, and journal misconduct also includes author misdemeanours like 'ghost', 'gift' and 'sale' of authorships (p. 117–136). In my own experience, to these could be added editors who are bullied by authors to fast track submissions or to publish articles despite negative peer reviews. Also perplexing is the publishing of original manuscripts without any peer-reviewed recommended revisions, which occurs when editors fail to exercise due oversight.

Residual problems

Chapter 7 on 'Problems Still Facing Scholarly Publishing' concludes that the 'research publishing system' has performed exceptionally well despite the incomplete reforms mooted in the 2006 report. As the 2018 Report concludes, 'economies-of-scale publishing houses are potentially major players in the rejuvenation of an over-large and somewhat static local journal publishing system' (p. 129). Included in the drivers of this has been the UNISA Press/NiSC/Medpharm/Taylor & Francis co-publishing model, which has elevated 50 local journals into the international arena. Extra capital and expertise have thereby been injected into journal development, in contrast to DHET that does not support journals (or presses) at all, but expects them nevertheless to enable massive publication incentive transfers to universities. Section

7.3 discusses DHET's reluctance to feed revenue into the journals themselves, partly because there are too many journals relative to the size of the national scholarly base but also because there are too many journals per discipline, and amalgamation is not occurring. The Report, as it should be, is aware of the negative outcomes of commercialisation, but mainly with regard to some local publishing houses that precipitously expand publication only to leverage article processing charges and to milk the DHET incentive. While subscription costs have increased, page charges have not expanded unduly with regard to the traditional international publishers that work with local journals either through UNISA Press, NiSC or bi-laterally.

The Report's conclusions elide this significant partnership in the publishing sector as being something of a troublesome 'add-on' to be rectified by drawing all South African journals to SciELO South Africa despite its relative lack of resources, while also shaking out under-performers. In an ideal world, SciELO could be an exemplar. The Report suggests that, with regard to pricing,

> *high level negotiation with the multi-national mega-publishers of commercial journals needs to be taken forward with determination, either by the appropriate government department or by a consortium of institutions at their highest level.* (p. 139)

Books and conference proceedings

Although the Report (p. 130) highlights that half of the top 20 book publishers of South African manuscripts are local, the larger pool of 368 reveals that overseas publishers are adding to the competition in the market for local scholarly presses, which also compete with trade and academic publishers that are widening the scope of what they publish. Between 2005 and 2014, 923 unique book titles were submitted by 323 unique publishers. The high number of competing book publishers (in relation to the size of the market) is hidden within the ASSAf report data as a concern pertaining to sustainability (p. 174–175).

Should OA book publishing be an aim? It is puzzling that SciELO South Africa has made no attempt to steer any books into this channel – yet it is recommended for all journals.

In all, the Report concedes that 11% of all subsidies paid originate from books and conference proceedings but it is not clear what the impact has been of the DHET's widening policy (of 2015) to enable reworked PhDs into books to earn book subsidies (apart from the 8.8% growth in output indicated). For conference proceedings, of the 3108 submitted for subsidy, only 1301 were successful.

Conclusion

The Report prefers a single scholarly publishing model, but ASSAf is cautiously tolerant of a pluralist approach that leverages all available options and resources, both locally and globally. These approaches might entail public, public–private and private partnerships and different business models that work for different journals and books, and, most crucially, work towards:

- restoring the objective of publishing for research integrity and social benefit rather than for authors primarily to 'game the system' (p. 121) for their institutions, and/or themselves;
- cautioning universities on narrow instrumental procedures like over-emphasising certain metrics that have built-in discrimination measurements that marginalise some disciplines over others (p. 132);
- restoring the value of quality over quantity; and
- facilitating effective publishing practices.

In short, this Report is a significant exercise in identifying objectives, policies and procedures, and how best to debate and then implement them in a rapidly changing publication environment. This Report should be prescribed reading for all researchers.

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Cardiac surgery publications in Africa over the last 20 years: A literature review

There is a significant burden of surgically correctable cardiovascular disease in Africa. The goal of this research was to review the last 20 years of literature on this topic. A systematic search was performed using PubMed, Embase and African Index Medicus for the period 1996–2016. Publications came from 29 countries, all of different income brackets. Research output increased by 15-fold over the 20-year time period, with the majority of publications authored by local teams (71.4%) compared to visiting (4.9%) and mixed teams (23.7%). Although increasing, clinical reporting on cardiac surgery is still limited. Increased publication of results should be encouraged to better benchmark capacity and improve research capacity.

Significance:

- The majority of the cardiovascular publications came from local research teams affiliated with public hospitals which suggests strong local engagement in research and cardiovascular care.
- Research output significantly increased and the share of literature from major research contributors has relatively shrunk over the study period, which suggests emerging research capacities from previously underrepresented regions.
- A demographic analysis of publications showed that studies were set in countries from all income brackets, with the majority of the studies originating from low-income countries.
- There is a need to standardise reporting of surgical outcomes which is dependent on perioperative care and maintenance of high-quality health records.
- Over half of the publications lacked evidence of outpatient follow-up or data on postoperative care, which highlights the need to focus on patient outcomes as a metric.

Background

There is a significant and growing burden of cardiac disease, and this is especially true on the African continent. Surgically amenable congenital heart disease is believed to account for 63 302 disability-adjusted life years in sub-Saharan Africa and an additional 1 692 728 in North Africa and the Middle East[1] – two of the largest shares of this burden found in the world. Nonetheless, there is only one paediatric cardiac surgeon per 38 000 000 persons on the continent, compared to one per 3 500 000 persons in Europe and North America.[2] Valvular heart disease also represents a significant share of the total burden of disease.[3] Estimates of the prevalence of clinically significant valvular dysfunction among children in Africa range from 7.5 to 51.6 per 1000 population, with significant variation based on region.[4,5] In terms of structural heart disease, endomyocardial fibrosis – the most common restrictive cardiomyopathy in the world – remains understudied, and may correspond to 7% of paediatric heart failure in Uganda.[6] The prevalence of endomyocardial fibrosis remains as high as 19.8% in rural Mozambique, and carries with it a life expectancy of 2 years once patients become symptomatic.[7,8]

These pathologies are increasingly joined by cardiac diseases typically associated with high-income countries.[9] Rapid urbanisation, dietary changes and smoking have increased the prevalence of obesity, diabetes and hypertension. Cardiovascular disease now accounts for 1 million deaths per year in sub-Saharan Africa alone.[10] In Tunisia, coronary artery disease mortality increased significantly between 1997 and 2009 (70–87 deaths per 100 000 for men, 28–41 deaths per 100 000 for women)[11], and a 2009 autopsy study in Kenya found cardiovascular disease to be the cause of death in 13% of patients.[12] Nigeria has a coronary artery disease prevalence of 16 per 1000, with those affected being predominantly male and urban-dwelling individuals.[13]

Despite this growing burden of cardiovascular disease, cardiovascular surgery needs are not being met. Cardiac surgery needs have been estimated to be 200 operations per million in low-income countries and >1000 operations in high-income countries non-endemic to rheumatic heart disease. However, cardiac surgery is provided at a rate of only 0.5 operations per million in low- and lower-middle-income countries and 500 operations per million in high-income countries.[14] Additionally, the quantity, quality, location and scope of cardiac surgical research emerging from Africa remains poorly defined. A 2015 systematic review of all surgical literature from low-income countries found that 62% of publications were case reports or case series, 43% lacked clinical outcome measures, 21% of articles were written with collaboration between authors of high-income countries (HIC) and lower- and middle-income countries (LMIC), and 55% were written exclusively by local authors. HIC and LIC were defined by the guidelines set by the World Bank.[15] Only 3% of the papers included data about cardiac surgery.[16] A bibliometric study of the *Journal of Cardiothoracic and Vascular Anesthesia* found that the total number of publications from Africa has remained unchanged from 1990 to 2011 (average 0.9 per year)[17] – a period in which the share of high-income contributions shrank and contributions from LMIC in other regions expanded.

There is also a paucity of literature surrounding the type and extent of engagement between HIC cardiac surgery programmes and African institutions. As of 2012, Sliwa and Zilla[18] reported fully independent programmes in only five African countries: South Africa, Egypt, Sudan, Kenya and Namibia. A recent study of non-governmental organisations involved in surgical care found 77 groups provide cardiac surgical care[19], while a recent survey by the World Society for Pediatric and Congenital Heart Surgery found 80 non-governmental groups involved

in such work, with 18% of groups working in Africa. Of these, 13% of groups reported being involved in exclusively educational and diagnostic partnerships, and 87% reported educational components to their work. This survey also showed that 26% of respondents reported that LMIC partners do not perform operations between HIC partner visits.[20]

The goals of the present review are to describe the demographics of those producing literature on cardiac surgery in Africa over the previous 20 years, to describe the degree of collaboration between HIC and LMIC actors, and to analyse whether the origin, type and quality of this research have evolved over the study period.

Patients and methods

Search strategy

We conducted a systematic search of literature related to cardiac surgery in Africa published from 1996 to 2016. PubMed, Embase and African Index Medicus databases were searched using cardiac surgery MeSH and Emtree terms, relevant anatomic and procedural terms, and geographical terms related to Africa. Geographical terms included regional terms as well as individual country names and derivatives. Our full search terms are included in Appendix 1 of the supplementary material.

Study selection

Articles identified by our search were compiled in an Endnote X7 library and duplicates were removed. Remaining titles and abstracts were screened in duplicate by four members of the research team (JSD, BMT, KT, SY). Articles pertaining exclusively to percutaneous, vascular or thoracic procedures were excluded from our study. Non-English language studies and those published before 1996 were excluded. In cases of ambiguity surrounding type of procedure or location, the full-text of the article was reviewed. Further uncertainty was resolved by a senior member of the research team (YL).

Data abstraction

After title and abstract screening, full-text articles were acquired via EndNote full-text search, Harvard Countway Library full-text article search, Google search, or interlibrary loan. A data abstraction tool was developed using Microsoft Excel. Data abstraction categories included: study identification (author names, dates, country and institutional affiliations), study design, patient population, indication for surgery, type of surgery, mortality data, major and minor morbidities as defined by the American College of Surgeons National Surgical Quality Improvement Program, and health-related quality of life (HRQL) measures, such as: New York Heart Association Heart Failure classifications, return to work status, measures of economic strain/medical impoverishment, and indications of difficulty managing anticoagulation due to cost or logistics.

To ensure quality and consistency, the abstraction tool was amended by consensus after each data abstractor (JD, BT, KT, SY) had reviewed 10 articles. A senior member of the research team (YL) reviewed a random 25% sample of each abstractor's data at two intervals during the abstraction process, and disagreements were reconciled.

Results

The initial search returned 2122 articles from PubMed, 2723 from Embase and 39 from African Index Medicus (Figure 1). Of the literature retrieved, 209 full-text articles and abstracts met the study inclusion criteria (Appendix 2).

Study setting

Studies were set in 29 of 54 African countries, of which 13 were low-income (44.8%), 11 were lower-middle-income (37.9%), and 5 were upper-middle-income (17.2%). The majority of articles published were set in just four countries: South Africa (19.8%), Tunisia (12.2%), Egypt (12.2%) and Kenya (6.8%), all of which are middle-income status (Figure 2).

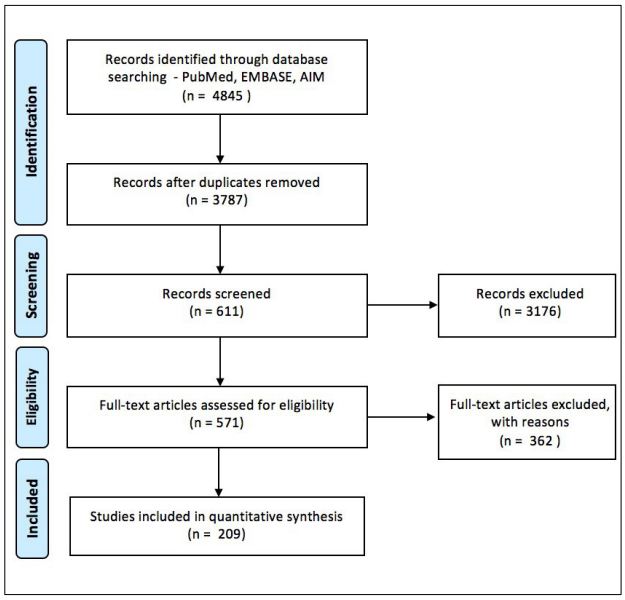

Figure 1: PRISMA (preferred reporting items for systematic reviews and meta-analyses) flow diagram.

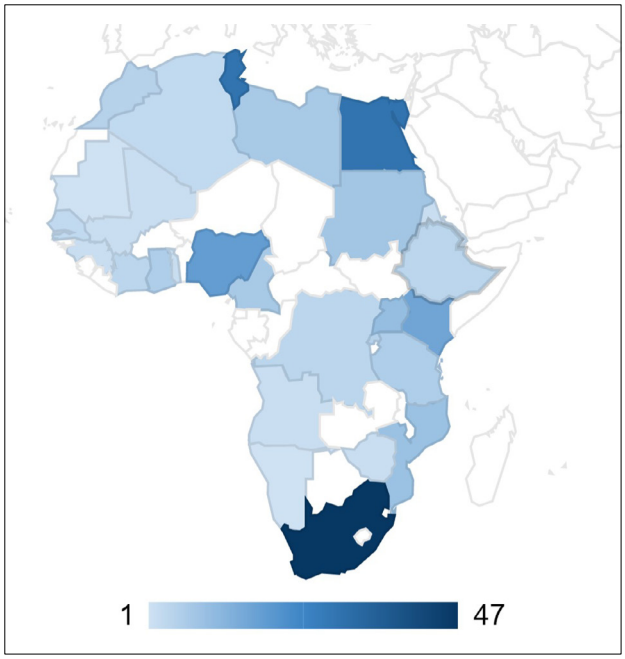

Figure 2: Countries contributing to the cardiac surgery literature.

Surgical care

Indications for surgeries were reported in 83.7% of all studies. Of these, congenital indications included: atrial septal defect (15.3%), ventral septal defect (13.4%), patent ductus arteriosus (9.6%), Tetralogy of Fallot (12.4%), and other non-specific congenital aetiologies (18.7%) (Table 1). The most common indications for acquired conditions included: unspecified valvular stenosis and regurgitation (20.6%), rheumatic heart disease (15.8%) and heart failure (10.5%). Other reported conditions were infectious endocarditis (7.2%), trauma (6.7%), pericarditis (5.3%), myocardial infarction (3.3%), cysts (2.4%), endomyocardial fibrosis (1.9%), Takayasu's disease (1.0%) and prosthetic valve obstruction (0.5%). The surgeries performed for these indications were described for adult patients (39.3%), paediatric patients (33.3%) or both (18.8%), or not given (8.6%).

Table 1: Indications for surgery and age group

Age group	
Adult	39.3%
Paediatric	33.3%
Mixed	18.8%
Not given	8.6%
Indication for surgery	
Congenital	
Atrial septal defect	15.3%
Ventricular septal defect	13.4%
Tetralogy of Fallot	12.4%
Patent ductus arteriosus	9.6%
Other non-specific congenital	18.7%
Acquired	
Valve stenosis and regurgitation	20.6%
Rheumatic heart disease	15.8%
Heart failure	10.5%
Infectious endocarditis	7.2%
Trauma	6.7%
Pericarditis	5.3%
Myocardial infarction	3.3%
Cyst	2.4%
Endomyocardial fibrosis	1.9%
Takayasu	1.0%
Prosthetic valve obstruction	0.5%
Not reported	13.4%
Not applicable	2.9%

Who and where

The majority of cardiac surgeries included in these studies were performed by local teams (71.4%), compared to visiting teams (4.9%) and mixed teams (23.7%). Authors were predominantly associated with academic institutions (73.2%). Public hospitals were the most common site of practice (79.5%), compared to non-governmental organisations (14.2%), private (1.6%) and other (4.7%) (Figure 3).

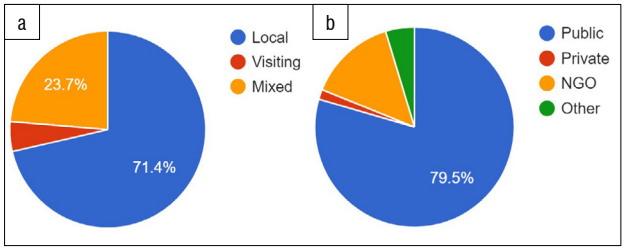

Figure 3: Teams performing cardiac surgery, by (a) team makeup and (b) location.

Research capacity

First authors were affiliated with institutions in a total of 34 countries, of which 69.9% were African. South Africa (19.1%), Tunisia (12.4%), Egypt (12.4%) and Nigeria (7.2%) represented the most common African affiliations, while the USA (6.7%) was the most common affiliation outside of Africa. Over the last 10 years, the overall volume of research has increased substantially. When looking at years with full data, we find that total output increased more than 15-fold between the first 2 years and the last 2 years of the sample (1996–1997 and 2014–2015). Research produced by the four major contributors to the literature (South Africa, Egypt, Tunisia and Kenya) continued to grow during this period, but its share of total research output dropped (66.6% to 51.1%) (Figure 4).

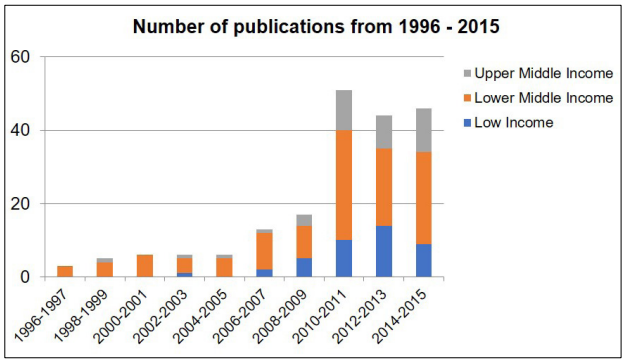

Figure 4: Number of publications 1996–2015 by country income classification.

Study design

Almost half (48.7%) of the studies were retrospective in design. Case reports, comments and descriptive studies represented 35.7% of publications. Only 14.1% were prospective studies, with interventional and observational design split evenly. Finally, three studies (1.5%) were randomised control trials. The share of lower quality evidence produced (case reports, comments and descriptive studies) was notably higher in the first decade of our sample (46.7%) compared to the last 10 years (29.4%).

Local teams produced randomised control trials (2.3%), compared to none in mixed teams or visiting teams (Figure 5). Local teams were more likely to produce prospective studies (59.5%), compared to mixed teams (41.0%) ($p=0.32$) and visiting teams (11.1%) ($p<0.01$). Mixed teams and visiting teams were more likely to publish case reports or comments (46.2% and 88.9%) compared to local teams (20.6%) ($p<0.01$) (Figure 5).

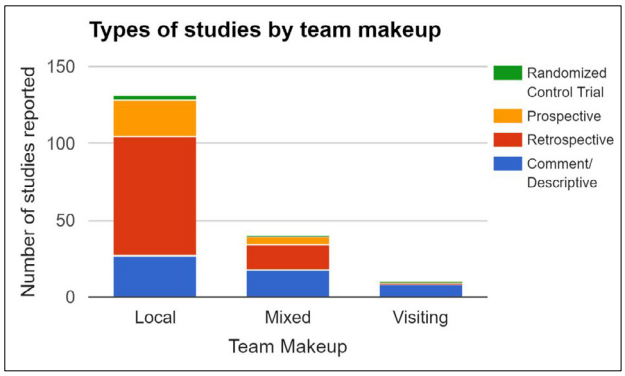

Figure 5: Types of studies by team makeup.

Outcomes

Fewer than half of the studies reported inpatient postoperative care data (45.9%) or evidence of outpatient follow-up (40.7%). Mortality outcomes were reported in 62.7% of publications (Table 2). Morbidity was reported in 45.5% of the studies, although the type of detail provided varied greatly. Major morbidities were reported in 36.8% of studies, of which reoperation for any reason (55.8%), permanent stroke (11.7%) and renal failure (11.7%) were most commonly reported. Minor morbidities were reported in 27.8% of studies. The most commonly reported minor morbidities were prolonged length of stay (36%), surgical site infections (32.8%) and wound dehiscence (10.4%). Health-related quality of life measures were reported in 4.8% of studies.

Table 2: Per cent of studies reporting outcomes

Mortality	
Reported (*n*=131)	62.7%
Not reported (*n*=78)	37.3%
Major morbidity	
Reported (*n*=77)	36.8%
Not reported (*n*=39)	18.7%
Not applicable (*n*=93)	44.5%
Minor morbidity	
Reported (*n*=58)	27.8%
Not reported (*n*=47)	22.4%
Not applicable (*n*=104)	49.8%
In-hospital follow-up	
Reported (*n*=184)	88.0%
Not reported (*n*=25)	12.0%
Outpatient follow-up	
Reported (*n*=177)	84.7%
Not reported (*n*=32)	15.3%
Health-related quality of life	
Reported (*n*=10)	4.8%
Not reported (*n*=199)	95.2%

Discussion

Our results show that 29 out of 54 (52.7%) African countries contributed to the cardiac surgical literature in our study period. The majority of this work was from African surgeons affiliated with public hospitals. This suggests a strong local engagement in cardiac surgical care and research. Overall, output increased substantially over our study period, and the share of literature produced by the largest contributors has shrunk in relative terms, suggesting emerging capacity in other states in the region. There was a notable increase in research productivity in our sample from 2009 to 2010. There are several possible reasons for this increase in production. One possible driving factor is the Fogarty Institute's Medical Education Partnership Initiative (MEPI) grants, which totalled USD130 million and was awarded to institutions in 12 African countries and US partner medical schools during this period.[21] While MEPI is credited with generating rich collaborations between US and African institutions, and between African institutions that previously were not in collaboration with one another[22,23], the effect of these collaborations on research output remains poorly studied.

In addition to the contributions of MEPI, there has been a growing interest and investment in international initiatives on reducing cardiovascular disease and increasing surgical capacities in LMIC between LMIC and HIC. This emphasis on international collaborations is especially important for fostering the development of research capacity in Africa. In recent years, there has been a call to develop cardiac care and research in low- and middle-income countries. The Cape Town Declaration aimed to accomplish this through policy advocacy and international initiatives and collaborations.[24] This focus on international initiatives was put into practice by the World Heart Federation Emerging Leader and the National Institute of Health Fogarty Wits Non-communicable Disease Research Leadership Training Programmes. These two global initiatives have been at the forefront of supporting and training leaders in research and policy change in Africa. Over the past decade, the two programmes have trained master's, doctoral and postdoctoral talents who have engaged in research that examined the social, genetic, epigenetic, clinical and physical factors that contribute to cardiovascular disease.[25]

In terms of developing surgical capacities in LMIC, interests in global surgery have increased in faculty and surgical trainees in HIC. Global surgery provides opportunities for mutually beneficial relationships between HIC and LMIC. Surgeons in HIC will be able to access the clinical workload in LMIC to develop surgical and clinical skills, research region-specific diseases, and explore their passion for global health. For LMIC partners, the interest in global surgery has led many Western organisations to assist LMIC in developing their surgical capacities by helping establish new surgical residencies and providing research training.[26] The growing interest and investment in cardiovascular disease and global surgery creates an important opportunity to build bilateral partnerships between HIC and LMIC. The financial support of MEPI and the symmetric exchange of knowledge and experience seen between HIC and LMIC are important catalysts that have likely facilitated the increased research production seen in this study. Therefore, promoting and supporting mutually beneficial, respectful and longitudinal relationships and collaborations is imperative in expanding the research capacity and growth of health care in both HIC and LMIC.

Research of overall higher quality evidence, such as prospective studies and randomised control trials, was more likely to be produced by local authors. On the other hand, research by visiting surgeons and collaborations between visiting and local teams was most likely to yield comments, case reports and descriptive studies. This raises important questions about the extent to which collaborations between HIC and LMIC surgeons are effectively leveraging the research experience and resources of high-income partners, and why the exceptional level of connectivity afforded in the world today is not permitting more long-term, long-distance, collaborative research.

One answer to this question may be the barriers in sustaining these collaborations longitudinally for surgeons in HIC. A survey performed by the Society of University Surgeons and the Association for Academic Surgery showed as few as 30% of academic medical centres in the USA held international partnerships and 70% of these partnerships were unfunded or relied on variable funding; 41% of the programmes reported a lack of allowance for time off to engage in international work.[27] Even though there has been a rise in global surgery engagement, there is currently inadequate infrastructure in place to support these longitudinal partnerships in the USA. Policy changes in academic medical centres in HIC that allow for time away and funding to engage in international partnerships can promote desired long-term, long-distance, collaborative research between HIC and LMIC.

In only half of the studies, surgical outcomes were reported, highlighting the need to improve the overall quality of the literature being produced. The reporting of outcomes needs further standardisation, with increased emphasis on the value of measuring morbidities and HRQL outcomes. It is notable that the reporting of such data is often contingent upon adequate perioperative care and the maintenance of high-quality health records.

Engagement with the academic medical literature plays an invaluable role in elevating the quality of care that can be delivered, and meaningful contributions to literature can inform broader priority setting both at national and international levels. The ability to participate in the community of academic surgery can bolster the perspectives of LMIC surgeons, and lead to significant opportunities for further collaboration and career and institutional advancement.

Inadequate research capacity was identified by the Lancet Commission as an obstacle to improving surgical programmes in LMICs.[28] In south sub-Saharan Africa, most countries allocated less than 1% of their gross domestic product to their health budget and less than 0.5% of this health budget was spent on health research.[29] Growing and investing in the research capacity of African LMICs can reduce inequities in research partnerships[30] and expand the applications of research findings to strengthen local programmes and policies[31].

For the last 20 years, there has been an ongoing debate in the literature about how to best tackle inequity in cardiac surgical care and the role that HIC institutions have in levelling this disparity.[32-34] The rise of medical tourism has complicated the dynamic, and within the literature, there is debate about the role high-income surgeons and institutions can and should play evaluating LMIC cardiac programmes.[35] Our study reveals

considerable and ongoing collaboration in the context of surgical research. It also highlights the need to ensure that these efforts be refocused, such that these partnerships begin producing the highest quality of evidence possible. Restructuring these collaborations around larger, prospective and randomised trials can bolster LMIC institutions in important ways: first, partnering with HIC institutions for such research can enhance funding opportunities; and, second, it can lead to the transfer of knowledge and best practices that might not otherwise be transferred in strictly clinical engagement.

There are several limitations to this study. Most importantly, published literature is not wholly representative of surgical care delivery. There are likely institutions performing cardiac surgery that do not contribute to the peer-reviewed literature, and our results should not be interpreted as depicting the entirety of care available in the region. For example, in South Africa, just 7 of 48 centres offering cardiac surgical care are academic in nature. While these seven centres serve some nearly 90% of the population, they serve only 20% of cardiac cases each year and are the only institutions contributing to our data. Thus, generalising operative volume or scope by working solely from the assembled literature would lead to a distorted portrait of ongoing cardiac care. This bias is perhaps most evident in the context of surgical indication. If interpreted as a representative sample, our data would suggest that rheumatic heart disease, even when coupled with valve stenosis and regurgitation, accounts for just 36.4% of cases. Those currently practising in Africa are likely to recognise this figure as a significant underrepresentation. Secondly, there is a great deal of heterogeneity in the type and quality of data reported in this literature, complicating the analysis of mortality, morbidity and HRQL measures. The diversity of the reported data emphasises the need for improved standardisation of reporting practices in the region.

Despite the discrepancy of published literature and true service delivery, research output is still one of the final indicators of cardiac surgical services and the role of academia. This review is an important first step toward understanding the scope of cardiac surgery currently practised in the region, and the type and quality of research surrounding this care. While these results provide an initial glance, the picture that emerges is still incomplete. It is imperative that the global surgery and cardiac surgery communities continue efforts to understand ways to best approach ironing out the profound inequity in access to care and research capacity.

Authors' contributions

Y.L. and R.M.B. were responsible for project management, design of methodology, conceptualisation, curation of data, analysis and interpretation of data, production of the initial draft, revisions, supervision of students, dissemination of results, and validation of work. B.M.T., S.Y., J.S.D., and K.T. contributed to curation of data, analysis and interpretation of data, and revision of the manuscript. N.L. and P.Z. supported data analysis and interpretation, and revision of the manuscript. All authors reviewed drafts of the manuscript and approved the final version for publication.

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Detailed palaeomagnetic record at Rose Cottage Cave, South Africa: Implications for the Holocene geomagnetic field behaviour and chronostratigraphy

Palaeomagnetic data from a sedimentary section spanning the Holocene and terminal Pleistocene (~13 kya) from Rose Cottage Cave, eastern Free State (South Africa), are reported. The palaeomagnetic analysis took into account rock magnetism and directional analysis. The former reveals that most samples show stable single domain and superparamagnetic particles of Ti-poor magnetite and haematite. Natural remanent magnetisation directions were determined by progressive alternating field demagnetisation methodology. Directional analysis shows normal directions between samples 18 to 39 and 85 to 92; however, during the Early and Late Holocene in samples principally from RC40 to 84 'anomalous' directions occurred. There is a significant westward shift in declination of ~80°, and a conspicuous fluctuating inclination in the lower part of the section during the Early Holocene at ≥9.5 kya and before ~12.0/13.0 kya. This palaeomagnetic record might become a chronostratigraphical marker for latest Pleistocene/Holocene sedimentary deposits in South Africa. Our two new accelerator mass spectrometry radiocarbon dates for the sampled deposit are 9500±50 BP and 1115±30 BP.

Significance

- The study provides new accelerator mass spectrometry dates on the chronological sequence existing in Rose Cottage Cave.
- The findings contribute to the knowledge of the geomagnetic field behaviour since the terminal Pleistocene to the Late Holocene in a period spanning the last 13 000/12 000 years.
- This palaeomagnetic record might become a chronostratigraphical marker for the latest Pleistocene/Holocene sedimentary deposits in South Africa.

Introduction

The primary goal of palaeomagnetism is retrieving past geomagnetic field (GMF) behaviour through time from geological and archaeological remains. During their formation process, certain minerals lock in a record of the direction and intensity of the GMF. In this way, rocks, sediments, and archaeological features and artefacts provide data on earth and humankind's evolution through changing geomagnetic field behaviours such as reversals, palaeosecular variations and excursions.[1,2] We briefly explain GMF, palaeosecular variations and excursions. One of the main features of the geomagnetic field (over millions of years) is its alternation between periods of normal polarity, in which its direction was similar to the present, and reverse polarities, with an opposite direction. Palaeosecular variations measure small changes, in the order of decades to millennia, occurring slowly and progressively in the geomagnetic field. The strength and direction of the total field vary as a result of changes in strength and direction of the dipole and non-dipole components. The other significant feature is a geomagnetic excursion, that is a major deviation in the geomagnetic field behaviour that does not result in reversal. Spanning centuries to millennia, an excursion is a striking disturbance characterised by a significant change in the geomagnetic field with a variation orientation of ≥45° from the previous pole, and it habitually involves declines in field strength of up to 20% of normal.[3,4]

The applications of palaeomagnetism can be useful for diverse issues in palaeosciences research, such as studies of the evolution and history of the earth's magnetic field, stratigraphy, age determinations, polar wander, and tectonics.[1-3,5-7] Particularly in South Africa, investigations of these topics have been of increasing interest since the beginning of the1960s.[8-13] Thus, with the aim of exploring GMF behaviour and its utility as a chronological tool, several Late Pleistocene and Holocene South African deposits were sampled.[14] Here we report the results obtained from Rose Cottage (RC) Cave, situated on the Platberg at 1676 m asl, at a short distance from the town of Ladybrand, eastern Free State (Figure 1).

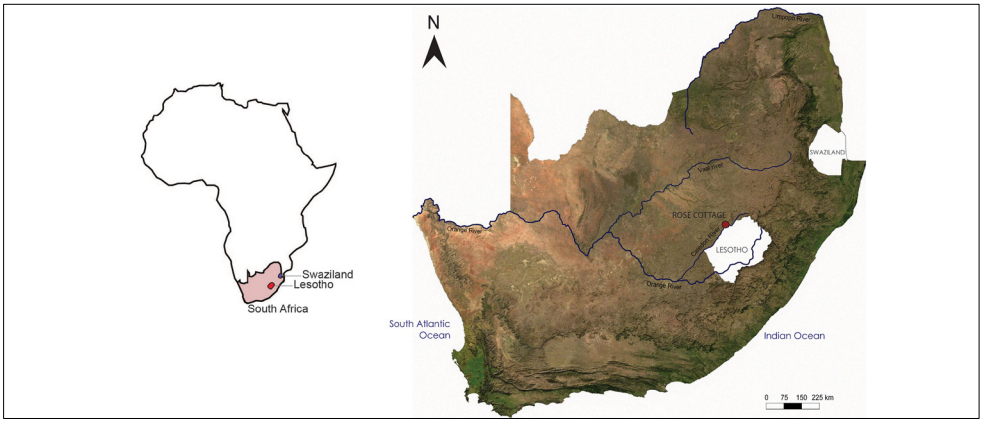

Figure 1: Location of Rose Cottage Cave in South Africa.

Sampling site, stratigraphy and chronology

Facing north, Rose Cottage (29°13´S, 27°28´E) is protected by a large boulder that encloses the front of the cave which is ~20 m long by ~10 m wide (Figure 2a). Archaeological excavations were performed by B.D. Malan between 1943 and 1946, P.B. Beaumont in 1962, Harper between 1989 and 1993[15,16] and Lyn Wadley between 1987 and 1997[17] (Figure 2b,c). The site has been extensively dated over the years. The first radiocarbon date (Pta-1) from the laboratory in Pretoria opened by John Vogel was from Rose Cottage Cave[18], and many more dates from this laboratory were obtained for the site over the next 30 years. Valladas[19] later conducted thermoluminescence dating on Rose Cottage lithics and Woodborne and Vogel[20] and Pienaar et al.[21] sampled the sediments for optically stimulated luminescence ages. Rose Cottage Cave has a long sequence of Middle Stone Age (MSA) to Late Stone Age (LSA) occupations dating from close to 100 000 years ago (100 kya) to just a few hundred years ago. The cultural sequence includes pre-Howiesons Poort, Howiesons Poort and post-Howiesons Poort (MSA) assemblages, a possible MSA/LSA transitional industry, and an LSA sequence containing Robberg, Oakhurst, Wilton and post-classic Wilton industries, some with ceramics.[17] The Robberg Industry is characterised by many ribbon-like blades (mostly <26 mm in length) derived from small conical blade cores; the Oakhurst Industry mostly lacks blades and is flake and scraper oriented. The Oakhurst lithic products are considerably larger than those elsewhere in the LSA sequence of Rose Cottage. The Wilton Industry is typified by microlithic backed tools, mostly segments, but there are also elongated scrapers. The post-classic Wilton retains some backed tools, but is dominated by a variety of scraper forms. For illustrations of the tool types, see previous detailed publications.[22-24] The Rose Cottage sedimentary fill shows a deep (more than 4 m in places) and varied stratigraphy that provides a complex sequence deposited between ~0.5 kya and about 90 kya.[17(p.440, Fig.3),19] However, the section sampled for palaeomagnetic research belongs to the last millennia of the Pleistocene and Holocene (Figure 2b,c).

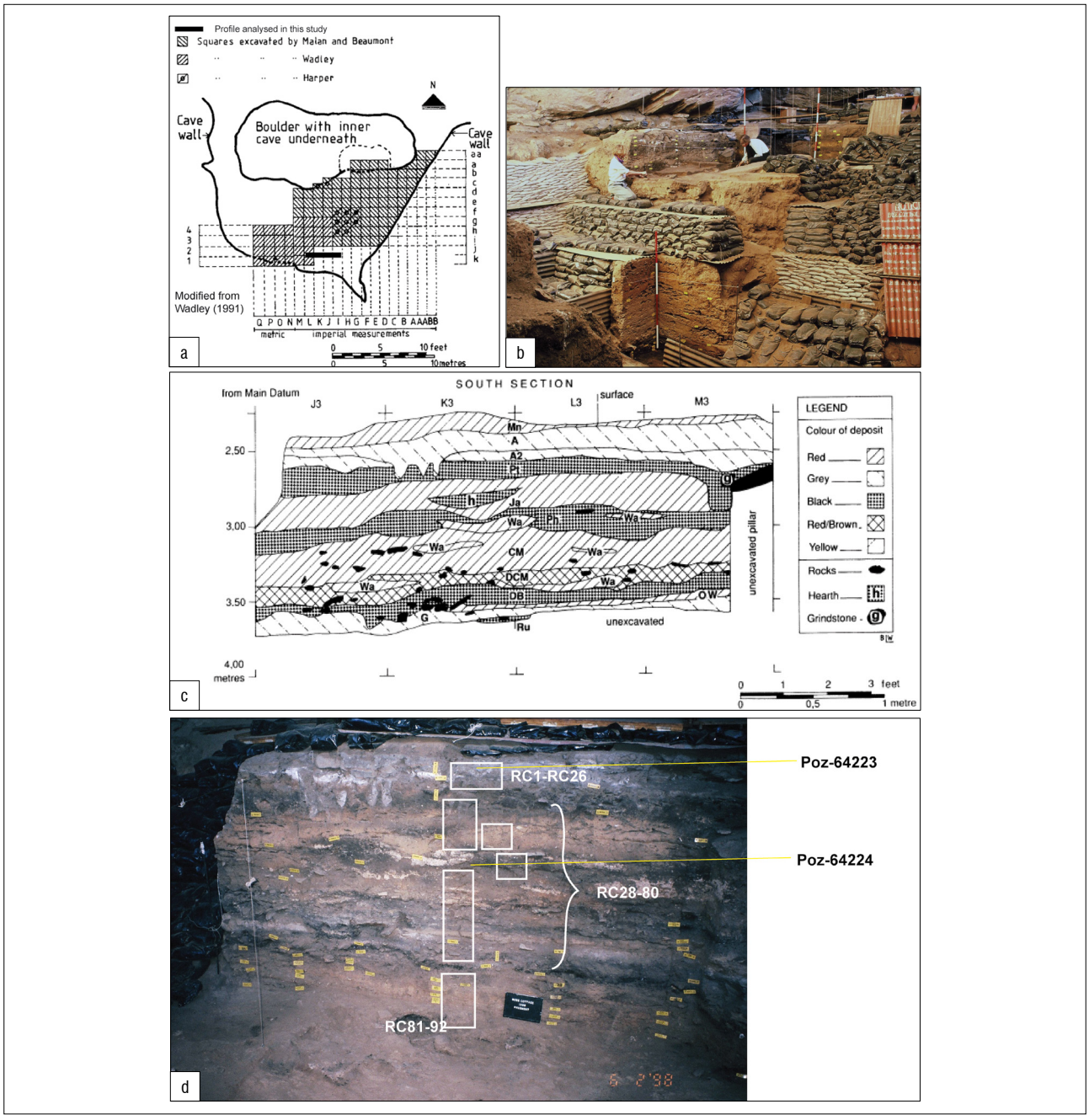

Figure 2: (a) Map of Rose Cottage Cave depicting the location of the palaeomagnetic study. (b) Lyn Wadley's excavation at Rose Cottage. (c) Stratigraphic section showing the layers sampled in this study. (d) Picture of palaeomagnetic sampling in the southern profile.

Radiocarbon dates (Table 1) imply several hiatuses, preceded and followed by pulses of intense occupation. The hiatus between ~2.2 kya and 6.0 kya demonstrates a sedimentary unconformity spanning a great portion of the middle and late Holocene. Another substantial hiatus occurs between layers G and DB2, although in parts of the cave a gritty orange wash dated ~15.7 kya separates the two layers.

Because of the dates and the relative densities of archaeological material, Wadley[17(p.440)] suggested that some of the darker organic-rich layers (e.g. Pt, H and DB) were slowly deposited during periods of gentle rainfall as shallow lenses with considerable anthropogenic content, while the underlying orange sands (e.g. CM to Ja and Wa1) accumulated rapidly and with less anthropogenic material. The latter were primarily formed through weathering or rock spalling of the sandstone roof and through material washed into the cave by springs, occasionally activated during protracted, heavy rains.[25]

To accurately contextualise all the palaeomagnetic results that will be discussed below, two charcoal samples were collected and submitted for accelerator mass spectrometry radiocarbon assays. The samples were processed by the Poznań Radiocarbon Laboratory, Poland. The new results obtained are given in Table 2. The date Poz-64224 (9500±50 BP) from layer Ja (the contents of which are attributed to the Oakhurst Industry), is somewhat older than the two dates (8380±70 and 8160±70 BP) previously obtained for layer Ja. The new date suggests that the entire Oakhurst sequence may be of greater antiquity than was previously thought.

Table 1: Uncalibrated radiocarbon dates from Rose Cottage Cave (from Wadley[17]). The dates in bold belong to the layers sampled for palaeomagnetic research.

Layer	Sample	Date
Ge	Pta-5592	31 300 ± 900
Dc	Pta- 5596	27 200 ± 350
J	Pta-6303	26 900 ± 550
Ru	Pta-6202	27 800 ± 1700
Ru	Pta-7126	27 700 ± 480
Ru	Pta-7184	28 800 ± 450
G	Pta-5598	20 600 ± 250
Wa1	Pta-6195	15 700 ± 40
DB2	**Pta-5601**	**13 360 ± 150**
DB	**Pta-5593**	**12 690 ± 120**
LB	**Pta-7275**	**9560 ± 70**
O	**Pta-5599**	**9250 ± 70**
H	**Pta-5560**	**8614 ± 38**
JaG	**Pta-5600**	**8380 ± 70**
Ja	**Pta-7122**	**8160 ± 70**
Pt (base)	**Pta-6783**	**7630 ± 80**
Pt (up)	**Pta-5934**	**5970 ± 70**
A2	**Pta-7117**	**2240 ± 60**
A	**Pta-5622**	**680 ± 50**
Mn	**Pta-6788**	**500 ± 50**

Table 2: New accelerator mass spectrometry uncalibrated dates taken from the sampled section

Depth (cm below surface)	Sample	Date (years BP)
-20	Poz-64223	1115 ± 30
-56	Poz-64224	9500 ± 50

Palaeomagnetic research

Sampling procedures

The palaeomagnetic samples (n=92) were taken from the fine sediments of the southern profile exposed by Wadley's excavations (Figure 2d). The profile reveals fine sediments with interbedded thin lenses of ashes, coarse-grained elements, and rock fall from the cave's roof. The orange sand, and intercalated lenses and levels of grey and/or rubefied material, testify to the presence of significant combustion phenomena, such as fireplaces. The samples – labelled RC together with a number – were vertically taken after carefully cleaning the section, then trying to follow the apparently undisturbed layers suitable for our research. Despite this it was difficult to attribute each sample precisely to the previously described stratigraphy. Samples were taken from layers A to DB as follows: samples RC1 to RC26 were generically from A and A2 corresponding to the Late Holocene, and RC28 to RC80 from levels Pt, Ja, H, CM and DCM. According to radiocarbon assays, they mainly belong to the Middle, Early Holocene (8–9.5 kya), and probably the Pleistocene–Holocene transition (~10.0/11.0 kya). Finally, the samples RC81 to RC92 came from the terminal Pleistocene DB and DB2 greenish sands which were dated at ~13–12 kya. We did not collect sediment between samples RC48 and RC49 at 74.0 cm and 79.0 cm depth, because sediments here were highly compacted by rubefaction. The date of 1.1 kya was obtained next to RC13 and RC14, corresponding to layer A, and the 9.5 kya assay was obtained close to RC44 and RC45, in the transition between the orange sand (layer Ja) and a compacted orange–grey sand with hearths embedded (layer Ph).

The cores were taken using 25-mm long and 20-mm diameter cylindrical PVC plastic containers. The cylinders were carefully pushed into the sediments, overlapping each other by about 50%. The sample's orientation was measured using a Brunton compass. Samples were consolidated with sodium silicate once removed and they were numbered from the top to the bottom. The depth of each sample is recorded in Supplementary table 1. Seven samples were taken for rock magnetic analysis nearby the location of palaeomagnetic samples.

Rock magnetic study

In previous work carried out by Herries and Latham[11,12] on magnetic properties in Rose Cottage Cave, they found that the frequency dependence of magnetic susceptibility between unburned and burned sediments was very small. They determined this using a susceptibilimeter (Bartington) of two frequencies (460 Hz and 4600 Hz). In our studies we used a Kappabridge AGICO of three frequencies (1000 Hz, 4000 Hz and 16 000 Hz) and we also measured the dependence of the susceptibility at high (room temperature to near 700 °C) and low (room temperature to near -190 °C) temperatures. This allowed us to better discriminate the burnt sediments from the unburned ones.

In order to characterise the magnetic mineralogy, we took seven samples catalogued as RC at respective depths of -16, -32, -46, -70, -85, -109 and -146 cm below surface. They were analysed with an AGICO MFK1-FA by using the variation of susceptibility (k) with temperatures from -190 °C to 700 °C, and the variation of susceptibility with applied fields from 10 A/m to 700 A/m at 1000 Hz; 10 A/m to 350 A/m at 4000 Hz and 10 A/m to 200 A/m at 16 000 Hz.

The variation of initial magnetic susceptibility with frequency was used as an indicator of superparamagnetic (SP) magnetite grains.[26,27] It is indicated as $X_{fL\_fH}\% = 100 \times [(X_{fL} - X_{fH})/ X_{fL}]$, where fL is the low frequency and fH the higher frequency. Frequencies are f1 = 1000 Hz, f2 = 4000 Hz and f3 = 16 000 Hz. Another parameter we used was proposed by Hrouda[27] as $X_R = (X_{f1} - X_{f2})/ (X_{f2} - X_{f3})$. According to Hrouda: 'The advantage of the X_R parameter is that it is not affected by any mineral fraction being frequency independent.' It can be used to estimate the size of the superparamagnetic grains, keeping in mind that its distribution follows a lognormal distribution.[28,29] According to this and the data shown in Figure 3a, Hrouda's[27] calculations show an estimate of grain size diameter for superparamagnetic particles in the range between between 39 nm and 11 nm (1 nm= 10^{-9} m). It is in agreement with the presence of very stable single mains, higher than 30 nm at room temperature, which are good magnetic remanence carriers.

Typical magnetic susceptibility versus temperature curves are depicted in Figure 3b. It can be seen that there is a steady linear increase of susceptibility from near -180 °C to 125 °C that could be related to unblocking of superparamagnetic to single domain grains of Ti-poor magnetite and/or maghemite. There is no evidence of Verwey transition near -155 °C, so multidomain pure magnetite is absent in these samples. Heating curves

show a Ti-poor magnetite Curie temperature near 575 °C, and a Curie temperature appropriate for haematite that perhaps formed as a byproduct when the hearths heated nearby strata. Due to the low magnetisation saturation of the haematite when compared with the Ti-poor magnetite or maghemite, it does not contribute significantly to the final remanence in these samples. Figure 3c depicts the low temperature susceptibility measurements of all the samples. The slope is related to the stable single domain/superparamagnetic transition because the blocking volume is proportional to temperature,[28,29] so when the temperature increases, more magnetic grains go from stable single domain to superparamagnetic and the susceptibility increases. Sample RC-70 shows the higher slope, indicating a higher concentration of very fine superparamagnetic fraction; this finding can be related to sediments that suffered burning or higher combustion temperatures, or use of the site for a longer time. Samples RC-16 to RC-85 exhibits a similar slope, while in RC-109 and RC-146 the slope is very low, suggesting that these samples were not affected by a combustion event. This is in agreement with the results of the frequency dependence section, where a very fine superparamagnetic particle is predicted due to a broad grain size distribution.

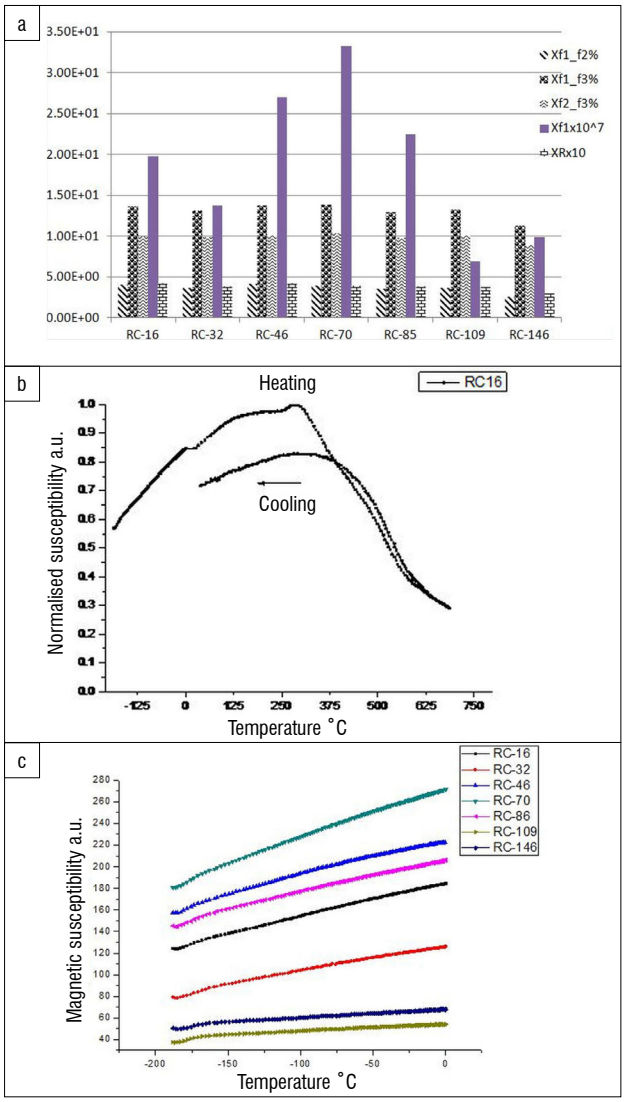

Figure 3: (a) Mass magnetic susceptibility and variation with frequency. f1 =1000 Hz; f2=4000 Hz; f3= 16 000 Hz. (b) Thermomagnetic susceptibility curve from approximately -190 °C to 700 °C for sample RC-16; the behaviour of the other samples seems similar. (c) Low temperature of magnetic susceptibility. The slope is related with SP mean diameter.

In conclusion, the strata with burnt sediments as observed in samples RC-16 to RC-85 show stable single domain and superparamagnetic particles of Ti-poor magnetite, together with haematite, which is compatible with chemical processes during heating in situ of iron-bearing minerals. The magnetisation of saturation in haematite is 100 times lower than in Ti-poor magnetite. Therefore, the remanence recorded here is carried mainly by Ti-poor magnetite grains. Only when the concentration of Ti-poor magnetite is very low, can haematite be considered as a magnetic carrier. In this case, magnetic measurements show that Ti-poor magnetite is the main magnetic remanent carrier. Stable single domain grains are very stable magnetic carriers, so these sediments are suitable for recording ancient magnetic fields acquired during burning. Samples RC-109 and RC-146 do not exhibit high superparamagnetic content, suggesting that no burning events affected these sediments.

Remanence directions analysis and results

All samples were subjected to detailed stepwise alternating field demagnetisation in progressive steps of 3, 6, 9, 12, 15, 20, 25, 30, 40 and 60 mT with a three-axis static degausser attached to a 2G cryogenic magnetometer (755R). Additional steps of 80 mT and 100 mT were used for some specimens. The RC samples showed a common pattern with highly reliable magnetic behaviour. Most specimens had a gradual decrease of magnetisation with almost all remanence erased at 25 mT (RC2; Figure 4b), but mostly at 50 mT and 60 mT (RC1, 5, 8, 11, 15, 18, 24, 37, 54, 59, 61, 66, 75, 91; Figure 4a, c–l, n–o, q–s, v); 10% remains at 30 mT (e.g. R44; Figure 4k), 40 mT (e.g. RC60; Figure 4p), while a few indicate a drop at 80–100 mT (RC40, 47, 51, 83, 90; Figure 4j, l, m, t–u). As seen in the previous section, these differences are related to the magnetic carriers of the remanence.

Palaeomagnetic directions were determined by the 'Remasoft 3.0 palaeomagnetic data browser and analyser' computer program. The characteristic remanent magnetisation directions were calculated using principal components analysis. In most cases, the characteristic remanent magnetisation trended towards the coordinate's origin in the Zijderweld[30] diagrams (Figure 4). The RC samples display varied patterns of behaviour in the vector diagram's projection. Some exhibit univectorial projections (RC1, 5, 24, 91; Figure 4a, c, h, v), while many have two magnetic components with one decaying to the origin (RC2, 11, 18, 40, 47, 51, 59, 61; Figure 4b, e, g, j, l–m, o, q). A viscous secondary component was easily removed in a number of specimens (RC2, 15, 40, 47, 51, 59, 66, 90; Figure 4b, f, j, l, m, o, r, u) between 3 mT and 12 mT and was not considered further. In a few specimens (e.g. RC40; Figure 4j), some scatter is observed when fitting the steps of demagnetisation to the origin of coordinates, probably due to the minor haematite presence (as recognised by rock magnetic experiments). Also, samples RC15, RC44 and RC90 do not go to the coordinates' origin of the orthogonal diagrams, but in these cases their harder component is similar to that obtained by samples decaying to the origin (Figure 4f, k,u). There were also several cores that recorded two geomagnetic field directions. As described in Supplementary table 2, the secondary ('soft') component in five samples recorded a normal position (e.g. RC11, 18; Figure 4e,g), but also an 'anomalous' direction in two specimens (e.g. RC75; Figure 4s); the 'hard' magnetisation is interpreted as an early remanence acquired during formation of the sedimentary deposit (e.g. RC11; Figure 4e). Finally, several cores recorded three magnetic components, one of which appears to decay to the origin (e.g. RC83; Figure 4t).

Many samples presented either a high (e.g. RC66; Figure 4r) or a low (e.g. RC60; Figure 4p) negative, and positive (e.g. RC11, RC40; Figure 4e, j) inclinations. Most specimens yielded a normal position (RC8, 15, 18, 90, 91; Figure 4d–e, u–v); a few samples showed northwesterly (RC2, RC15; Figure 4b, f), northeasterly or easterly (RC47, 60, 83; Figure 4l, p, t) directions, several of which had steep inclinations (RC60; Figure 4p). 'Anomalous' southward directions were found in various cores, mainly in the lower portion (RC40; Figure 4j). The number and intervals of the demagnetisation steps used to isolate the characteristic remanent magnetisation are given in Supplementary table 1, which also depicts the maximum angular deviations that generally have low values, ranging from 0° to 5° (n=82, 89.13%), and from 5.1° to 10° (n=10, 10.87%). This analysis shows that the RC samples mostly display normal, but also intermediate and reverse magnetic remanence of low negative and

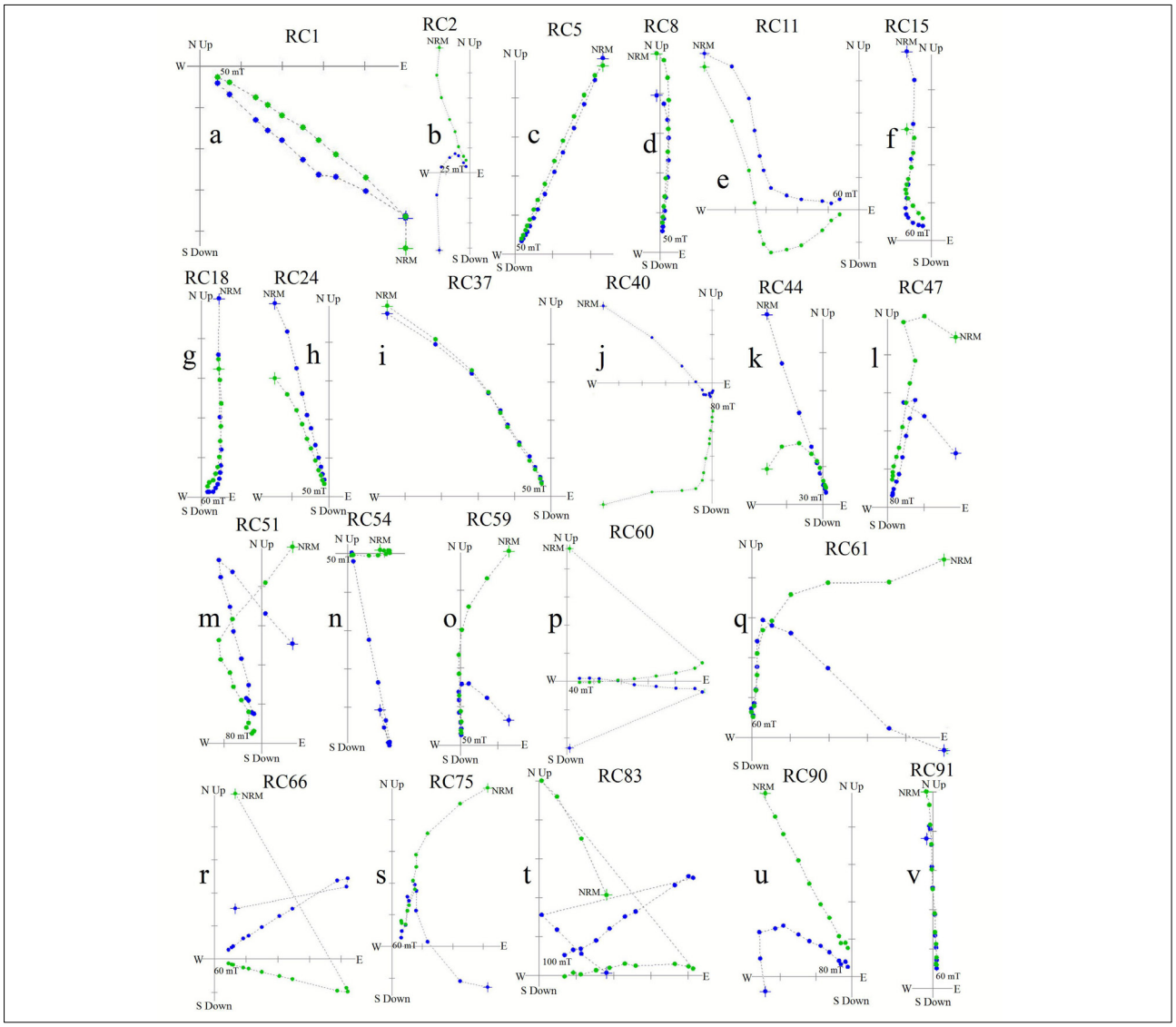

Figure 4: Vector components diagrams showing the behaviour of typical samples cleaned using alternating field progressive demagnetisation from Rose Cottage Cave. The totality of the vector projection diagrams illustrated in the figures is directional data with corrected field. Blue and green symbols correspond to projection on the horizontal and vertical planes, respectively.

positive inclination values. Figure 5 illustrates the stereographic projection of characteristic remanent magnetisation for the RC sampling.

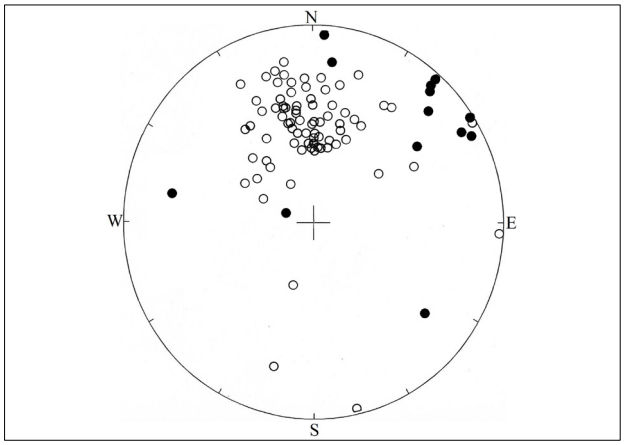

Figure 5: Directional data with field correction of characteristic remanent magnetisations of each sample for the section reported in this paper. Negative inclination (open circle) and positive inclination (solid circle).

The magnetograms of the declination and inclination profile (Figure 6) exhibit wide amplitude fluctuations both in declination and inclination in the upper and lower portions of the section. In the former, directions vary widely with transitional positions gradually changing to normal from samples 1 to 19. Despite directional variations, with the exception of RC11, the inclination values are quite constant and normal directions with little difference from the present geomagnetic field occur up to RC39. It is noteworthy that there is a stable record with normal directions between samples RC19 to RC39, and a highly fluctuating log from RC39 to RC61 which is depicted with pointed lines and marked with arrows. Samples RC38 to RC41 show similar directions, but with a pronounced swing of ~130° to a positive inclination in RC40. Between RC45 and RC54, the samples exhibit similar inclination, but with varying directions, and with a deviation of ~180° from the normal geomagnetic field. Between samples RC53 and RC58, there is a strong swing both in declination and inclination values with transitional normal-reverse-normal positions, which in the latter are observed in samples between RC85 and RC92. As seen in Figure 6, the resulting logs show an important difference of ~50–60° in inclination in the period ~≥9.5 kya.

After checking that the directional data from Rose Cottage were useful for assessing a Fisherian distribution, the site mean directions were computed (Figure 7).

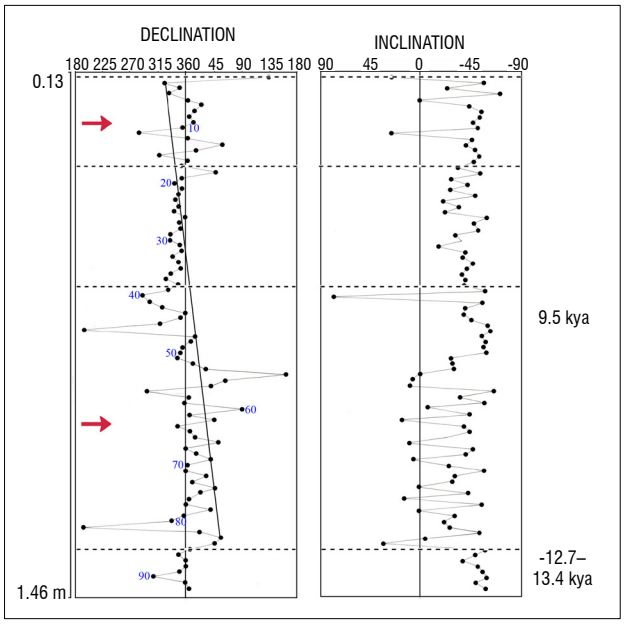

Figure 6: Stratigraphic plots of the declination and inclination profiles from Rose Cottage Cave. The more conspicuous long direction departures are depicted between dashed lines and pointed with an arrow. The numbering of the samples in the declination magnetogram is indicated every 10 specimens.

Additionally, the mean direction was calculated by segmenting the Rose Cottage record according to the most frequent directional changes observed in its upper, middle and lower portions (Supplementary table 3). From this study, it is observed that Rose Cottage mean directions show a consistent agreement; they are also located close to the International Geomagnetic Reference Field direction (D=337.4°, I=-63.9°) for 2014, the year in which the sampling was performed. However, a significant difference is observed for the mean directions calculated in the upper and lower portion of the section (Figure 7).

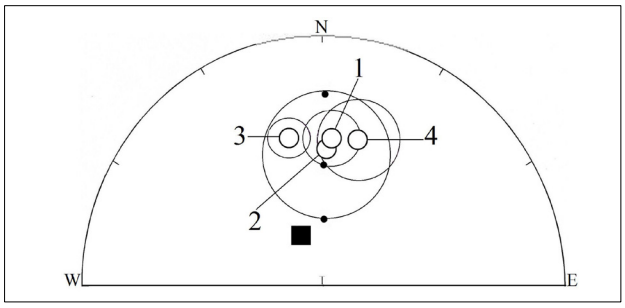

Figure 7: Site mean magnetisation directions for (1) RC, (2) RC #1–17, (3) RC #18-39 and (4) RC #40–92. The International Geomagnetic Reference Field direction is indicated by the square.

The virtual geomagnetic pole positions were calculated from the aforementioned directions (Supplementary table 1, Figure 8a). When plotted on a present world map, besides normal positions, virtual geomagnetic pole positions show intermediate and reverse positions from the rotation axis of the earth (Figure 8b). The virtual poles in the northern hemisphere are located in North America, Greenland, and north, east and southeastern Asia, and northern South America. Virtual geomagnetic pole positions in the southern hemisphere are situated in Indonesia, South of the Pacific Ocean, and west of southern Africa; those ones calculated from secondary directions are located close to New Zealand. Surprisingly, virtual geomagnetic pole position locations from Rose Cottage show a remarkable agreement with those calculated from Klasies River Cave 1.[14(Fig.8)] Interestingly, as seen in Figure 8b–f, virtual geomagnetic pole positions from Rose Cottage show consistency between the locations observed in other places during the Pleistocene–Holocene transition and Holocene.[31,32] Virtual geomagnetic pole positions located in the above-mentioned positions, mainly near the Americas and Australasia, attract attention because they agree with the transitional longitudinal bands registered in excursions and polarity transitions in different parts of the world since the early Jurassic.[33] Also they coincide with present-day zones of fast seismic velocity at the core–mantle boundary.[34]

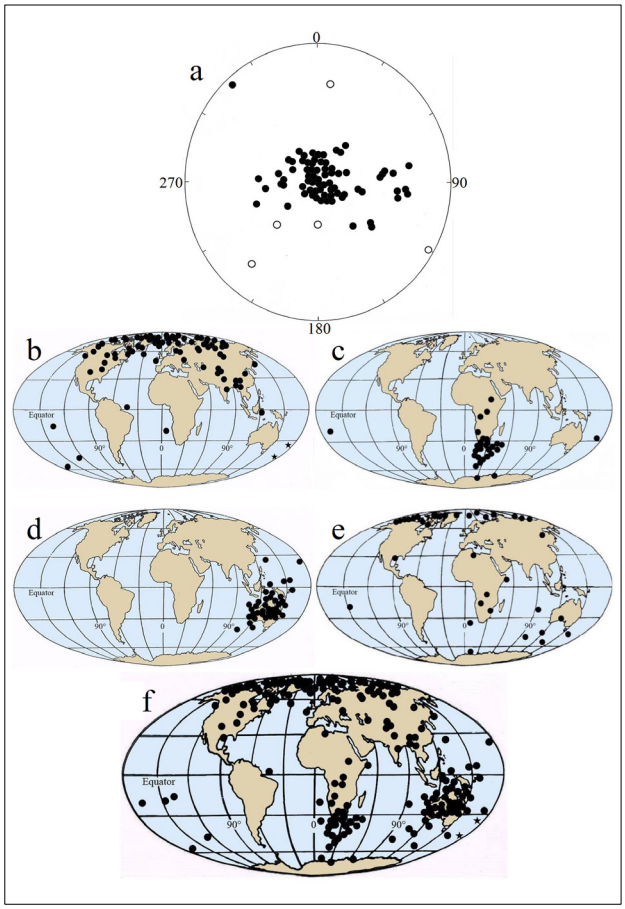

Figure 8: (a) Stereographic projection of virtual geomagnetic poles (VGPs) calculated from directions of characteristic remanent magnetisations isolated in the Rose Cottage site. Solid circles show those ones located in the northern hemisphere. The centre of the projection is the Geographic Southern Pole. (b) VGPs paths plotted on a world map for the RC section. The stars show the VGPs calculated from the secondary direction of RC75 and RC76. Examples of VGPs location from samples with anomalous directions recorded during the Pleistocene–Holocene transition and early Holocene in some sites from different places of the world: (c) El Tingo (Ecuador), (d) Barrancas de Maipú (Argentina) and (e) Mylodon Cave (Chile). (f) The totality of VGPs from the locales illustrated in (b–e). Modified with permission after Nami et al.[55,56] and Nami[60].

Discussion and conclusion

Palaeomagnetic data obtained in the fine-grained sediments from a section at Rose Cottage have mostly shown normal directions, especially between samples RC18 to RC39 and RC85 to RC92; however, some samples, principally from RC40 to RC84, exhibit 'anomalous' southward directions where wide pulses occurred at different times during the Early and Late Holocene. A significant westward shift in declination of ~80° can be observed, and a conspicuous fluctuating inclination in the lower part of the section during the Early Holocene at ≥9.5 kya, and after ~12.0/13.0 kya (Figure 6). The normal directions correspond to the palaeosecular variations record for South Africa during

the time span under consideration. Most oblique directions far from the present geomagnetic field are located mainly in the lower portion of the upper sediments. Such palaeomagnetic records may be due to several reasons. Various issues can give rise to anomalous directions of remanent magnetism that do not reflect the true geomagnetic field behaviour, such as diverse deposition processes, chemical alterations as well as sedimentary physical disturbances[35,36] and human error. If the directional data observed at Rose Cottage are not from any of the aforementioned causes, they correspond to the geomagnetic field record for southern Africa during the last millennia of the Pleistocene and Holocene.

As noted above, the Rose Cottage sedimentary stratigraphy is the result of episodic sedimentation[37] registering a discontinuous record with gaps of ≥3.8 ky between ~2.2 kya and 6.0 kya, that is, during the Late and Middle Holocene. Despite discontinuities, the unstable directional logs suggest some instability during certain periods of the Holocene. The Rose Cottage oblique normal and oblique reverse samples exhibit several palaeomagnetic consistencies such as their location in the northeast quadrant of the stereoplot, something that also occurred at Klasies River Cave[(Fig.5)], South Africa. Fluctuating logs were also reported at a similar latitude to Rose Cottage in southern Brazil[38], and northeastern Argentina, some of them with positive inclination values[32,39]. In other places in the southern hemisphere, low values, some with positive inclination, were recorded during very recent times in the Late Holocene.[31(Fig.9-10),32,40,41] However, due to the larger number of specimens, our main focus is on the anomalous directions observed in the lower segment of the magnetograms with a direct date of ~9.5 kya corresponding to the Early Holocene. Hence, at this time the Rose Cottage record suggests that swings with wide amplitude variations in declination alternated between normal, intermediate and reverse positions. This suggests that the geomagnetic field might have anomalous behaviour in South Africa during the Pleistocene–Holocene transition and early Holocene. It is significant to point out that the current paradigm in palaeomagnetic research is that during this time, the geomagnetic field behaviour was normal as it is now.[42,43] However, since the 1970s, a number of similarly aged records with anomalous directions were reported in samples taken from diverse materials, and environments in different parts of the world.[31,32,44-56] Interestingly, samples from the Starnö core in Sweden, dated by varved chronology to 10 127–10 153 BC or 12 077–12 103 years BP, yielded virtual geomagnetic pole positions located in northern South America.[44(Fig.9),47(Fig.2)] Of importance, as seen in Figure 8d, almost all of the samples from the El Tingo site in Ecuador gave virtual geomagnetic pole positions located in southern Africa.[55] A list of well-dated records of the possible excursion that occurred during the terminal Pleistocene/Early Holocene is given by Nami and colleagues[56(Table2)]. The inclinations have the expected values during the time span under consideration. Large amplitude swings in declination were recorded in Scandinavia and northern Russia.[57,58] A similar situation was also registered in southernmost Patagonia at Potrok Aike lagoon; there the palaeosecular variation record yielded logs of negative inclination values with large amplitude variations in declination during the early Holocene at ~7-9 kybp.[59] These large reverse pulses spanning short periods might alternate with normal geomagnetic field directions that might mask or cover up their existence in the palaeomagnetic record.

In summary, the Rose Cottage deposit can be interpreted as a preliminary palaeosecular variation record for South Africa. It shows significant directional changes in declination and inclination with intermediate and reverse virtual geomagnetic pole positions during the terminal Pleistocene and Holocene. Therefore, these results should be simply interpreted as chronostratigraphic tools. Hence, if the presented palaeomagnetic features are true geomagnetic field behaviour, the remarkable palaeosecular variation record can serve to correlate regional stratigraphies, and calibrate relative and absolute chronologies.[1,5-7] Additionally, if the anomalous directions do represent an excursion, it may be used also as a dating device[1,3,5-7], becoming an excellent magnetostratigraphic marker for the period spanning the Rose Cottage palaeomagnetic record.

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Authors' contributions

H.G.N. was responsible for conceptualisation, project leadership, methodological design, data collection, sample analysis and the write-up. C.A.V. was responsible for sample analysis and writing concerning rock magnetism. L.W. was responsible for validation and writing on the research. P.d.l.P. was responsible for conceptualisation, project leadership, project management, methodological design, data collection, the writing, and acquiring the funding (PAST and DST/NRF CoE).

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Opportunities and challenges for seasonal climate forecasts to more effectively assist smallholder farming decisions

The ability of smallholder farmers to utilise seasonal climate forecast (SCF) information in farm planning to reflect anticipated climate is a precursor to improved farm management. However, the integration of SCF by smallholder farmers into farm planning has been poor, partly because of the lack of forecast skill, lack of communication and inability to see the relevance of the SCFs for specific farming decisions. The relevance of seasonal climate forecasting in farming decisions can be enhanced through improved understanding of SCF from the smallholder farmers' perspective. Studies that have been done of how smallholder farmers understand SCF and how the available SCFs influence smallholder farmers' decisions are limited. Therefore, the objective of this paper was to review how smallholder farmers make decisions on farming practices based on SCFs and the challenges and opportunities thereof. The review shows that the majority of smallholder farmers in Africa make use of either scientific or indigenous knowledge climate forecasts and, in some cases, a combination of both. There are mixed results in the area of evaluating benefits of SCFs in decision-making and farm production. In some cases, the outcomes are positive, whereas in others they are difficult to quantify. Thus, the integration of SCFs into smallholder farmers' decision-making is still a challenge. We recommend that significant work must be done to improve climate forecasts in terms of format, and spatial and temporal context in order for them to be more useful in influencing decision-making by smallholder farmers.

Significance:

- At the farm level, making the right decisions at the right time is rendered even more difficult in light of the increasing frequency of extreme weather patterns.
- The threat of climate change makes accurate seasonal climate forecasting essential for African smallholder farmers.
- Technological, social and interdisciplinary issues, communication and scale are some key challenges which impact the utility and uptake of SCFs in rural smallholder farms.
- The integration of both scientific and indigenous knowledge forecasts is an opportunity for further exploration.

Introduction

Smallholder farmers, defined as farmers who possess small pieces of land largely below 2 ha[1], constitute nearly 60% of the farming population in sub-Saharan Africa and are vital to food security in this region[2]. Simplicity, use of 'old-fashioned' technology, low income, high seasonal labour fluctuations, and women playing a key role in production are some of the main characteristics of the smallholder farming systems.[1] The smallholder farmers grow subsistence crops and one or two cash crops and rely almost solely on household labour. Besides a general lack of resources – such as seeds, insecticides, fertilisers, hay, water – smallholder farmers' high dependence on rainfed farming makes them more susceptible to effects of climate variability and change.[3] Consequently, there is a need to minimise the effects of climate variability and change on smallholders' agricultural production. One way to contribute to improving production is by increasing the use of seasonal climate forecasts (SCFs).

The timely availability of SCFs to smallholder farmers can improve their decisions in efforts to increase and sustain agricultural production.[4] Rainfall amount and distribution, the extent and the commencement date of the rainfall season, as well as the frequency of dry spells, are some of the important climatic factors that influence farming decisions. However, these key climate variables vary substantially from year to year due to climate change.[2] In consequence, an accurate SCF is deemed crucial to benefit smallholder farming in Africa.

Sowing date, which cultivar to plant, the type and amount of fertiliser application, and livestock-related management options are decisions associated with climatic conditions.[5] Several studies indicate that SCFs may have the capacity to increase the resilience of African agriculture to weather shocks and reduce vulnerability to climate extremes such as droughts and floods.[6,7] What remains unclear is how farmers would use SCF information on crop and livestock management decisions and whether doing so would benefit them.[8] The adoption of SCFs in management practices and farming decision-making strategies has been inadequately exercised by subsistence smallholder farmers for various reasons.[5] Some of the reasons cited for low uptake of SCFs in farm decision-making are the complexity and probabilistic nature of the SCF information provided and in some instances incompatibility with existing practices.[9] Thus, it is important that SCFs be presented in formats that suit smallholder farmers' needs. The questions we considered are: how do rural farmers appreciate the value of SCFs; and how do they use SCF information for their benefit? Some studies have provided insight into spatial, temporal and format issues, including challenges in the SCF application to agriculture, but there has not been a comprehensive review of applied social science research that synthesises farmers' perceptions of SCFs as well as the use of SCFs to adapt to climate variability risks.[10]

Therefore, the objective of this review was to determine how smallholder farmers make on-farm decisions based on SCFs and the challenges and opportunities thereof.

Seasonal climate forecasts available to smallholder farmers

Smallholder farmers have access to both scientific and indigenous knowledge SCFs.[11] Scientific seasonal climate forecasts (SSCFs) are delivered through a number of sources, for example, regional climate outlook forums (RCOF), national meteorological offices, and research institutes. SSCFs are disseminated through media like radio, television, newspapers, bulletins, websites, and farmers' workshops. The dissemination approach often involves collaboration with government agricultural officials to assist in the interpretation of SCFs to farmers for the majority of Southern African Development Community countries and agribusiness; for example, in countries such as Burkina Faso and Senegal.[12] In contrast, indigenous knowledge climate forecasts are produced locally by rural communities through environmental observation and traditional experiences.[13] These are disseminated via oral and social communication horizontally in the immediate community and vertically through generations. Although there is some convergence between SCFs and indigenous knowledge system (IKS) forecasts, the following sections provide some distinction between the two sources of SCFs.

Scientific seasonal climate forecast products

RCOF and national meteorological services are the main providers of SSCF information for agriculture. National meteorological services provide mainly weather forecasts (temperature, rainfall, frost, etc.) on a daily basis, but they also work with RCOFs for SCFs. RCOFs produce and deliver seasonal forecasts to stakeholders in climate-sensitive sectors in Southern (SARCOF), Eastern (GHACOF), Western (PRESAO) and Central Africa (PRESAC) (Table 1).

Table 1: Regional climate outlook forums (RCOFs) in sub-Saharan Africa

Forum	Main seasonal climate products	Issuing period	Forecasted seasons
Southern Africa RCOF (SARCOF) (Southern Africa)	Rainfall, temperature, frost, food security status	Aug/ Sep	Oct–Mar
Greater Horn of Africa COF (GHACOF) (Eastern Africa)	Rainfall, temperature, frost, food security status	Aug, Feb	Oct–Dec, Mar–May
Prévision Saisonnière en Afrique de l'Ouest (PRESAO) (West Africa)	Rainfall, temperature, frost, food security status	May	Jul–Sep
Prévision Saisonnière en Afrique Centrale (PRESAC) (Central Africa)	Rainfall, temperature, frost, food security status	Sep/Oct	Oct–Dec

Adapted from Hansen and Mason[12]

The scientific forecast products are predominantly rainfall and temperature estimates. Additional products may include frost and other extreme weather events such as cyclone occurrence. Scientific forecast alludes to prepared information and products about the atmosphere–ocean processes over short (hours to days) and long (seasonal to decadal) scales.[13] However, scientific forecasts are not normally packaged to match the requirements of rural farmers in terms of the content, scale accuracy and reliability. According to Vermeulen et al.[14], these variables have constrained the extensive use of SCF among rural smallholder farmers. For most African countries, the current SCFs show a bias towards the prediction of normal conditions because of limited forecasting skill. A rainfall forecast expressed as below normal to a smallholder farmer may be inadequate for the farmer to make a clear decision on farm management. This is because the meaning of the rainfall prediction of below normal must be interpreted in terms of the expected volume and distribution of the rainfall. For example, the volume of expected rainfall helps farmers choose the crop variety. The distribution of rainfall is important in determining the timing of field operations such as when to plant, when to fertilise and when to weed. The insufficient number of adequately equipped data recording weather stations is cited as the main challenge with scientific climate information in Africa[15], especially in rural communities. This challenge influences the analysis of the past climate and the capacity to create SCFs that suit local level contexts. As a result, the reliability and accuracy of the SCFs are compromised. The methods of communication used to access these data or information are also not available to all rural farmers.

The potential for SCFs of rainfall for parts of Africa is still high. However, the capacity to forecast seasonal rainfall remains variable within diverse areas of the continent.[16,17] Moreover, SCF data are for the most part supply driven, at the national level, and reflective of farmers' needs.[17] In effect, smallholder farmers eventually revert to IKS for what they deem to be more accurate forecasts.

Indigenous knowledge seasonal climate forecast products

IKSCF plays an important role in climate forecasting in Africa's smallholder farming communities, particularly in occasionally predicting local weather information and frost. The term 'indigenous knowledge' is entrenched within the literature; however, other terms such as local, ethnographic, traditional or folk knowledge, are also used.[18] In this review, the term 'indigenous knowledge' was adopted to refer to the sum of facts and place-based knowledge known or learnt from cumulative day-to-day experience, or acquired through observation and study, and handed down from generation to generation by individuals and communities.[19,20]

There are concerns over incorrect IKSCF application and changes in baselines utilised because of changing climate conditions, increasing population and other natural pressures.[11,21] IKSCF is suggested by some studies as an appropriate entry point for climate change and adaptation research.[22,23] To ensure effective change in practices by smallholder farmers, climate information from different source needs to be translated into attestable formats to enable creation of a SCF that is beneficial for farm decision-making at given temporal and spatial scales.[15] The translation should involve the climate-affected smallholder farmers and other key stakeholders, including meteorological services.

Comparison between SSCF and IKSCF products

The SSCFs differ from IKSCF in scale and, to some extent, in the indicators used. Some of the principles of prediction of the indicators like wind flow and temperature changes of IKSCFs converge with those of SSCFs. The SSCFs are developed using indicators such as wind and sea surface temperature, which are primarily meteorological, whereas IKS seasonal climate is highly specific to the local area. IKSCFs are derived from an intimate interaction with micro-environment observations made over a period of time. SSCFs are generated at a much larger geographical scale. The reliability of the IKSCF indicators is not guaranteed, but they help the farmer to prepare for the timing and distribution of rainfall, whereas SSCFs help farmers prepare for the volume of rainfall.[24]

Value of SCFs on farm management decisions

Although there has been continuous improvement in the technology of climate forecasting to manage climate risks, it has been problematic to measure the value of SCFs in many uses, especially in smallholder agriculture. The value of SCFs can be defined as the net benefit a smallholder farmer incurs from their use,[25] which depends on the farmer's readiness to diverge from past decisions, the characteristic anticipated climate conditions, and the possible distribution of SCFs with other communities.[17] In some developing countries, studies indicate an increase in farmers' income resulting from the provision and utilisation of SCFs.[21,26]

So why is the method of evaluating the socio-economic value of SCF so problematic? A number of researchers agree that a prerequisite for the value of SCF is that their use should result in changes in farm management decisions,[27,28] subsequently bringing about outcomes that differ from those based on maintaining the status quo. Based on the SCF deviation from long-term average approach, Garbrecht and Schneider[29] designed a technique to assess the usefulness of SCFs. According to Garbrecht and Schneider[29], the usefulness of SCFs is a component of the deviation of the

SCF from the long-term average and this helps smallholder farmers adjust their farm management decisions in line with the deviations. Hence it is important to look at the opportunities and challenges in SCFs.

Opportunities and challenges for effective (scientific) SCFs

In addition to SCFs, other factors such as input costs, target markets and production level also play an important role in agricultural decision-making.[26] The largest opportunity for SCF is thus to take an holistic approach in the provision of climate forecasts to smallholder farmers that would take into account context, socio-economic status of the farmer, and technical aspects of the forecasts, e.g. skill and format. Interdisciplinary studies have been suggested as a way of exploring farm decision-making and integration of social and climate science in order to enhance the value of SCFs.[30] Success in the use of SCFs in decision-making has occurred when forecasts are delivered in participatory modes.[31] There are, however, many challenges.

Technical constraints include the spatial and temporal resolutions of forecasts. Traoré et al.[32] argue that 'high spatial resolution is required to allow management decisions on a field-scale'. Smallholder farmers' spatial scale refers to village or ward level. Farmers' decisions on cropping-cycle activities and operational options require field-scale SCF information. Studies have also shown that the timing of available forecasts can negatively affect smallholder farmers' production activities if not issued in line with key farming timelines for planting, weeding, etc.[33-35] In other words, scientific SCFs should be delivered on a very regular basis and in time for farmers to be able to make informed decisions on short (monthly) and seasonal timelines. Furthermore, social and economic barriers, resulting in a divide between consumers and producers of SCF[34,35], are a hindrance to the uptake of SCFs. Insufficient institutional ability to successfully convey and utilise climate information has also been cited as a barrier to the uptake of SCFs.[13]

The use and benefits of SCF among smallholder farmers have been constrained by legitimacy, limited access, limited skills and understanding, and data scarcity.[12] The reasons for poor utilisation of SCFs by smallholder farmers include perceived low forecast accuracy, out of context forecasts, short forecast lead time, inflexible farm management and other non-climatic risks like markets changes. Table 2 summarises the challenges facing farmers in climate forecast use. According to Hansen and Mason[12], and illustrated in Table 2, the challenges can be grouped into three categories: information content, access and socio-economic challenges.

Interdisciplinary studies have been cited as an emerging intervention to improve the value of SCFs. This involves the exploration of agricultural decision-making with the integration of social and climate sciences.[26] The incorporation of social science will assist with the inclusion of farmers' opinions (as well as IKS) to make the forecast more usable for smallholder farmers. Despite some studies to evaluate the possibility of integrating IKS with scientific forecasts, not much has been done to assess the extent to which IKS influences decisions. As such, IKS could offer an entry point into the assessment of how to integrate forecasts in farm management decisions.[22,23] Arunrat et al.[21] also suggested that the use of IKS should be regarded as the basis for climate communication processes to ensure the formulation of relevant decisions when uncertainty arises for smallholder farmers.

Conclusion

The majority of smallholder rainfed farmers in Africa make use of either scientific or IKS derived forecasts, and in some cases, both SCF and IKS. The distinction between the two is that IKS is provided locally by the farmers themselves through observation of their environment, whereas SCFs are provided externally and remotely and allude to prepared climate information. Both systems of climate forecast have advantages and limitations. Drawing from the literature, we find that, at the farm level, reaching the right decisions at the right time is rendered even more difficult in light of increasing frequency of extreme weather patterns. The threat of climate change makes accurate climate forecasting essential for African smallholder farmers. Nonetheless, a SCF is only useful to a particular recipient if it is sufficiently accurate, timely and relevant to the actions that the recipient can take to make the right decisions to improve agricultural production. The usability of forecasts strongly depends on the characteristics of users, inclusive of both temporal and spatial aspects.

Technological, social and interdisciplinary issues, communication, and scale are some key challenges which impact the utility and uptake of SCFs in rural smallholder farms. Integration of SCF and IKS is an opportunity that could be explored but requires further research. SCFs have attracted a lot of research attention in recent years, but most research has focused on improving forecasting skills, reliability, accessibility and accuracy. Indeed, these are key areas that require continuous improvement. Nevertheless, as SSCFs are improved, there is also a need to continuously test their usability and influence on decision-making. A good forecast is one that leads to informed decisions and improved agricultural production. There have been mixed results in the area of evaluating benefits of SCF in decision-making and farm production. In some instances, the outcomes have been positive, whereas, in other circumstances, the outcomes have been difficult to quantify. This review shows that there still are some challenges in using SCFs which stem from inadequate understanding around how and why smallholder farmers make decisions. Therefore, the value of and methods

Table 2: Challenges to climate forecast use by farmers

Categories of challenge	Challenges	Impact on farmers decisions	References
Content of the SCF products	Coarse spatial scale and lacks local information	Affects the relevance of the forecast to the farming decisions	Patt and Gwata[36]
	Lack of information about timing of rainfall		Klopper et al.[37]
	Lack of information about season onset or length		Klopper et al.[37]; Archer[38]
	Not clear on temporal scale of the forecast		Klopper et al.[37]
	Forecast accuracy not sufficient		UNDP[39]
Access to SCF information/products	Inequitable access	Timing of farming operations like weeding, planting is affected	Archer[38]; UNDP[39]; Phillips et al.[40]
	Forecasts available too late		UNDP[39]
	Neglected communication of favourable forecasts, bias toward adverse conditions		Phillips et al.[40]
Smallholder farmers' lack of resources	Limited access to draft power	Influences the response to SCF	Phillips et al.[40]
	Limited access to seed of desired cultivars		Klopper et al.[37]
	Limited access to credit		Klopper et al.[37]
	Limited access to fertile soils		Klopper et al.[37]

Adapted from Hansen and Mason[12]

to improve these SCFs with respect to smallholder farmers need to be further evaluated.

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Authors' contributions

B.C. was responsible for the conception and design of the study; reviewing the literature; and writing the initial draft. A.M. was responsible for revising the article and providing final approval of the version to be published; student supervision; and oversight of the study. K.N. was responsible for writing and revising the manuscript; and student supervision. E.E.P. was responsible for writing and revising the manuscript.

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Spatio-seasonal variations in the faecal bacterial community of Zulu sheep grazing in communally managed rangeland

The adaptation of Zulu (Nguni) sheep (*Ovis aries*) to environmental stress and survival under extensive conditions makes them uniquely important to rural Nguni farmers of South Africa. Here, the faecal bacterial community of five Zulu sheep populations managed under extensive conditions across summer and winter seasons was investigated in order to understand the influence of prevailing seasonal factors. Bacterial operational taxonomic units (OTUs)/species (at 97% 16S rRNA gene similarity) in Zulu sheep faeces were more diverse in winter than in summer at most (80%) sites and varied between seasons at specific sites. Firmicutes was the most abundant phyla in both summer and winter seasons, while the relative abundance of Actinobacteria reduced in 80% of sites from summer to winter. The genera (or family) such as *Akkermansia*, *Eubacterium coprostanoligenes* group, *Intestinibacter*, R-7 group (family *Christensenellaceae*), *Ruminococcus*, *Ruminoclostridium*, *Treponema* and UCG-005 (family *Ruminococcaceae*) were relatively more abundant and belonged to a 'core microbiome' of Zulu sheep faeces. Between seasons, *Acinetobacter*, *Jeotgalicoccus*, *Methanobrevibacter*, *Phascolarctobacterium* and *Planomicrobium* were differentially abundant. Overall, results suggest increased richness and diversity of bacteria from summer to winter which may be related to spatio-seasonal variations in grazing management, forage types and availability. This observation serves as baseline evidence, justifying further controlled studies investigating, amongst other factors, effects of forage type and availability across seasons on ruminal microbiota of Zulu sheep grazing in communally managed rangelands.

Significance:

- Spatio-seasonal dynamics in the bacterial community of Zulu sheep faeces suggest differences in forage type and availability across sites potentially influence faecal bacteria of Zulu sheep.
- The study provides a basis for further controlled studies investigating the influence of environmental factors on rumen and faecal microbiomes of Zulu sheep.

Introduction

Zulu sheep (*Ovis aries*) are one of the oldest and most prominent indigenous Nguni sheep in KwaZulu-Natal Province, South Africa. These sheep play a major role in the livelihood of rural farmers, including being a source of meat, manure, hides and income as well as serving socio-cultural purposes.[1,2] The Zulu sheep breed possesses traits for survival and adaptation to environmental stresses such as drought and animal diseases peculiar to the KwaZulu-Natal region of South Africa.[3] The sheep are commonly grazed under extensive production on marginal ecological areas which are not suitable for crop cultivation.[1,4] Moreover, animal production under extensive agriculture is notably influenced by several environmental conditions, which include changes in forage availability and weather patterns (or seasons).[5-9] This necessitates the seasonal assessment of the nutritional requirements and health status of animals in pastures.

Recent studies in ruminants indicate that the rumen microbiome varies with diet and host breed.[10] According to McSweeney and Mackie[11], ruminants and their gut-associated microbes have mutually co-evolved while adapting to climatic and botanic environments. The mutualistic contributions of rumen microbes include the breakdown of substrates (which the ruminant host cannot normally metabolise) and the synthesis of essential vitamins.[12,13] Overall, rumen microbes contribute to the animal's well-being by performing nutritional, physiological, immunity and protective functions.[11,12,14]

Unfortunately, the composition and abundance of this functionally important gut microbial species can be altered by several factors, which include antibiotic use, age of the animal, geographical location, seasonal changes, feeding regimes, forage quality and the health of the host animal.[15-17] Such factors may predispose increased faecal shedding of rumen microbiota, including some pathogenic species.[18-20] For example, cold stress in animals[5,6,9,17] could predispose the migration of microbial cells from the rumen to the lower tract[6,21]. Similarly, the faecal shedding of some bacterial species, including *Escherichia coli* and *Listeria monocytogenes,* has been correlated with an increase in temperature and antibiotic administration in dairy cows.[19,22] Presently, there is little or no information on the faecal microbiota of indigenous Zulu sheep breeds grazing in their native environment. It is also unknown how seasonal factors influence microbial shedding in the faeces of Zulu sheep populations in communally managed pastures. Therefore, this pilot study aimed to investigate the spatial and seasonal variation in the faecal bacterial community of Zulu sheep grazing in pasture-based systems. This pilot study serves to present baseline data for further controlled studies investigating the effect of forage type and environmental conditions on the dynamics of the rumen and faecal bacteria of Zulu sheep.

Materials and methods

Study sites and sample collection

The Zulu sheep populations sampled were from five communally managed rangeland-based production systems (extensive conditions) in KwaZulu-Natal Province of South Africa: Mooi River (MR), Msinga (MSI), Jozini (JOZ),

KwaMthethwa (MTH) and the University of Zululand (UZ) (Figure 1). The size of the herd at all locations ranged from an estimated 55 to 120 sheep. These study sites are located at altitudes of 90 m to 1900 m above sea level. Annual rainfall for this area ranges from 600 mm to about 1400 mm, while temperature ranges from 16 °C to 25 °C in winter (June to August) and from 23 °C to 33 °C in summer (mid-October to February).[23] Winter months are cold and dry, while summer months are warm and wet. The forage grasses at these sites include *Hyperrhenia hirta* (thatching grass), *Pennisetum clandestinum* (Kikuyu grass), *Cynodon nlemfuensis* (African Bermuda grass) and *Panicum maximum* (Guinea grass) (Table 1).

Table 1: Dominant grass species in the study locations in KwaZulu-Natal, South Africa

Study area	Dominant grass species	
	Scientific name	Common name
University of Zululand	*Hyperrhenia hirta*	Thatching grass
	Pennisetum clandestinum	Kikuyu grass
KwaMthethwa	*Cynodon nlemfuensis*	African Bermuda grass
Jozini	*Panicum maximum*	Guinea grass
	Pennisetum clandestinum	Kikuyu grass
Mooi River	*Pennisetum clandestinum*	Kikuyu grass
Msinga	*Hyperrhenia hirta*	Thatching grass

In each of the five sites, 20 healthy (based on physical inspection) adult sheep were randomly sampled (without respect to sex) in the summer (October/November) and winter (June/July) seasons of 2014 and 2015, respectively, amounting to a total of 200 samples. For each individual sheep, faecal samples were collected aseptically from the rectum and immediately placed on ice. All procedures performed on animals during sample collection were in accordance with the ethical standards of the UniZulu Research Ethics Committee (certificate number UZREC171110-030 PGM 2015/250). Samples were stored at -20 °C in the laboratory prior to genomic DNA extraction.

Extraction of genomic DNA

Genomic DNA was extracted directly from approximately 150 mg of the faecal sample by using the ZR Fecal DNA MiniPrep Extraction kit (Zymo Research, Irvine, CA, USA) according to the instructions of the manufacturer. The integrity of DNA was verified by agarose gel electrophoresis while DNA concentration was determined using a NanoDrop Spectrophotometer (ND1000, NanoDrop Technologies Inc., Wilmington, DE, USA). DNA was stored at -20 °C prior to downstream analysis.

16S rRNA gene library preparation

The bacterial community in Zulu sheep faeces was analysed using high-throughput sequencing of the partial 16S rRNA gene (hypervariable region V3-V4) on the Illumina MiSeq sequencer (Illumina Inc., CA, USA). A partial 16S rRNA gene library was constructed by using universal primers 341F (forward) and 805R (reverse)[24] as previously described[25,26]. Because an objective of this pilot study was to obtain an overview of the core bacterial population in each sampling location per season, all genomic DNA of samples from each location per season (sample size, $n=20$) were pooled in equal proportions (equimolar basis) prior to library preparation. Library preparation was then duplicated for each DNA pool. Following library preparation, a 2 x 300-bp paired-end sequencing run was performed on the Illumina MiSeq sequencer (Illumina Inc., CA, USA). The DNA extraction, library preparation and Illumina sequencing were performed at the Microbiology Group of the Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa.

Bioinformatic analyses

Sequence reads were first de-multiplexed and trimmed of primers and barcode sequences by using the on-board MiSeq reporter software (Illumina Inc., CA, USA). Sequence quality was further assessed using Fastqc (Babraham Bioinformatics, UK; https://www.bioinformatics.babraham.ac.uk/index.html) prior to assembling paired reads and quality-filtering to remove sequences with ambiguous bases and spurious length by using PANDAseq software.[27] Thereafter, assembled quality-filtered reads were clustered into operational taxonomic units (OTUs) at

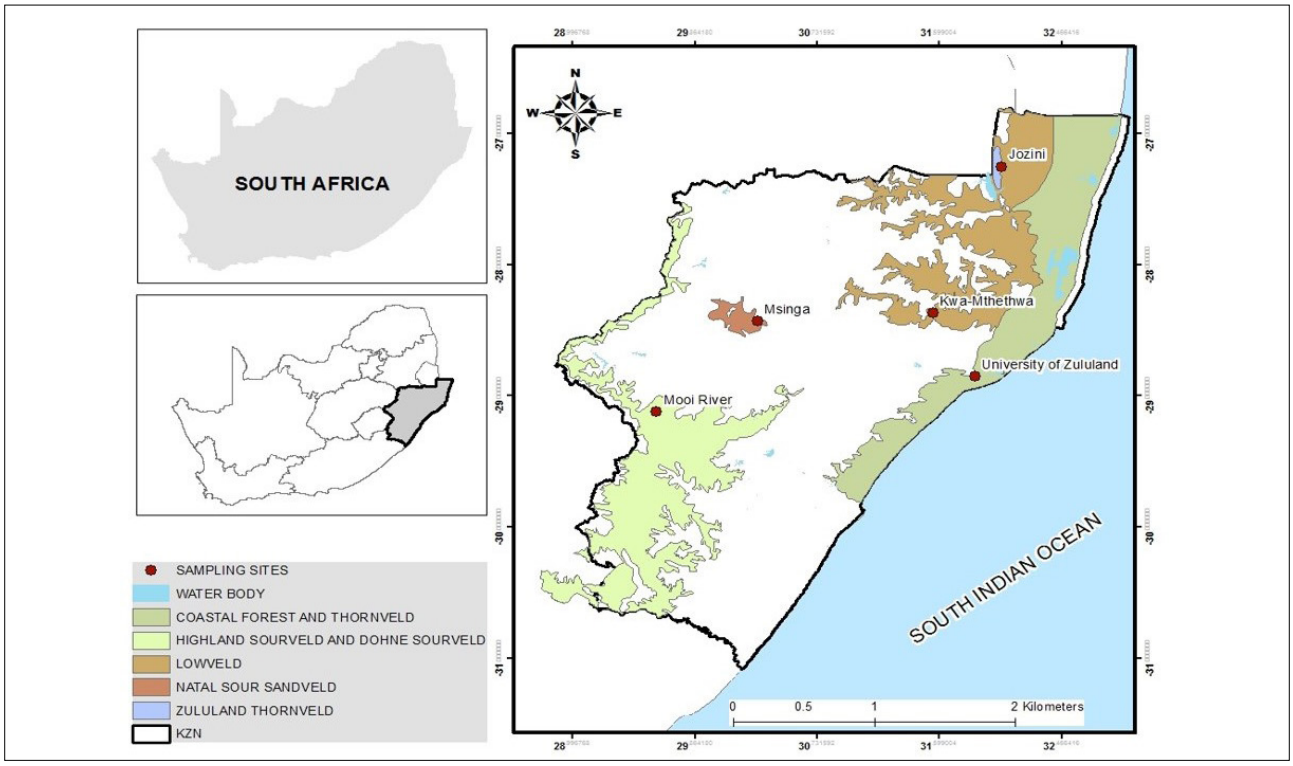

Figure 1: Map of South Africa showing the geographical location of study sites.

97% 16S rRNA gene sequence similarity by using the closed-reference OTU picking script in Quantitative Insight into Microbial Ecology (QIIME) software (version 1.9)[28] and by aligning against the Silvangs rRNA database (release 123)[29]. Similarly, the taxonomic assignment of OTUs was performed using the Silvangs rRNA database taxonomy. The OTU table was depleted of singletons and rarefied to a single depth before computing alpha and beta diversities in QIIME software. Alpha diversity indices computed included observed OTUs (richness), Chao1 and Shannon–Wiener index of diversity (*H'*). For beta diversity, Bray–Curtis dissimilarity distances between samples was computed using the vegan package (version 2.5.5)[30] of R software (version 3.5.3)[31] and subsequently subjected to principal coordinate analyses by using the 'ape' package (version 5.3)[32]. Additionally, a core microbiome analysis was performed in QIIME to determine the bacterial phylotypes which are present and relatively dominant in all faecal samples.

Statistical analysis

Except otherwise stated, all statistical analyses were performed in R software. Alpha diversity indices were subjected to Wilcoxon rank-sum test for comparison between seasons and to Kruskal–Wallis H-test for comparisons across sites. Statistical tests for differences in bacterial community composition and structure amongst groups were performed by using a two-way (season x site) permutational multivariate analysis of variance (PERMANOVA) by using the 'adonis ()' function of the vegan package. Permutational test of homogeneity of multivariate dispersion (PERMDISP) was further used to test the difference in spread among groups. Before multivariate analysis, singletons and OTUs present in only one sample were eliminated by using the 'dropsec ()' function in the labdsv package (version 1.8.0).[33] Multivariate analyses were performed on the $\log_{10}$-transformed relative proportion of each OTU within a sample by using the 'decostand ()' function in the labdsv package of R software. The log-transformation was of the order $\log_{10}(x)+1$, where $x > 0$.[34] Lastly, the linear discriminant analysis effect size (LEfSe)[35] was used to determine differential abundant taxa between seasons as well as amongst sites. For LEfSe, default parameters (i.e. Wilcoxon rank-sum test or Kruskal–Wallis test $p<0.05$, linear discriminant analyses (LDA) >2.0) were used. The output from LEfSe was further visualised as an annotated cladogram using GraPhlAn.[36]

Data accessibility

Raw sequence reads obtained in this study are available in the Sequence Read Archive of the US National Center for Biotechnology Information (https://www.ncbi.nlm.nih.gov/sra) under the BioProject accession number PRJNA356736.

Henceforth, wherever applicable, abbreviated site names with 'W' appended at the end (e.g. MRW, MSIW, JOZW, MTW and UZW) denote winter samples, while abbreviated site names with 'S' appended at the end (e.g. MRS, MSIS, JOZS, MTS and UZS) denote summer samples. Duplicate samples have a '2' added after 'W' or 'S'.

Results

Spatio-seasonal comparison of alpha diversity OTUs in Zulu sheep faeces

In total, 2 151 796 sequence reads were obtained after quality trimming and assignment of reads into OTUs. Following rarefaction (without replacement) of sequences at a depth of 11 700 sequences per sample, a total of 5530 OTUs (1385 OTUs unique to summer, 1379 OTUs unique to winter and 2766 shared OTUs) were obtained in all samples (data not shown). The richness, Chao1 richness estimation and Shannon–Wiener index of diversity for OTUs in faeces of each Zulu sheep population did not significantly differ between summer and winter (Wilcoxon rank-sum test, $p>0.05$) (Table 2). Similarly, differences in these alpha diversity measures were not significant (Kruskal–Wallis test, $p>0.05$) across sites during either summer or winter. However, higher OTU richness and diversity were observed in winter compared to summer in all but one (Msinga) location (Table 2). Overall, these results suggest that the faecal bacterial community of Zulu sheep is more diverse in winter, which may indicate increased shedding of bacteria in faeces during the winter season compared to the summer season. The non-significant ($p>0.05$) difference in Chao1 but significant differences in richness and Shannon–Wiener index of diversity between overall winter and summer faecal OTUs may be due to the lack of sufficient sub-sampling depth as revealed by the rarefaction curve of Figure 2. Thus, indications are that the observed richness and diversity of OTUs are underestimated.

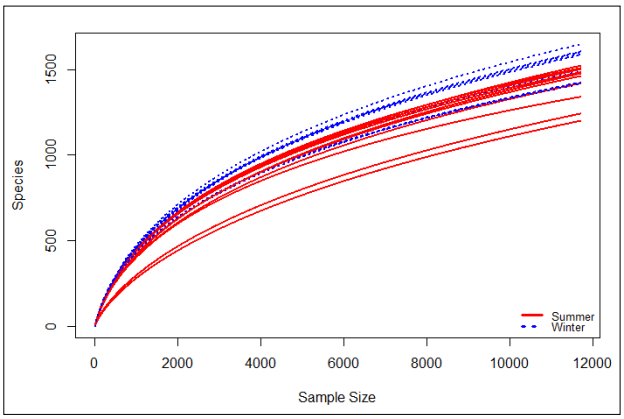

Figure 2: Rarefaction curve of bacterial diversity (operational taxonomic units) in Zulu sheep faeces across winter and summer. Rarefaction curve was constructed using the vegan package of R software.

The unweighted (absence/absence of taxa) and weighted (absence/absence and relative abundance of taxa) Bray–Curtis distance's principal coordinates analysis (PCoA) plots of the OTUs distributions (at 97% 16S

Table 2: Alpha diversity indices of faecal bacteria of Zulu sheep

Site	Observed OTUs		Chao1		Shannon–Wiener Index (*H'*)	
	Summer	Winter	Summer	Winter	Summer	Winter
JOZ	1379±56[a]	1451±53[a]	2126±282[a]	2151±106[a]	8.50±0.00[a]	8.83±0.04[a]
MR	1514±10[a]	1594±15[a]	2387±177[a]	2446±4[a]	8.91±0.00[a]	9.00±0.04[a]
MSI	1220±30[a]	1601±1[a]	2101±37[a]	2501±113[a]	6.68±0.19[a]	8.63±0.15[a]
MTH	1491±13[a]	1424±1[a]	2299±96[a]	2218±20[a]	8.86±0.02[a]	8.80±0.06[a]
UZ	1468±11[a]	1618±40[a]	2279±71[a]	2499±100[a]	8.50±0.02[a]	9.07±0.06[a]
Average	1414±115[b]	1537±90[a]	2239±164[a]	2363±169[a]	8.29±0.87[b]	8.87±0.18[a]

OTU, operational taxonomic unit
Values are mean±s.d. of duplicate determinations. Values for observed OTUs and Chao1 are rounded off to the nearest whole number.
Different superscript letters across rows for each alpha diversity index denote significantly different values (Wilcoxon rank-sum test, p>0.05). There are no differences in alpha diversity indices amongst sites during each season (Kruskal–Wallis, p>0.05).

rRNA sequence similarity) shown in Figure 3 indicate that the bacterial community in Zulu sheep faeces at given sites differed between winter and summer seasons. Distinctively, the bacterial community composition (unweighted) and structure (weighted) of faeces in summer were very dissimilar from their winter counterparts in Msinga and Jozini sites (Figure 3a,b), suggesting that large differences exist in the type and abundance of bacteria shed in the Zulu sheep faeces between winter and summer. However, the close associations in the faecal bacterial community of Zulu sheep in Mooi River rangelands during winter and summer may suggest that prevailing environmental conditions in this location are similar across winter and summer seasons.

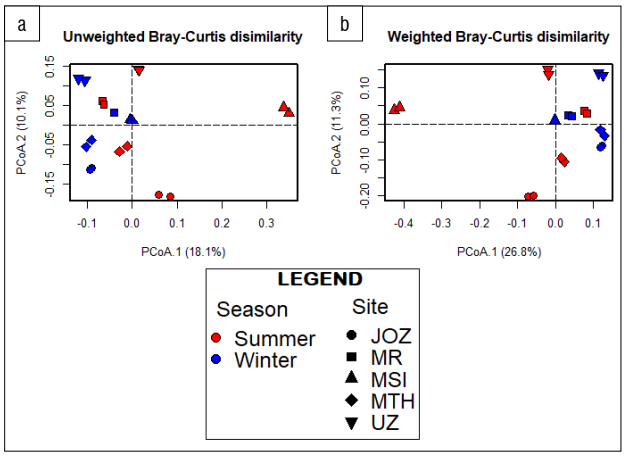

Figure 3: Principal coordinate analyses (PCoA) of Bray–Curtis distance matrix showing differences between summer and winter faecal bacterial communities of Zulu sheep: (a) unweighted and (b) weighted. Effects of interaction between season and site are significant (PERMANOVA $p<0.001$).

PERMANOVA of both unweighted and weighted Bray–Curtis dissimilarities between bacterial OTU diversity of Zulu sheep faeces show that effects of interaction between factors (site and season) are significant ($p<0.001$) for both unweighted and weighted Bray–Curtis dissimilarities between sample groups. However, a significant PERMDISP ($p<0.001$) result observed for individual effects suggests that differences between sites and seasons may be due to lack of homogeneity in spread within each sample group. Thus, the 'location' and 'site' effects on bacterial community composition and structure suggested by PERMANOVA may be due to other co-founding or random variables, including sampling and site-specific variations. This assumption is further supported by a PERMANOVA *r*-square value which indicates that the site × season interaction accounts for only 24.4% and 29.0% variations in the Zulu sheep faecal bacterial community composition (unweighted) and structure (weighted), respectively.

Taxonomic diversity of relatively abundant and core phylotypes of Zulu sheep faecal bacteria

Most of the OTUs were taxonomically assigned to 21 phyla (Figure 4). In Figure 4, the relative abundance of phyla in Zulu sheep faeces differs among sites and between seasons. Firmicutes was the most abundant phylum of the faeces in summer (64.96±5.32%) and winter (64.52±9.36%) (Figure 4).

The phylum Bacteroidetes was the second most abundant phylum in winter at all sites, and in summer at all but the Msinga site, where Actinobacteria was the second most abundant phylum (Figure 4). Other phyla that constituted at least 1% relative abundance of the Zulu sheep faecal bacteria in both summer and winter included Proteobacteria, Spirochaetae and Verrucomicrobia. On average, the Firmicutes: Bacteroidetes ratio was approximately 4:1 (64.96±5.32%: 15.39±8.29%) in summer and 2:1 (64.52±9.36%: 26.02±8.74%) in winter. From summer to winter (the chronological order of sample collection), the Actinobacteria phylum population generally reduced in the faeces of Zulu sheep in a majority (80%) of the sites (Figure 4).

At the family taxa level, *Ruminococcaceae* was the most abundant in summer (29.95±10.03%) and winter (33.77±3.50%) (Table 3). Other families, which constituted at least 5% relative abundance of OTUs in either summer or winter included *Bacteroideceae*, *Christensenellaceae*, *Lachinospiraceae*, *Micrococcaceae*, *Peptostreptococcaceae*, *Planococcaceae*, *Prevotellaceae* and *Rikenellaceae* (Table 3). Across locations, *Rumminococcaceae* was the most abundant family in the faeces of Zulu sheep in the winter. However, in the summer, *Rumminococcaceae* was the most abundant in only four of the five study sites; in the remaining one location (Msinga), *Planococcaceae* was the most abundant family (data not shown).

The relative abundance of OTUs at the genera taxa level (family names are provided where OTUs are unclassified at genus taxa level) which constituted at least 1% maximum relative abundance in all study sites are shown in the heat map of Figure 5. Summarily, species of the genera (or family) such as R-7 group (family: *Christensenellaceae*), UCG-005 (family: *Ruminococcaceae*) and *Intestinibacter* were amongst the relatively more abundant genera across samples (Figure 5). In addition to the aforementioned relatively more abundant phylotypes, a core microbiome analysis (OTUs present in all samples) revealed that a majority of the phylotypes presented in Figure 5, including *Akkermansia, Alistipes, Bacteroides, Eubacterium coprostanoligenes* group, NK4A136 group (family: *Lachnospiraceae*), *Phocaeicola*, RC9 gut group (family: *Rikenellaceae*), *Ruminoclostridium, Ruminococcus*, UCG-003 (family:

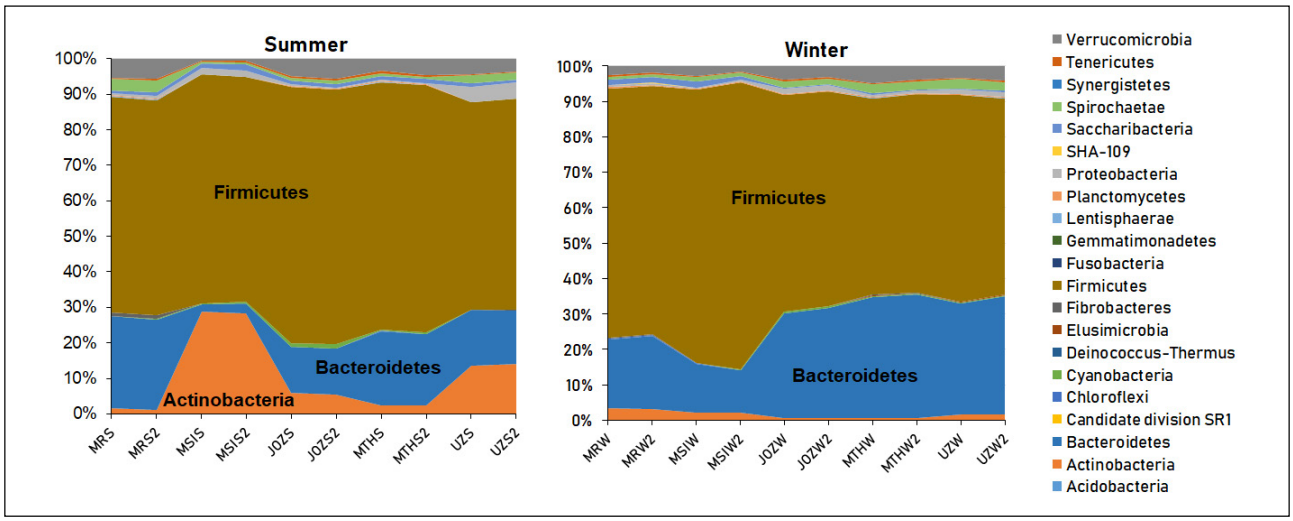

Figure 4: Relative abundance of bacterial phyla of Zulu sheep in summer and winter.

Prevotellaceae), UCG-004 (family: *Prevotellaceae*), UCG-010 (family: *Ruminococcaceae*), UCG-013 (family: *Ruminococcaceae*) and *Treponema* (Figure 5) constitute the 'core microbiome' of Zulu sheep faeces.

Table 3: Relative abundance of phylotypes at family taxonomic level

Summer		Winter	
Families	**Relative abundance (%)**	**Families**	**Relative abundance (%)**
Ruminococcaceae	29.95±10.03	*Ruminococcaceae*	33.77±3.50
Christensenellaceae	8.67±2.69	*Christensenellaceae*	8.73±1.64
Peptostreptococcaceae	7.03±2.37	*Peptostreptococcaceae*	8.62±4.70
Lachnospiraceae	6.26±1.54	*Rikenellaceae*	8.51±2.89
Micrococcaceae	6.06±9.36	*Lachnospiraceae*	7.28±1.87
Rikenellaceae	4.59±2.05	*Prevotellaceae*	5.92±2.30
Verrucomicrobiaceae	3.97±1.84	*Bacteroidaceae*	5.48±1.27
Planococcaceae	3.86±6.09	*Verrucomicrobiaceae*	3.27±0.96
Bacteroidaceae	3.82±1.97	*Erysipelotrichaceae*	2.23±0.96
Prevotellaceae	3.68±2.27	*Spirochaetaceae*	1.79±0.73
Corynebacteriaceae	2.64±3.84	Family XIII	1.64±0.55
Erysipelotrichaceae	2.26±1.03	S24-7 group (order: Bacteroidales)	1.47±0.84
Family XIII	2.16±0.64	Incertae sedis (order: Bacteroidales)	1.37±0.51
Staphylococcaceae	1.91±3.72	p-2534-18B5 gut group	1.22±0.41
Spirochaetaceae	1.58±1.10	Others (families with <1% relative abundance)	8.71±0.00
Coriobacteriaceae	1.01±0.30		
Others (families with <1% relative abundance)	10.56±0.00		

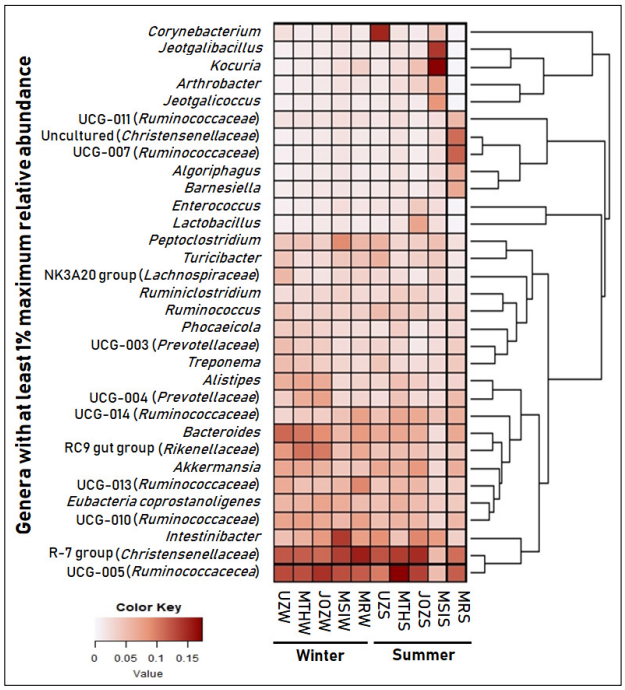

Figure 5: Heat map showing genera with at least 1% maximum relative abundance in at least one sample. Cluster dendrogram is based on average linkage hierarchical clustering of the Bray–Curtis distances of operational taxonomic units at genus taxa level. Average abundance value of the duplicate sample libraries was used. Family taxonomic classification is provided in parenthesis where genus taxonomic names are potentially ambiguous.

Spatio-seasonal differential abundance of faecal bacteria

The discriminant analyses revealed that a majority (75%) of the bacteria phylotypes which were discriminatory (Wilcoxon rank-sum test, $p<0.05$, LDA>2.0) between seasonal faecal bacterial communities of Zulu sheep were uncultured (Figure 6). The phylotypes (classifiable at the genus taxonomic rank) *Acinetobacter*, *Jeotgalicoccus*, *Methanobrevibacter* and *Planomicrobium* were differentially more abundant in summer than in winter (Figure 6), whereas *Phascolarctobacterium* was differentially more abundant in winter than summer (Figure 6). Across sites, a total

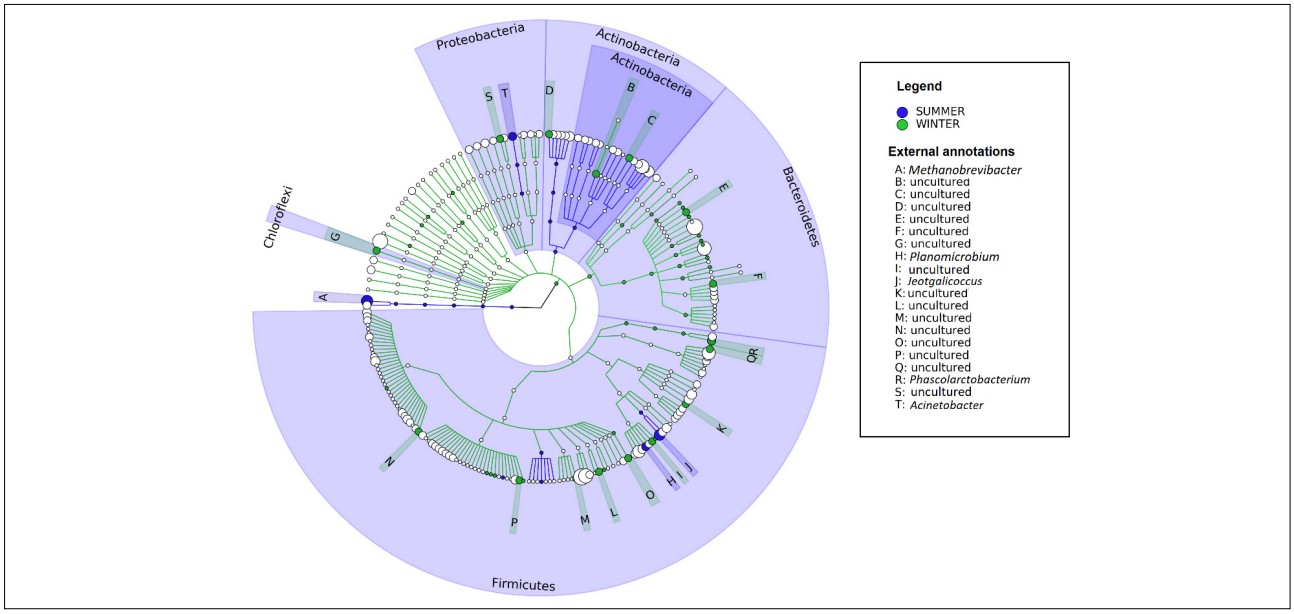

Figure 6: Differentially abundant bacterial phylotypes of Zulu sheep faeces between summer and winter. Rings (from inside out) 1,2,3,4,5 and 6 are the domain, phylum, class, order, family and genus taxonomic ranks, respectively. Only features with a linear discriminatory analysis value > 2.0 are shown.

of 99 features (or phylotypes) were discriminative (Kruskal–Wallis, $p<0.05$, LDA>2.0) across all taxonomic ranks (Figure 7). These phylotypes potentially drive the differences observed among the faecal bacterial community of Zulu sheep populations in multivariate space (Figure 3). In particular, *Bacillus* and *Domibacillus* were differentially most abundant in Jozina while *Atopobium*, *Fibrobacter* and *Saccharofermentans* were differentially most abundant in Mooi River. Similarly, *Alloprevotella*, *Atopostipes*, *Intestinibacter*, *Methanosphaera*, *Olsenella*, *Peptoclostridium* and *Succiniclastium* were differentially most abundant in Msinga, *Alistipes* and *Bacteroides* in KwaMthethwa, while *Acetitomaculum*, *Cellulosilyticum, Enteractinococcus*, *Fastidiosipila*, *Flaviflexus*, *Kandleria, Oligella* and *Turicibacter* were differentially most abundant in the faeces of the Zulu sheep population located at University of Zululand (Figure 7).

Discussion

The dynamics of the faecal microbiota community diversity of ruminants may be driven by several factors including variations in feeding operation, geographical availability and type of forage.[18,19,22] In this study, high-throughput sequencing of the bacterial 16S rRNA gene was used to elucidate the faecal bacterial community dynamics of Zulu sheep populations during winter and summer seasons. Furthermore, the study provided an insight into the potential of Zulu sheep faeces to serve as a source of potential pathogens around grazing environments.

The observed higher faecal bacterial OTU richness and diversity in the winter compared to the summer in a majority (except KwaMthethwa) of the study sites suggest increased faecal shedding of Zulu sheep gut microbes during the winter season. Some studies have shown that cold stress may predispose the increased shedding of rumen bacteria.[21,37,38] The observed higher OTU richness and diversity in winter may be predisposed by variation in diet across summer and winter. A previous study by Shanks et al.[18] on the faecal microbiome of cattle fed in feedlots with different feeds – forage, processed grain and unprocessed grains – suggested that feeding operations or feed type were predictors of the faecal microbiome of cattle compared to the geographical location of the feedlot. Similarly, Callaway et al.[39] reported that the inclusion of dried distiller grains in cattle feeds reduced faecal bacterial diversity in comparison to that in cattle which were fed a basal feedlot diet. These studies essentially show that a link exists between diet and the faecal microbiome of ruminants.

In rangelands such as in the current study, forage type and availability vary along seasonal lines. Between summer and winter, Zulu sheep feed on a variety of feed types, which subsequently predisposes variations in the population numbers of bacterial flora associated with the gut and faeces.[39,40] For example, feed types have been suggested to increase the levels of certain bacteria in the faeces of cattle.[40] Indeed, in the summer season, these regions are usually characterised by adequate agronomic conditions, which favour the growth of forage (grass) species on which the animals graze. It has been reported that the availability of grass species during the summer months influences the animals' preference for forage types. Such preferences include grazing on grass species in the summer to grazing on dry grasses and browsing on trees and shrubs in the dry winter months.[41,42] However, the observed non-significant differences in the bacterial richness and diversity in faeces of most Zulu sheep populations between winter and summer suggest that any potential differences in feed type and availability between seasons are not determinants of the faecal bacterial richness and diversity of Zulu sheep. Nevertheless, the non-significant differences may also be due to the small sample number, pooling of samples in the present pilot study as well as the limitations of next-generation sequencing technology employed in the present study (discussed later).

In multivariate space, differences in bacterial community composition and structure were significantly influenced by an interaction amongst sites and between seasons. Possibly, the differences observed in the faecal bacterial community composition and structure across seasons, particularly in the Msinga Zulu sheep population may be due to the influence of seasonal variation in feed type and availability. Elsewhere, faecal microbial community composition of adult beef cattle was more shaped by feeding operations than by geographical location.[18] However, Durso et al.[43] observed a variation in the faecal bacterial communities of beef cattle which could not be linked to the influence of diet or weather. Further large-scale studies are required to validate the observations made in this study as well as to confirm factors which predispose the large variation (in multivariate space) between the summer and winter faecal bacterial community composition and structure observed in Msinga.[18] In addition, because this study involved sheep breeds under extensive animal management, several co-founding variables – including

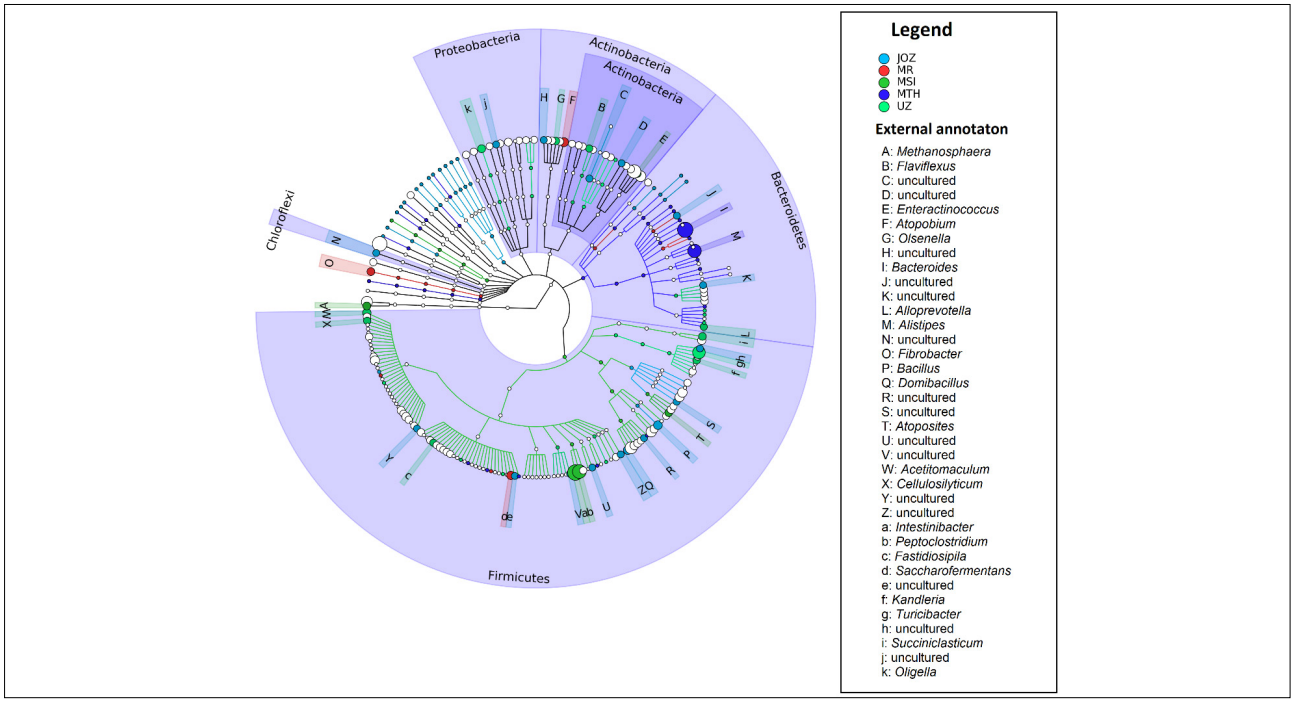

Figure 7: Differentially abundant bacterial phylotypes of Zulu sheep faeces across sites. Rings (from inside out) 1, 2, 3, 4, 5 and 6 are the domain, phylum, class, order, family and genus taxonomic ranks, respectively. Only features with a linear discriminatory analysis value > 2.0 are shown.

environmental parameters, management practices, forage types and availability – render explanations for the faecal bacterial community diversity dynamics inconclusive. Further studies are required to determine the specific contribution and extent to which each of these factors influence the faecal bacterial community dynamics of Zulu sheep. Such further studies will assume a similar approach to that of recent investigations on the faecal microbiome of some ruminants.[44,45]

Firmicutes and Bacteroidetes phyla dominated the bacterial composition of Zulu sheep in both summer and winter seasons. Similar observations have been reported in previous microbiological studies of the faeces of ruminants, including beef and dairy cattle[18,39,45,46] as well as sheep and goats[44,47]. In contrast, the high relative abundance of Actinobacteria in the faecal microbiome of Zulu sheep in the Msinga location is a rather surprising observation when compared to other sites (or populations), to its (Msinga population) winter faecal microbiome, and to other published studies.[18,39,43,44,46,47] The disparity may suggest a stack contrast in prevailing conditions between winter and summer in Msinga, and from those of other sites. The relatively high composition of OTUs belonging to Actinobacteria phyla most likely account for the large bacterial community variation observed in multivariate space between summer samples from Msinga and those of its winter samples as well as those from other sites (Figure 3).

At the family taxa level, the majority of the OTUs belonged to the family *Ruminococcaceae*. The prevalence of bacteria belonging to the family *Ruminococcaceae* is not surprising considering the vast literature reporting their presence in ruminant stomach chambers[48-50] as well as in faeces[18,43,50]. The abundance of *Ruminococcaceae* in ruminant faeces has been linked to carbohydrate-rich diets.[10,51] It has been suggested that *Ruminococcaceae*, along with other families in the Zulu sheep faeces such as *Lachinospiraceae* and *Prevotellaceae,* predominantly contribute to ruminal biohydrogenation and breakdown of complex polysaccharides through the secretion of cellulolytic and hemicellulolytic enzymes.[52-54] At the genus level, several genera, including *Ruminococcus*, *Ruminoclostridium*, *Treponema*, *Akkermansia* and *Eubacterium coprostanoligenes* were relatively abundant (≥1% maximum relative abundance) and present in all Zulu sheep faeces analysed. The presence of these species in all Zulu sheep faeces suggests that they constitute a 'core microbiome' of Zulu sheep faeces. Likewise, the presence of a core microbiome has been reported in previous faecal microbiome studies.[18,44] These core genera largely belong to the families highlighted earlier and are therefore involved in the degradation of a wide range of organic matter, including forage feeds and complex polysaccharides.[10,12,51]

Season-wide and site-wide differential abundance analyses were performed to identify species which statistically varied in relative abundance between summer and winter as well as between sites. Such differential species are likely sensitive to the prevailing seasonal or site effect on Zulu sheep metabolism. For example, studies have shown that faecal shedding of pathogenic microbes may be correlated with temperature.[19,22] Orpin et al.[48] reported that the differences in forage type, feeding duration and rate as well as the flow rate of digesta through the rumen between summer and winter seasons may influence the ruminal microflora in Svalbard reindeer (*Rangifer tarandus platyrhynchus*). Deductively, such differences may also occur in summer and winter faeces of ruminants. More importantly, the differential shedding of these species may reflect conditions in the rumen[39] which could have implications for animal production, particularly in terms of forage digestibility, feed nutrient utilisation and animal performance.[13,55]

More importantly, Zulu sheep faeces may serve as a source of pathogenic species in the vicinity in which they graze. In the present study, some abundant and differentially abundant phylotypes across season or site included genera of which some species are known human pathogens. Such genera include *Enterococcus*, *Treponema* and *Peptoclostridium*. Further studies utilising quantitative polymerase chain reaction (qPCR) of specific gene loci are required to detect and quantify the levels of potentially pathogenic species that may be present in Zulu sheep faeces. In addition, the isolation and characterisation of some of the differentially abundant bacteria may provide insights into their function and potential utilisation as bioindicators of ruminant health as well as for evaluating potential risks associated with Zulu sheep grazing on the environment.

The unavailability of detailed information on the prevailing management practices as well as feed type and quantities available to the Zulu sheep populations during the seasons constitute some of the limitations of this study. Such information is important in order to aid the understanding of possible factors driving the faecal bacteria dynamics across sites and season. As no approach is without limitations, the varying copy numbers of the 16S rRNA gene marker, the low-resolution of the next-generation sequencing approach to detect metabolically active but less dominant species, PCR bias, the inability to identify bacteria to species levels and the possibility of the sequence count rarefaction step to distort the true ecological diversity of a given environment[56,57] are additional limitations of the study. Indeed, these limitations may influence the abundance estimates and richness of bacterial phylotypes reported. Nevertheless, the approach (next-generation sequencing of the 16S rRNA gene) is widely considered to be a robust and rapid method for profiling the bacterial community of any environment at a high-throughput scale.

In conclusion, the faecal bacterial community of Zulu sheep varied along spatio-seasonal lines, thereby suggesting differences in animal management practices and feed type, amongst other factors, across seasons and between locations. The faecal bacterial dynamics of specific species between seasons point towards similar dynamics in the bacterial communities along the stomach chambers of Zulu sheep. Further large-scale and controlled studies are required to investigate the effect of seasonal factors, including forage type and availability, as well as other management practices on the rumen bacterial community of Zulu sheep grazing in communally managed rangelands. Such studies will be important for maximising animal production through improving the digestibility of forage in the sheep rumen across seasonal lines.

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Authors' contributions

N.W.K. and C.C.B. conceived and supervised the study. T.G.X. conducted the sampling. T.G.X., A.K.G. and C.M. performed the laboratory analyses. O.T.E. performed the bioinformatics and statistical analyses. O.T.E. and T.G.X. wrote the first draft of the manuscript. All authors reviewed and approved the final manuscript.

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Irrigation wheat production constraints and opportunities in South Africa

South Africa currently faces a wheat production crisis, suggesting that current policies, research and development projects may not be well aligned to farmer priorities. Through exploratory research, which included field inspections and farmer and researcher interviews, we identified the major constraints to irrigation wheat yield and explored opportunities for improving the yield and farmer profits. The dominant constraint to yield was identified as the low market price for grain, which makes farmers reluctant to invest in inputs for increasing wheat yield. Poor cultivar choice, cereal-based monocropping, the high cost of irrigation, inadequate irrigation water, low crop stands, soil acidity, no-till practices and red-billed quelea (*Quelea quelea*) birds are negatively impacting yields. Most importantly, we highlight a misalignment between current research efforts and farmer priorities. Recommendations for corrective measures necessary to improve yield and farmer profits are provided. This new knowledge will be useful to policymakers and researchers for better orienting investments in research and development projects aimed at addressing the current wheat production crisis in the country.

Significance:

- We highlight a misalignment between current research efforts and farmer priorities in the wheat sector, and provide new knowledge for better orienting investments in research and development projects aimed at addressing the current wheat production crisis.

Introduction

South Africa, like other developing countries, faces the challenge of an increasing population and food insecurity. The national yield of wheat (*Triticum aestivum* L.) decreased by approximately 740 000 tons between 2002 and 2012,[1] leaving a gap of approximately 1 million tons annually, which had to be imported. This trend has continued to the present. A continual decline in wheat production has drawn the attention of both policymakers and researchers. According to the Agricultural Policy Action Plan for 2015–2019, this situation is alarming as the dependency on imported wheat is likely to increase. As such, Vision 2030 of the National Development Plan argues that 'research and development projects in the wheat sector are not coordinated, and alignment to government and industry priorities needs to be improved on'[2]. There are basically two options for increasing wheat production in South Africa: to expand the area under production (horizontal expansion) and to increase yields of existing croplands (vertical expansion). This also must be done in ways that are economically, environmentally and socially sustainable. The increase is unlikely to come from horizontal expansion due to competing land uses from other equally important agricultural sectors.

In this article, we address possibilities for vertical expansion, through a belief that there remains untapped potential to improve irrigation wheat yields and farmer profits in South Africa. Yield gap refers to the difference between the attainable yield and the actual yield.[3] A preliminary study on yield gaps of irrigation wheat in South Africa showed that while yield averages ranged from 6.0 t/ha to 8.3 t/ha, the yield potential ranged from 7.6 t/ha to 11.5 t/ha.[4] Conclusions were that irrigation wheat yields could be increased by 26–38% in the major production areas of South Africa. However, information presented in the yield gap studies was not conclusive regarding solutions for closing the yield gaps.

If there is a need to understand the challenges faced by farmers, it makes the most sense to ask the farmers. Therefore, in search of strategies for increasing irrigation wheat yields and farm profits, exploratory research was carried out to obtain more information on the technical, biophysical and policy constraints of irrigation wheat yield. Exploratory research is conducted for a problem that has not been studied more clearly, with the aim of establishing priorities that may include development of a new research agenda. In this case, research was done through farmer interviews and field observations. The surveys were conducted in collaboration with the National Wheat Cultivar Evaluation Programme (NWCEP) during the 2015/2016 and 2016/2017 wheat production seasons. It was hoped that new knowledge on wheat yield constraints would be revealed, as a step towards identifying solutions to South Africa's wheat production challenge.

As alluded to previously, wheat production is on the decline in South Africa, suggesting that policies, research and development efforts in the industry are likely not aligned with farmer priorities. Hence, this study was extended to also answer the question: Are wheat scientists and policymakers well informed regarding the most important yield constraints on wheat fields in South Africa? It should be noted that the goal of this study was not to criticise wheat researchers, but to propose a new research agenda for the wheat industry – one that is well aligned to farmer priorities, yet builds on the current scientific knowledge.

Methodology

Farm inspections and farmer interviews

The irrigation wheat industry is made up of mostly large-scale commercial farmers, and the smallholder sector is virtually non-existent. From a commercial farmer perspective, production constraints can be classified as either biophysical, technical or policy related. Biophysical factors include climate, soils, water and pests. Technical constraints are related to tillage practices, cultivar choice, fertiliser use, pest management and other production

practices. Policy issues have to do with market price for wheat, as well as input cost and supply, which can be influenced by various policies.

Annually, the Agricultural Research Council – Small Grain (ARC–SG) conducts the NWCEP in all the major irrigation wheat production areas of South Africa, in collaboration with wheat farmers. Representative producers in the cooler central, eastern highveld, KwaZulu-Natal and warmer northern irrigation areas (Figure 1) were identified from the NWCEP. Surveys were conducted by means of diarised face-to-face discussions and telephonic interviews. Ethical clearance was provided by the ARC–SG Research Planning Committee. A purposive sampling strategy was used, as only those farmers who gave researchers permission to visit their wheat fields were considered for this study. Over a period of 2 years, the NWCEP provided opportunity to interview various wheat farmers as well as survey representative irrigation wheat fields in search of yield constraints. A total of 162 farms of wheat grown under centre pivots were surveyed for the study (130 in 2015/2016 and 32 in 2016/2017). The field inspections and interviews were aimed at attempting to understand the way that production practices for wheat are carried out by the farmers. These important production practices are land preparation (tillage or no-till), seeding rates, pest control, fertiliser application, crop rotation, irrigation and yields. In total, 32 farmers were interviewed and expressed their views regarding major constraints to yield on their fields. Wheat cultivar performance and soil fertility data discussed in this article are derived from the on-farm wheat cultivar performance guidelines that are published by the ARC–SG annually. The data are also available online from the ARC website (http://www.arc.agric.za/arc-sgi/Pages/ARC-SGI-Homepage.aspx).

Research scientist and industry expert interviews

Researchers and industry experts interviewed for this study included wheat researchers, experienced employees of various wheat breeding companies, university lecturers who are experienced on wheat, as well as retired personnel who worked in the wheat industry. The data were collected by means of a questionnaire distributed via email. The key question addressed in the questionnaire related to perceptions on the most important yield constraints of irrigated wheat on production lands in South Africa. From the 100 questionnaires distributed, we received 47 responses. Areas of specialisation of the respondents were crop protection (53.1%), plant breeding (4.3%), agronomy (38.3%) and wheat processing (4.3%).

Results and discussion

Farmers' perspective on causes of yield loss

The yield potential of irrigation wheat is attained through planting the best cultivar for the area, use of quality seeds at the correct seeding rate, proper timing of planting, good land preparation, optimal plant stands, balanced fertiliser use, rational irrigation, as well as adequate control of pests. The effectiveness with which these practices are implemented determines the yields obtained by the farmers. Table 1 shows the responses of farmers to three categories of yield constraints, namely technical, biophysical and institutional.

Table 1: Responses of South African wheat farmers to questions regarding yield constraints of irrigation wheat

Category of production constraints		Percentage of farmers
Technical	Soil fertility constraints	6.3
	Shortage/expense of irrigation water	52.2
	Lack of high-yielding cultivars	31.3
Biophysical	Red-billed quelea birds	18.5
	Hail damage	3.0
	Heat damage	9.4
	Take-all fungus (*Gaeumannomyces graminis* var. *tritici*)	3.0
	Insect pests and weeds	0.0
	Poor soil	0.0
Policy	Low market price of wheat	93.8
	Poor research support and extension	12.5
	High input cost for electricity and fertilisers	68.8

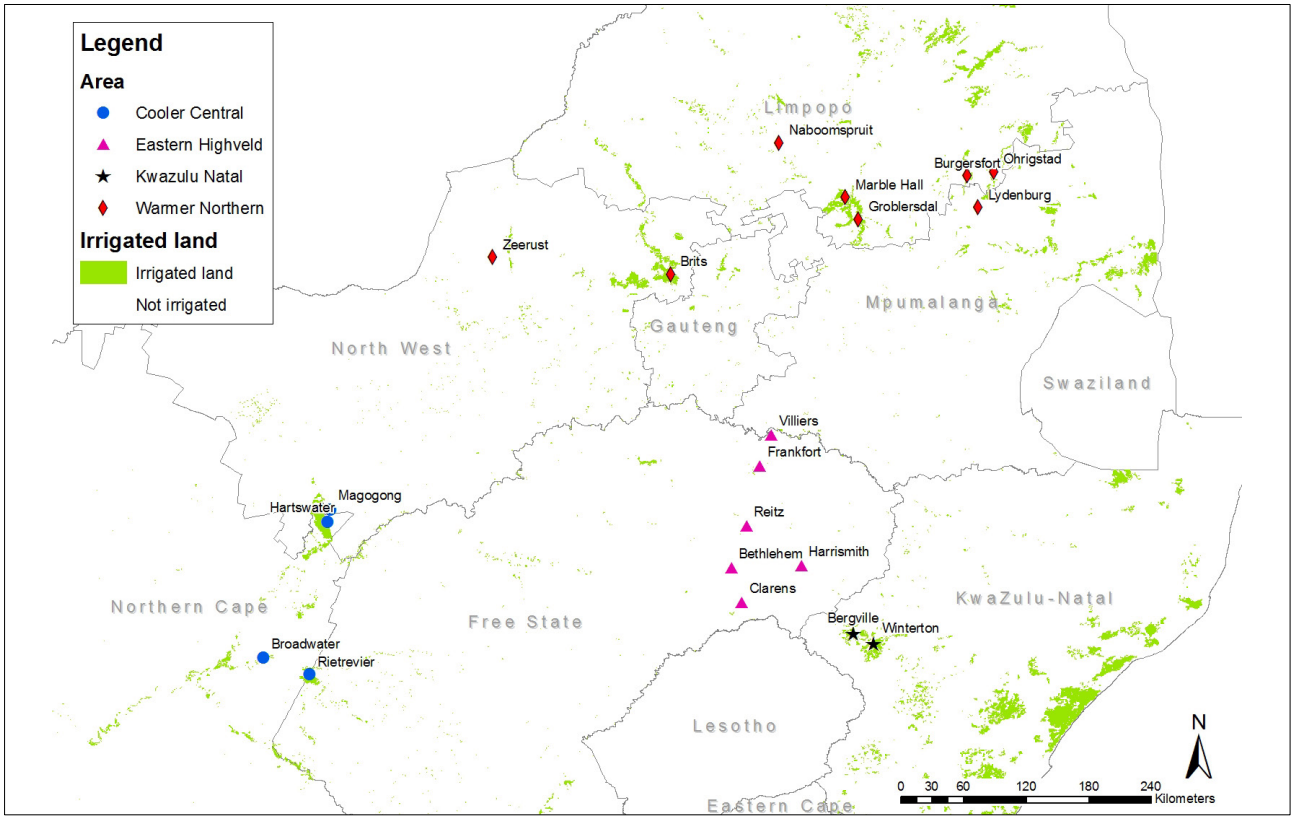

Figure 1: Map showing the locations of various irrigation wheat producers who participated in the study.

The most frequent response on technical constraints was inadequate water for irrigation, followed by a lack of high-yielding cultivars. The biophysical constraints of major concern were red-billed quelea birds (*Quelea quelea*) and heat damage. There was very little to no concern about weeds, animal pests and diseases of wheat as being major yield constraints. On the policy constraints, nearly all the farmers (93.8%) cited low wheat market price and high input cost as the major reasons for low wheat yields. The reasoning behind this is that the farmers are not making much profit from wheat, hence they are reluctant to invest in crop management efforts that would increase wheat yields. As one farmer said: 'Everything about how you manage a wheat crop boils down to the market price of wheat'. Further detail regarding the other constraints observed, as well as those reported by the farmers, is presented in subsequent sections.

Water management constraints

Inadequate water supply during critical periods of crop growth was pointed out as a major yield constraint by the majority of the farmers, hence this issue deserves further discussion. As a winter crop, wheat grown in summer rainfall areas is almost wholly dependent on irrigation for growth and yield, therefore adequate irrigation is indeed critical, especially during flowering and grain filling periods. In the warmer areas, irrigation also serves to cool crops during hot weather periods and minimises yield losses. The major problem is that for most irrigation farmers, wheat competes directly for water with their summer crops such as maize (*Zea mays* L.). There is sometimes a tendency to save some water for the subsequent irrigation maize. Other farmers stated that during peak demand on hot days, the irrigation requirement is so high that they just cannot keep up with the irrigation cycles, and electricity bills. Water shortages, because of rationing, was also mentioned as part of the problem by irrigation wheat farmers in the Vaalharts and Riet River irrigation schemes.

Farmers also indicated that they wished to have 'water-efficient' irrigation wheat cultivars, i.e. irrigation cultivars that produce more grain with less water applied. Limited research has been carried out in this regard in South Africa. A change in policy would be required in order to subsidise the electricity costs of irrigation wheat farming. On the other hand, field surveys also showed that water wastage through overwatering was rampant on some irrigation wheat farms, mostly because of leaking old irrigation infrastructure. Farmers are indeed aware of the importance of proper irrigation scheduling, and nearly all of them (86%) had automated irrigation scheduling equipment. It appeared that the problem of overwatering was mainly caused by leaks and uneven terrain, which results in the large pivots having ponds on certain parts.

Pest management

There were very few observations of wheat diseases on inspected fields. All the farmers indicated that they used preventative strategies against wheat diseases, and in some cases outsourced the spraying services of chemical companies. Preventative strategies included using disease-resistant cultivars. It appeared that the majority of the commercial farmers had adequate expertise and means to manage pests of wheat, except for red-billed quelea birds. One farmer in the warmer northern irrigation areas indicated that he had stopped planting wheat because '…the quelea birds ate it all'. The problem of queleas is worse for farmers who plant early, especially in the northern parts of the country, where yield losses of up to 100% were reported. The Department of Agriculture, Land Reform and Rural Development has sole mandate to control quelea birds in terms of the *Conservation of Agricultural Resources Act 43 of 1983*. Farmers are supposed to report swarms and roosting sites of the queleas to facilitate their control. Queleas are also pests of summer crops such as pearl millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* (L.) Moench). Popular opinion is that their population may be on the increase because of an all-year-round supply of food. The environmental agency of the government needs to intensify efforts to control queleas, especially in the northern parts of the country.

Soil fertility management

Adequate fertiliser nutrients must be applied to wheat in order to achieve the yield potential. None of the farmers interviewed mentioned soil fertility as a major constraint, and it also appeared that some of the farmers outsourced soil fertility management to private fertiliser companies. Many fertiliser companies in South Africa actively market their fertiliser products to commercial wheat farmers, and at times provide free soil sampling and analysis services along with fertiliser packages. Nitrogen-based fertilisers currently contribute the most (up to 60%) to total variable costs of wheat establishment,[5] and are a major determinant of profitability. Intensive fertiliser use by irrigation wheat farmers should be a cause for concern as it reduces farmer profits, and thus becomes a cause of disinterest in wheat production. There are currently no recommendations for nitrogen or phosphorus fertiliser efficient cultivars on the market. It should be noted that private breeding companies in South Africa have been primarily concerned with breeding for high yields as a marketing point, with limited to no focus on input-cost reduction. Public institutions such as ARC–SG should look at the wheat production challenge more holistically and try to breed cultivars for both minimising input costs and maximising outputs.

On-farm soil fertility data from the NWCEP reports of the 2016/2017 season (Table 2) suggest that all important nutrients were adequate on all irrigation wheat fields, except for phosphorus.

Table 2: Soil analysis results from irrigation wheat fields in different localities for the 2016/2017 National Wheat Cultivar Evaluation Programme

		Soil nutrients (mg/kg)				
Locality	**pH (KCl)**	**P**	**K**	**Ca**	**Mg**	**S**
Bergville	5.6	66.7	371.5	1340	193.4	17.74
Bergville	**4.8***	**9.3***	149.5	1100	230.5	28.22
Winterton	**4.6***	33.2	120.6	899.0	170.9	28.35
Winterton	**4.6***	69.8	101.3	866	151.6	7.76
Colenso	5.0	**24***	116	2927	1410.3	25.66
Villiers	7.0	69.2	167.9	809	185.6	11.39
Welkom	4.7	32	119	799	162	28
Harrismith	5.7	**24***	155.7	762	121	19
Harrismith	5.7	**21.6***	201	1037	226	5.51
Clarens	5.5	61.7	192.1	873	146.3	89.92
Prieska	7.7	46.5	369.9	2013	447.3	39.87
Modder River	5.7	59.1	266.1	559	113.2	9.31
Hopetown	6.1	41.7	241.6	2243	404.2	8.17
Riet River	5.2	34.3	110.8	300	76.2	2.37
Modder River	**4.1***	54.0	152.4	438	103.9	3.22
Douglas	**4.0***	77.3	249.9	2620	292.2	157.90
Barkley West	7.2	100.3	267.6	936	202.1	28.31
Prieska	5.6	41.0	75.3	1248	363.4	1.86
Rama	5.8	53.4	298.2	2116	478.2	5.56
Hopetown	6.8	80.1	428.8	3264	419.9	15.68
Brits	7.0	**6.0***	234.0	7800	1512.7	44.08
Burgersfort	7.6	69.5	257.5	837	363.6	7.34
Groblersdal	6.8	**21.1***	192.4	1023	558.2	47.55
Hartswater	7.1	46.9	410.7	1118	226.7	251.15
Koedoeskop	6.8	12.6	93.5	2431	895.6	35.33
Makoppa	7.5	39.9	233.4	1073	404.5	8.09
Ohrigstad	7.5	67.0	361.4	2779	840.1	9.24
Potchefstroom	7.0	**21.9***	51.1	768	255.7	56.89
Skuinsdrif	6.1	51.1	224.0	2253	803.9	13.40
Upington	6.4	50.6	304.2	2002	442.8	5.99
Vaalharts	6.2	43.4	226.5	583	193.0	13.44

**Soils with acidity and phosphorus problems*

Acidity problems were also evident on some farms, especially in KwaZulu-Natal and the highveld regions. Phosphorus is known to be a difficult nutrient to manage, especially in no-till systems. Further research efforts

are required in order to evaluate some production practices that could be used to enhance the availability of phosphorus in the soil for wheat crops.

Cereal-based monocropping

Farmer interviews and field observations revealed that most irrigation wheat farmers in the cooler and central irrigation areas practice 'wheat on maize' rotations. In sustainable agriculture, monocrops are strongly discouraged because they cause pest build-up, as well as soil fertility depletion. The general rule of thumb is that crops that belong to the same family should never be sown in succession. A good crop rotation increases yield and profit, and allows for sustained production.[6] Monocropping causes annual yield depressions of 5–20%, and no amount of fertiliser or pesticide can compensate completely for that difference.[6] The causes of the rotation effect are not well understood, but improvements in soil physical properties and soil organic matter probably play a beneficial role in rotations that include legumes. It is common knowledge amongst commercial farmers that monocropping is not good for the soil, and it is important to understand the reasons for this continued practice by farmers.

Farmers in the cooler central and warmer northern irrigation areas pointed out that they practise wheat on maize rotation for economic benefits. Wheat is the only winter crop option for the farmers. Planting wheat on maize allows the farmers to double crop and achieve two crops in one year, which makes the system more profitable through maximising resource utilisation. Some farmers mentioned that they plant wheat on maize continuously because it is much more profitable and easier for them than rotating wheat with soya bean (*Glycine max* L.). The farmers pointed out that the cereals-only system was attractive for them because of the ease of management and marketing, and the associated lower risk due to reduced up-front costs and more reliable performance in difficult seasons. In wet conditions under centre pivots, soya beans can suffer many devastating disease problems that can require expensive chemical control measures. In conditions of water scarcity, soya beans are much more sensitive than maize to hot and dry conditions. The farmers also mentioned that they were very aware that they probably missed the yield potential of wheat because of monocropping. In search of solutions to close wheat yield gaps, research support for the current intensive wheat-maize cropping systems needs to be maintained. This scenario is likely to be better accepted by farmers. Apart from their profitability, intensive cereal cropping systems provide the added benefit of high crop residue biomass yields for feeding livestock, especially given that most South African farmers practise mixed crop and livestock farming.

Policy constraints

It is well known that policies have significantly influenced farming practices in South Africa.[7,8] The liberalisation of wheat marketing, for example, is partly blamed by many farmers for precipitating the current wheat crisis. Farmers' capacity and willingness to adopt new and improved technologies and implement best management practices depend on the profitability of the crop. Policy initiatives that increase the profitability of wheat farming or ensure a competitive price for what they produce will increase the willingness of the commercial farmers of South Africa to adopt management systems and technologies that improve yield. Some suggestions include electricity and fertiliser subsidies, as well as preferential water allocation for irrigation wheat farmers.

Research scientists' perspectives on irrigation wheat yield constraints

In this section, insights from wheat scientists and industry experts on the research priorities for increasing irrigated wheat yields in South Africa are provided. A summary of the main findings is presented in Table 3.

Cultivar choice

It can be noted from Table 1 that some farmers expressed the unavailability of high-yielding cultivars as the primary reason for poor irrigation wheat yields. For various confidentiality reasons, most farmers interviewed were reluctant to disclose information on the specific cultivars which they had planted during the season. Such information could have been useful in determining the popularity of different cultivars. Nonetheless, many researchers interviewed were of the opinion that irrigation wheat farmers were not fully embracing the newest, most well-adapted and high-yielding cultivars, and hence were sometimes experiencing low yields. This issue was also thought to be related to practices such as seed retention by the farmers, as well as risk avoidance through adherence to a tried-and-tested cultivar. There are many irrigation wheat cultivars currently on the market from which farmers can choose.

Table 3: Responses of South African wheat experts to questions regarding yield constraints of irrigation wheat ($N=47$)

Category	Specification
Technical	Fungal diseases: fusarium head blight (*Fusarium graminearum*) ($n=17$), stem rust ($n=15$), take-all ($n=5$), powdery mildew (*Blumeria graminis* f. sp. *tritici*) ($n=7$), stripe rust (*Puccinia striiformis* f.sp. *tritici*) ($n=15$), leaf rust (*Puccinia triticina*) (n=14)
	Poor soil fertility ($n=2$)
	Poor cultivar choice ($n=11$)
Biophysical	Abiotic stresses: lodging ($n=2$), frost damage ($n=1$), pre-harvest sprouting ($n=2$)

Seed pricing is generally the same across South African seed companies, and it is only the newer cultivars that tend to cost a bit more. This difference between the newer and older cultivars is usually not more than ZAR500 per 50-kg bag. It should also be noted that seed costs typically contribute less than 5% of establishment costs for a commercial irrigation wheat crop in South Africa,[4] hence lower seed price is seldom the major reason for choosing a lower yielding cultivar over a higher yielding one.

Mean yield of different cultivars from the NWCEP is presented to show the importance of cultivar choice in irrigation wheat production (Table 4).

Table 4: Mean irrigation wheat yields of different cultivars in the production systems of South Africa, based on on-farm yield data from the 2016/2017 National Wheat Cultivar Evaluation Programme results

	Mean grain yield (t/ha)			
Cultivar	**Cooler central areas**	**Warmer northern areas**	**Highveld**	**KwaZulu-Natal**
Duzi	9.36	7.20	6.67	6.82
Krokodil	10.06	8.14	6.85	6.68
PAN 3400	10.12	7.29	7.33	7.07
PAN 3471	10.08	6.50	7.34	6.65
PAN 3497	9.88	6.90	8.38	5.95
PAN 3515	9.15	6.78	7.24	7.23
PAN 3623	8.71	7.79	6.94	6.81
Sabie	9.09	6.73	6.89	5.52
SST 806	9.76	7.21	7.17	6.81
SST 8125	9.56	7.00	7.31	6.76
SST 8135	9.63	7.27	7.10	7.21
SST 8154	8.95	7.09	6.83	7.35
SST 8155	9.13	6.90	7.15	5.83
SST 835	9.57	7.04	7.40	6.56
SST 843	7.62	7.60	6.64	6.20
SST 866	9.64	7.68	6.43	5.89
SST 875	9.35	7.62	7.05	6.26
SST 877	9.09	6.85	6.99	6.85
SST 884	9.45	8.01	6.66	6.90
SST 895	9.45	7.57	6.89	6.86
Mean	9.38	7.26	7.06	6.61
***Difference**	**2.56**	**1.64**	**1.95**	**1.83**

**Difference between highest-yielding and lowest-yielding cultivar*

These data were collected from cultivar trials that were replicated across many locations in each of the production regions. As shown in the table, cultivar choice is an extremely important decision in yield improvement, as the difference between the highest yielding cultivar and the lowest yielding cultivar can range from 1.64 t/ha to 2.56 t/ha within a season.

Analyses of the relative performance of irrigation wheat cultivars released in South Africa over the period 1998–2013 by Dube et al.[10] showed genetic yield stagnation for cultivars produced in KwaZulu-Natal and warmer northern irrigation areas. In the cooler central areas, the genetic yield gain was only 0.4% per year. Meanwhile, stagnation of genetic wheat yield progress has been reported from many other places across the globe.[11,12] The prospects of obtaining new cultivars that have higher genetic yield potential are getting poorer. Meanwhile, it is necessary to place stronger emphasis on the need for farmers to fully exploit the yield potential of current cultivars, through best practices in crop management. Farmers are primarily concerned with profit, which is a function of yield and input cost. Much more focus should thus be placed on soil management and agronomy research aimed at reducing fertiliser, tillage and irrigation requirements of wheat.

Poor crop stands

Poor crop stands were observed in many irrigation wheat fields, where stand counts were far below the recommended populations for yield potential. There was also a suspicion highlighted by expert research scientists that most irrigation wheat farmers fail to calibrate their planters correctly because they do not incorporate the individual kernel weight of specific cultivars in their seed rate formulae. Kernel weight data in Table 5 show that there is considerable variation across cultivars, and in some cases, differences of nearly 100% in seed weight. A good comparison is the cultivar SST 806 (27.2 g/1000 kernels) compared to Krokodil (50 g/1000 kennels). The ignorance of many farmers on this matter was confirmed through surveys as most of the farmers expressed that they did not consider 1000 kernel weight in their calculations for planting density and planter calibration.

Table 5: Variations in thousand kernel mass across cultivars, and corresponding seeding density required for optimising yield of different cultivars

Cultivar	1000 kernel mass (g/1000 kernels)	Seeding density (g/plot) required for optimising yield	
		Highveld (225 plants/m^2)	KwaZulu-Natal (275 plants/m^2)
Duzi	42.0	140.0	171.1
Krokodil	50.0	166.7	203.7
PAN 3400	37.1	123.7	151.2
PAN 3471	44.8	149.2	182.3
PAN 3497	39.5	131.5	160.7
PAN 3515	36.6	121.8	148.9
PAN 3623	45.3	150.9	184.5
Sabie	47.5	158.3	193.5
SST 806	27.2	90.8	111.0
SST 8125	30.6	101.9	124.6
SST 8135	29.9	99.7	121.9
SST 8154	28.3	94.3	115.2
SST 8155	30.4	101.4	123.9
SST 835	26.8	89.3	109.1
SST 843	30.9	102.9	125.8
SST 866	25.4	84.7	103.5
SST 875	23.4	78.1	95.5
SST 877	26.7	88.9	108.6
SST 884	29.2	97.3	119.0
SST 895	29.4	98.0	119.8

Wheat diseases

Six diseases caused by fungal pathogens were identified as the most problematic causes of yield loss for irrigated wheat in South Africa, as shown in Table 3. Three physiological disorders – namely lodging, frost damage and pre-harvest sprouting – were also considered important. Fusarium head blight (*Fusarium graminearum*) was mentioned most frequently as a problematic disease in all irrigation areas. Very few such diseases were observed on farmers' fields through inspection. We note with concern that many scientific research articles on wheat production constraints in South Africa are typically sentimental and tend to report impressively high potential yield losses and large areas that are at risk without much scientific basis as they try to justify their studies. Results show that different wheat scientists have diverse views on the most important causes of yield loss on irrigated wheat fields in South Africa, and these views tend to be biased towards area of specialisation for the individual scientists.

Is wide-scale promotion of conservation agriculture the solution?

Conservation agriculture has gained acceptance among policymakers in South Africa as the ideal farming approach for sustainable crop yield improvement, and there currently are calls on all farmers in the country to adopt the practice. Farm surveys show that many farmers in the KwaZulu-Natal production region have moved away from conventional farming towards conservation agriculture. By definition, conservation agriculture is a concept for resource saving in agricultural crop production that strives to achieve acceptable profits along with high and sustained production levels, while concurrently conserving the environment.[13] The three principles of conservation agriculture are (1) minimal mechanical soil disturbance, (2) permanent organic soil cover through cover crops and diversified crop rotations and (3) associations with various species that include legumes. These three principles are known to result in crop yield improvement if applied correctly, holistically and simultaneously.[14,15] There is also much published literature on situations whereby the practice of conservation agriculture resulted in crop yield depression.[16] Conversations with most irrigation wheat farmers in other parts of the country revealed that they were fully aware of the envisaged benefits of conservation agriculture, but were reluctant to adopt it. Some of the farmers indicated that they had tried it, but that it did not work for them.

There is a recent publication[17] which provides worldwide data to show that no-till negatively impacts crop yields by 5.7%. The authors concluded that the meta-analysis of crop production data indicated that no-till is limiting rather than enhancing global crop production and sustainable intensification efforts. However, they recommended that continuous no-till was important for reducing environmental degradation, and that if continuous no-till is carried out along with the other two conservation agriculture principles (crop rotation and use of cover crops), it often represents a more profitable management system, because of reduced energy/diesel costs related to tillage rather than yield benefit. Indeed, reduced fuel and labour costs, soil conservation and soil fertility improvement were the most commonly stated reasons for adoption of no-till and other conservation agriculture principles by farmers in KwaZulu-Natal. To help close the yield gap with conventional tillage, these findings suggest that implementing no-till should not be recommended as the first step towards conservation agriculture in cropping systems in which residue retention and crop rotation are absent.

Conclusion and recommendations

In South Africa, yield gaps of irrigation wheat are high, owing to various technical, biophysical, and institutional and policy issues. Through field surveys and farmer and researcher interviews, we explored opportunities to improve yield in a sustainable manner for irrigation wheat farmers. The dominant constraint to irrigation wheat yield is probably a low market price/value which makes farmers reluctant to invest in inputs for increasing wheat yield, and also to apply cost-cutting measures that have yield penalties. Cultivar choice was shown to be an important decision in improving irrigation wheat yield in South Africa. Other significant direct yield-reducing factors – as observed from irrigation wheat fields and confirmed by farmers – are quelea bird damage, low plant stands, phosphorus deficiency, soil acidity and water shortages. Most wheat

scientists were of the view that constraints to yield are due to poor cultivar choice and wheat diseases. Farmers attributed water problems during peak demand as the main cause of low yields, especially in the cooler central and warmer northern irrigation areas. It is also noted that the perceptions of researchers regarding the major yield constraints of irrigation wheat were quite different from those of the farmers. A general recommendation is that researchers must work closely with farmers to develop farmer-based technologies that are easily acceptable to farmers to help remove constraints on yield as well as improve farmer profits. While breeding for yield, the focus should also be on reducing input requirements, such as water and fertilisers. The wheat industry needs cultivars that are water and fertiliser efficient for improving profitability of wheat farming. Future research efforts must focus on resource-conserving technologies for sustainable management of intensive cereal-based cropping systems of South Africa, rather than conservation agriculture per se. A well-supported agronomy research wing for wheat already exists in the form of the ARC–SG. Funding for agronomic research aimed at refining wheat production practices towards reducing production costs in this unit should be increased. Considering the constraints highlighted in this study, there is a need for more government resources and commitment in terms of policy to set in motion necessary actions to support irrigation wheat farmers.

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Authors' contributions

All authors contributed equally to the writing of the manuscript. Additionally, E.D. and N.Z.S. performed the surveys and analysed the data. T.J.T. made conceptual contributions to the study as the Senior Research Manager at ARC–SG. M.F. assisted in data analyses and discussion of the findings.

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A revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste management

A major limitation to improved waste management in South Africa lies in the paucity of reliable waste data and the exclusion of the contribution of the informal sector from reporting. Due to the disparity in the provision of formal waste management services across households in South Africa, omission of the quantified contribution of informal management practices leads to an inaccurate representation of waste management practices in existing waste data repositories. Given the potentially adverse social and environmental consequences of unregulated waste management practices, a lack of representation thereof has the potential to underestimate impacts. As of 2015, 31% of households are reported as lacking a basic refuse removal service; however, this number cannot necessarily be applied directly to waste quantities, given the regional and socio-economic differences that occur in per capita waste generation rates. The total quantity of domestic waste in South Africa and fraction disposed informally are estimated here, taking into account differences in waste generation rates based on income and settlement type. The characterisation and quantification of unregulated waste streams is beneficial in assessing the magnitude of the problem and, where necessary, identifying mitigation action. The results obtained show that 29% (3.67 million tonnes per annum) of domestic waste generated is not collected or treated via formal management options. Of this waste, the majority (85%) is generated in rural areas. The most common waste management option for unserviced households is a private dump. An estimated 94% of households in unserviced rural areas make use of private dumps, while in unserviced urban and metro areas this decreases to 74% and 71% of households, respectively. Illegal dumping is the next most common waste management option for unserviced areas. The proportion of household waste disposed of via illegal dumping ranges from an estimated 5% for unserviced rural households to 27% in metro areas with the balance made up by 'other' disposal/treatment options.

Significance:

- The proportion of domestic waste that is mismanaged in South Africa is significant and its exclusion from national waste estimates leads to the inaccurate representation of waste management practices in existing waste data repositories. Unregulated waste management practices can have potentially adverse social and environmental consequences, i.e. leakage into the environment, or if burnt, the generation of atmospheric pollutants.
- The quantity of mismanaged waste and distribution of this waste between different management options is important for the development of improved National Waste Management Plans.
- Waste generation rates and subsequent waste quantities estimated using this approach are strongly dependent on both income and settlement type (rural vs urban). For countries such as South Africa where there exist large disparities in income and population distribution, understanding waste generation as a function of these factors is critical for accurately modelling waste quantities.

Introduction

According to global standards, South Africa is classified as a developing country. However, in many respects this classification is contentious. As the biggest economy of the southern African region[1], South Africa reflects a number of the characteristics of a developed country with a high level of urbanisation, wealth and infrastructure. However, this level of development is unequally distributed amongst the population, and a notable disparity exists from both an economic and social perspective. The effect of this disparity is particularly evident in service delivery. According to the results of the Community Survey 2016[2], households in rural municipalities typically receive fewer and inferior services than households in more affluent, urban municipalities[3]. Whilst various factors contribute towards this discrepancy, significant factors include the historical inequalities in the provision of development support and services (evident predominantly in former homeland areas) due to the country's political past, the high level of poverty (resulting in the inability to pay for services), and the practical and financial constraints associated with extending services to remote rural or inaccessible informal areas.[3]

Waste management, in particular, illustrates this disparity. Within South Africa, waste management is the responsibility of local government; however, large discrepancies exist in the level of service provided by different municipalities. Where most larger municipalities provide a complete service, including waste collection and appropriate disposal (albeit not consistently meeting regulated environmental controls), many smaller municipalities – typically rural – lack the capacity for any form of waste service delivery.[4] While the range in waste service delivery is most notable between urban and rural municipalities, it has been suggested that variation can, and does, occur across provinces, district councils and local municipalities.[3] For example, while relatively affluent urban areas typically receive a complete waste service, certain urban communities – specifically in informal settlements – may lack even basic refuse removal.[5] This disparity can in part be attributed to the fundamental, unserviceable nature of informal settlements, where limited road access, high settlement density, poor spatial planning and layout of settlements, and illegal land tenure complicate or prohibit the delivery of waste collection services.[6]

Given the disparity in the provision of formal waste management services across the country, the determination of a representative waste scenario (as for example needed for product environmental stewardship) for South Africa

is complicated, and requires consideration of both formal and informal management scenarios. A lack of formalised waste management can result in unregulated management practices, i.e. waste management or disposal occurring outside of, or separate to, formal waste systems. These include for example, illegal dumping, uncontrolled burning, the operation of illegal dumpsites, and unlicensed landfills.[7] Such practices typically provide poor management and containment of the waste stream, resulting in a high potential for leakage of waste and contaminants into the environment.[7]

In South Africa, national waste estimates are typically modelled, based on per capital waste generation rates and waste characterisation and distribution studies. The allocation of national waste quantities between management systems tends to be limited to formal systems such as municipal landfill sites and recycling facilities. Given the potentially adverse social and environmental consequences of unregulated waste management practices (i.e. leakage into the environment, or if burnt, the generation of atmospheric pollutants), the lack of recognition (or distinction) of informal, unregulated waste management practices in waste studies has the potential to underestimate impacts. The characterisation and quantification of unregulated waste streams can therefore be beneficial in assessing the magnitude of the problem and, where necessary, identifying mitigation action.

It is therefore the objective of this paper to report on a model developed to inspect formally reported domestic waste quantities generated in South Africa by including the portion managed via informal practices, as well as to identify what fraction of domestic waste is disposed of in this manner and where this disposal may occur.

Review of waste services and generation rates

The occurrence of informal waste management practices is common amongst developing countries. Unlike developed countries, where a high level of wealth and infrastructure supports the provision of a complete and efficient waste service with an emphasis on waste diversion and material/energy recovery[8], waste management in developing countries is typically characterised by ineffective or partial waste service provision[9]. The lack of consistent waste services, combined with limited environmental and waste awareness among the general public, can result in the occurrence of practices such as illegal dumping, waste scavenging and littering.[9] Informal waste management practices are fast falling under global scrutiny, as increasing waste generation rates in developing countries, coupled to population growth, increases the threat that poor waste management practices can pose to both public health and the environment.[10] Understanding the various waste systems in operation and the magnitude of each is an important first step in addressing the challenges of informal waste management; however, the availability of the necessary waste data is frequently lacking in developing countries.[8]

Indeed, in South Africa the lack of data availability poses a key challenge in the characterisation and quantification of unregulated waste. However, the challenge of data availability is not limited to informal practices, and even for so-called formal waste management there is a paucity of consistent and reliable waste data.[11] For example, the South African Waste Information System was established in terms of Section 60 of the *National Environmental Management Waste Act (Act 59 of 2008)*[12] with the objective of addressing the paucity of reliable waste data through the provision of a national repository of waste data for both organs of state and the public. However, the system is not yet fully representative, with only a proportion of active facilities reporting data, and furthermore, doing so with a questionable accuracy. In lieu of a fully functioning and verified national waste repository, the most comprehensive source of quantified waste data is that contained in the National Waste Baseline Report.[11] However, not only are these results somewhat outdated, but they are also of unspecified precision and partly based on questionable assumptions.[13]

A further limitation in the South African Waste Information System data in providing a quantified national waste estimate lies in its omission of informally managed waste, resulting in the potential under-representation of both waste quantities and waste management practices. The quantification of national waste tonnages is therefore likely to be more accurate in the National Waste Baseline Report[11] given that this is modelled from per capita waste generation rates (as opposed to collection rates). However, the allocation of waste in this report is limited to formal management systems, thus providing a limited view of waste management practices in the country. The disparity in the level of waste services between South African households highlights the necessity of accounting for informal waste when developing a national waste estimate. Considering the results of the General Household Survey 2015[5] (shown in Table 1), if it is assumed that any form of regular waste collection service and centralised communal dumps constitute a formal waste management service, with the latter three categories shown in Table 1 constituting informal waste management, then overall, only approximately 69% of households in South Africa receive some form of formal waste management service. The results of this survey also show that there are large discrepancies between waste services provided to households in rural and urban areas and, to a lesser extent, between urban and metropolitan areas. Considering waste service delivery per settlement type (i.e. services received by households in rural, urban and metropolitan areas) shows that 94.5% and 87% of households in metropolitan and urban areas, respectively, receive some form of waste management service, while in rural areas this decreases to just 13%.

Table 1: Household refuse removal in South Africa by settlement type (rural, urban and metro households)[5]

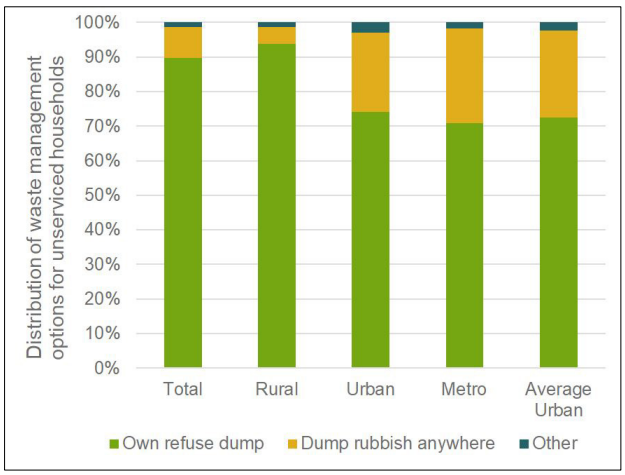
	Total	Rural	Urban	Metro
Refuse removed at least once a week	63.5%	9.6%	81%	88%
Refuse removed less than once a week	2.4%	1.0%	3.4%	2.7%
Communal refuse dump	2.9%	2.2%	2.0%	3.9%
Own refuse dump	28%	82%	10.0%	3.9%
Dump rubbish anywhere	2.8%	4.4%	3.1%	1.5%
Other	0.4%	1.1%	0.40%	0.10%
Percentage of serviced households	69%	13%	87%	94.5%
Unmanaged unserviced households	31%	87%	14%	5.5%

It should be noted that access to a formal waste management service does not preclude unregulated waste management practices from occurring. Illegal dumping can occur across serviced and unserviced areas, particularly for construction and demolition waste and garden waste. Recognition of the prevalence of unregulated waste management therefore challenges the assumption that the latter three categories in Table 1 occur exclusively in unserviced areas. For the sake of accuracy, the necessity of adapting the approach to allow for overlap in management options between serviced and unserviced areas should be considered. However, the quantity of waste in serviced areas falling into one of these three informal management categories is likely to be relatively low for the following reasons: (1) where formal waste services are available these are likely to be used and (2) illegally dumped waste in serviced areas will be recovered and thus enter the formal waste stream. It is unlikely that this allowance would make a significant difference to the overall distribution of waste between formal and informal streams.

Following the assumption that private refuse dumps, dumping, and 'other' can be considered informal waste management, the relative uptake of informal options by households in different settlement types is illustrated in Figure 1.

Figure 1 suggests that the most common waste management option for unserviced households is the use of a private refuse dump. The use of private dumps by unserviced households is most prominent in rural areas (94%) but is also relatively high in urban and metro areas (74% and 71%, respectively). Illegal dumping of household waste ranges from 5% for unserviced rural households to 27% in metro areas, with the balance made up by 'other' disposal/treatment options. Although further detail with regards to the nature of these management options is limited, it can be assumed that private refuse dumps lack any form of engineering or control (essentially an open dump) and 'other' refers to treatment

such as open burning. Whilst Figure 1 and Table 1 provide information with regard to the service level received by different households, this should not necessarily be applied directly to waste quantities, given the regional and socio-economic differences that occur in per capita waste generation rates.[14] In other words, although approximately 31% of South African households do not receive a formal waste management service, this figure does not necessarily equate to 31% of the total domestic waste generated in the country. Obtaining accurate waste generation rates that are sensitive to income and settlement type is therefore an important aspect of waste modelling.



In the absence of a fully functioning and representative national waste data repository, per capita waste generation rates provide a cost-effective and quick estimate of waste quantities without undertaking primary data collection.[11] Although this method provides an indication of total waste generation rather than the management distribution thereof, it is a useful starting point for determining waste generation volumes and assessing the recovery potential for different waste types. Whilst regional per capita municipal solid waste generation rates have been proposed by both the Intergovernmental Panel on Climate Change[15] and Hoornweg and Bhada-Tata[8], both sources acknowledge the lack of available and accurate waste data in developing countries – particularly in Africa – as prohibitive in the development of waste generation rates for these regions. Following the limitations in obtaining regionalised waste generation data for certain countries/regions, country income-specific waste generation rates have been proposed by Hoornweg and Bhada-Tata[8] (Table 2) and provide a useful alternative to waste modelling in countries lacking regionalised rates.

Table 2: Municipal solid waste generation rates based on country income level[8]

Country income	Municipal solid waste generation (kg/capita/day)
High	2.1
Upper middle	1.2
Lower middle	0.79
Low	0.60

Despite the benefit of waste generation rates in terms of quantifying waste, the availability of South African specific rates is limited. Few independent waste generation studies have been undertaken in South Africa and of those that exist, limited socio-economic distinction in the waste generation rate has been made. A comparison of independent studies reporting South African specific waste generation rates is shown in Table 3. This comparison indicates the variability in existing waste generation rates, with different sources providing a different level of disaggregation in terms of regional and socio-economic influences. While it is unlikely that Table 3 provides an exhaustive summary of available domestic waste generation rates for South Africa, it provides further indication of the disparate and inconsistent nature of waste reporting at a national level.

Comparison of Table 2 and Table 3 suggests that there is a wide range in South African waste generation rates when using income based population grouping. This discrepancy is in part due to variations in the definition of socio-economic groupings used. Given the high income inequality in South Africa, conducting a reasonable grouping of individual or household income presents a particular challenge. The development of income groupings to establish a representative South African 'middle class' is particularly complicated, with the low average and median levels of income and wide income distribution being recognised as particularly challenging in this regard.[16]

Another factor contributing to this variability is the definition of the waste generation rate in terms of what waste it encompasses. Waste generation rates frequently vary in definition, with some sources reporting a municipal waste generation rate, some a domestic waste generation rate, and others an unspecified waste generation rate. This variability challenges the translation of this information into comparable waste estimates. It is unclear whether domestic waste is comparable to municipal waste, and indeed to what extent municipal waste is representative of general waste categories. Extrapolating the domestic or municipal component of waste determined using waste generation rates to a national waste estimate is particularly challenging as it is dependent on accurate waste characterisation data.

Table 3: Per capita domestic waste generation rates in South Africa

Region	Domestic waste generation (kg/capita/day)			Source
	Low income	Middle income	High income	
South Africa[a]	0.41	0.74	1.29	Department of Environmental Affairs and Tourism[17]
South Africa[b]	0.2–0.7	0.7–1.9	1.5–3.0	Department of Agriculture, Conservation and Environment, North West Provincial Government[18]
Johannesburg	0.38	0.66	0.99	Gauteng Department of Agriculture and Rural Development[19]
Limpopo[c]	0.32	0.4	0.7	Ogola et al.[20]

[a]Socio-economic groups were not defined in terms of income characterisation. Original source of data referenced to 'Waste Generation in South Africa: Baseline Studies' by the Department of Water Affairs and Forestry (1998); however, this document was not available.
[b]Socio-economic groups were not defined in terms of income characterisation. This source quotes figures from Integrated Waste Management Plan guidelines (DEA[21]); however, these figures could not be found in the original document.
[c]Socio-economic groups defined according to residential stand size: low income <300 m², middle income 300–500 m², high income >500 m².

The quantified mapping of waste flows in South Africa is further challenged by the interaction between the informal and formal waste sectors. Although it is a requirement stipulated in Chapter 5 of the *National Environmental Management: Waste Act, No. 59 of 2008*[12] that all waste management activities with the potential to cause a detrimental effect on the environment obtain a waste management licence, the current number of unlicensed waste management facilities is unknown. In 2006, according to the Department of Environmental Affairs and Tourism (DEAT)[17], 760 sites (both illegal and legal) were operating without a permit. This figure excludes small, unrecorded sites in rural areas, and hence is likely to be higher with their inclusion. This implies that waste that is formally collected can be disposed of in either municipal or privately owned and managed, but unlicensed, landfill sites or treatment facilities. Furthermore, waste which is informally disposed of can be recovered and enter into the formal waste stream. This is typically seen in the municipal clearing of dumped waste, or the informal scavenging of recyclable materials from dumped or littered waste.

It should be considered that although the distinction between formal and informal waste management based on waste service delivery is convenient, it does not necessarily provide an indication of 'good' and 'bad' environmental performance. For example, while the environmental impacts of landfilling can be controlled if operations are adequately managed, so-called formal landfill sites can vary in terms of design and management, with shortcomings in siting, design and operation presenting a significant potential for pollution.[22] Quantifying this mismanaged formal waste fraction is in itself difficult, owing to the paucity of consistent and reliable waste data.[11]

Approach for the estimation of informally managed household waste

Given the lack of quantified information regarding waste managed outside of formal waste streams in South Africa, an estimate of the quantity of household waste managed informally via unregulated waste management practices was developed. The starting point in this analysis was the distribution of waste management services in South Africa, as available in the General Household Survey 2015[5] (Table 1). As previously noted, the distribution of waste services does not necessarily translate into an equivalent distribution of waste quantities owing to regional and socio-economic differences in the per capita waste generation rate. Therefore, in order to estimate the total quantity of domestic waste generated that is informally managed in South Africa, a model was developed taking into account differences in waste generation rates based on income and settlement type.

In addition to the national distribution of waste management services, key modelling parameters included national waste generation rates and population statistics. The waste generation rates used in this model were those provided by the DEAT[17] (Table 3). Despite being based on 1998 waste generation and population statistics, in lieu of more updated information, these rates were considered to be the most representative of national waste generation rates, as they are recommended for use in the determination of municipal waste quantities in the national guidelines for the development of integrated waste management plans.[21] Household income distribution was as reported by Stats SA.[23] The key modelling parameters considered (excluding national waste service delivery, as available in Table 1) are shown in Table 4.

Table 4: Key parameters for waste generation and population distribution as used in the model for the quantification of domestic waste flows in South Africa

Data					Source
South African Population 2016	54 978 907				Worldo-meters[24]
	No income	**Low income**	**Middle income**	**Upper income**	
National household distribution	15.5%	29.0%	48.3%	7.3%	Stats SA[23]
Rural % of income group	29.9%	46.8%	27.2%	7.60%	Stats SA[23]
Urban % of income group	70.1%	53.2%	72.8%	92.40%	Stats SA[23]
Domestic waste generation rate (kg/capita/day)[a]	0.41		0.74	1.29	DEAT[17]

[a]It was assumed that 'domestic waste' as used by the DEAT[17] refers to the domestic proportion of municipal waste, thus excluding commercial and industrial waste.

The intention of this model was to provide an estimate of domestic waste flows and thus several simplifying assumptions were used. Key assumptions used in this model were.

1. Household settlement (rural, urban and metro) distribution and income distribution based on number of households in each category could be used as a proxy for urban, rural and metro population distribution and income distribution, even though rural households typically have a higher number of inhabitants than households in urban and metropolitan areas.
2. Statistical data for 2011 and 2015 are representative of the 2016 status quo with regard to household waste service delivery and income distribution between settlement types.
3. Waste generation rates in no-income and low-income population groups are directly comparable.
4. The level of waste service delivery in rural areas is consistent across income groups.
5. In urban and metro areas, 100% of unserviced households fall within the no-income/low-income population group.

The first step in the modelling approach required the determination of the population per income group and settlement type. This was undertaken using Equation 1, with the necessary parameters obtained from Table 4.

$$\text{Population}_{\text{settlement type,income group}} = \text{South African national population}_{\text{year}} \times \%\text{population}_{\text{settlement type,income group}} \quad \text{Equation 1}$$

The next step required the determination of total domestic waste generation per income group and settlement type. This was undertaken using Equation 2, utilising the data shown in Table 4 and the results obtained from Equation 1.

$$\text{Domestic waste}_{\text{settlement type,income group}} = \text{Waste generation rate}_{\text{income group}} \times \text{population}_{\text{settlement type,income group}} \quad \text{Equation 2}$$

The final step required the estimation of the informal proportion of waste per income group and settlement type. This was based on the distribution of waste services (Table 1). It was assumed that any form of regular waste collection service and centralised communal dumps constitute a formal waste management service, with the last three categories shown in Table 1 constituting informal waste management. Informal domestic waste generation per income group and settlement type was then calculated according to Equation 3. Further assumptions regarding the distribution of waste services are as reported in the list of assumptions provided above. Equation 3 was applied to each income group for rural and urban settlements.

$$\text{Informal domestic waste}_{\text{settlement type,income group}} = \text{Domestic waste}_{\text{settlement type,income group}} \times \%\text{unserviced households}_{\text{settlement type,income group}} \quad \text{Equation 3}$$

Results and discussion

The resulting model provides an estimate for both total domestic waste generation and the amount of waste that is informally managed in South Africa. The results obtained from this model are shown in Table 5.

If income-specific waste generation rates are considered, it is estimated that South Africa generates approximately 12.7 million tonnes of domestic waste per annum. This amount is comparable to the 15.9 million tonnes of domestic waste (GW01, excluding commercial and industrial waste) reported in the National Waste Baseline Report[11] for 2011. The higher value reported in the Baseline Report is likely due to the calculation approach, which applied an average per capita waste generation rate across the population, unlike the model approach where different rates were applied by population grouping. Using the model output and 2016 population statistics, an average per capita domestic waste generation rate for South Africa can be estimated at 0.63 kg/capita/day. Comparison of this figure to the domestic waste generation rates reported by the DEAT[17] (Table 3) suggests that this generation rate lies between that of low- and middle-income groups. This provides a more realistic estimate for average per capita waste generation in South Africa as opposed to using the arithmetic mean of the domestic waste generation rates reported by the DEAT[17] (0.81 kg/capita/day), which suggests that average waste generation lies between middle-income and high-income

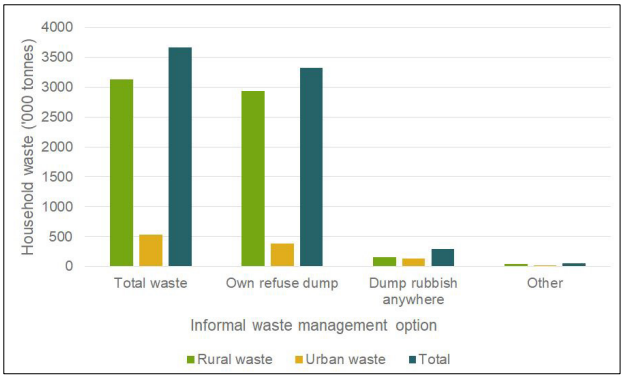
groups. Given the income inequality in South Africa, the arithmetic mean is unlikely to be representative of the actual mean, as a large proportion of the population falls below the middle-income grouping. Indeed, if the arithmetic mean is used to determine annual waste generation in South Africa, this results in an estimated 44 million tonnes of domestic waste. This is notably higher than the quantity reported by either the National Waste Baseline Report[11] or that estimated by means of the modelled approach.

Table 5: Model results for estimated total and informally managed domestic waste in South Africa

	No income	Low income	Middle income	Upper income
Total domestic waste generation (t/a)				
Rural	381 000	1 120 000	1 950 000	1 440 00
Urban	894 000	1 270 000	5 210 000	1 750 000
Total (per income group)	1 280 000	2 390 000	7 160 000	1 890 000
Total	12 720 000			
Waste subjected to informal management (t/a)				
Rural: 87.2% of population unserviced	333 000	974 000	1 700 000	125 000
Urban: 9.5% of population unserviced	84 900	121 000	495 000	166 000
Total (per income group)	417 000	1 090 000	2 190 000	291 000
Total	3 988 000			
Correction for distribution of waste services between income groups				
Rural: 87.2% of population unserviced, waste service delivery in rural areas is consistent across income groups	333 000	974 000	1 700 000	125 000
Urban: 9.5% of population unserviced, 100% of unserviced households fall within the no-income/low-income population group	533 000		–	–
Total informal waste generation	3 665 000			

As shown in Table 5, accounting for both settlement type and income distribution suggests that informal household waste generation in South Africa is in the order of 3.67 million tonnes. Comparison of this figure to the 12.7 million tonnes estimated for total domestic waste generation suggests that approximately 29% of domestic waste generated in South Africa is not collected or treated via formal management options. Although the model was developed to take into account income specific waste generation rates and the population and income distribution of different settlement types, it was assumed that waste generation rates were not affected by settlement type. While settlement type has been recognised as a factor in terms of waste generation[14], this observation was not applied to the model due to limitations in the availability of national waste generation rates accounting for both income and settlement type. The model output could be improved with further refinement of the waste generation rates used. However, this would require – amongst others – the development of more representative national waste generation rates.

In lieu of a more detailed estimate, the model result for domestic waste that is informally managed can be used in conjunction with Figure 1 to estimate the quantity of waste per management option utilised by unserviced households. This result is shown in Figure 2. According to this figure, the use of a private dump is the most common waste management option for unserviced households, with an estimated 3 million tonnes of waste disposed of annually in this way. It is important to note that the results in Figure 2 are intended as an approximation only and are based on a number of assumptions and a high level of uncertainty. All results presented should therefore be regarded as indicative rather than absolute and interpreted as such.



Given that the model result provides an estimate for domestic waste managed informally, it represents only a portion of the total informal general waste generated in South Africa. If all general waste is considered, the contribution of categories such as builder's waste (widely recognised as the most frequently dumped material) and commercial and industrial waste is likely to increase the estimated quantity of informal waste further. However, limited quantified information is available to obtain an estimate for such illegally dumped materials. Furthermore, given that the clearing of illegally dumped material is the responsibility of the municipality, such material is frequently re-incorporated into formal waste streams. Limited documentation of this recovered material further complicates the quantification of informal waste tonnages. A similar challenge exists with regard to quantifying both recovered and unrecovered litter. Despite the extent of littering being visually obvious in many parts of South Africa, the availability of studies which focus on the quantification and characterisation of litter are limited. Available studies also tend to represent litter occurring in a relatively defined area and, as such, have limited application to the national level.

Conclusion

Given the current limitations in the availability of accurate and reliable waste data at the national level, a model was described in this paper to develop a basic mapping of domestic waste flows in South Africa, providing an estimate for both formally and informally managed waste. The results suggest that 29% of domestic waste generated by weight in South Africa is not collected or treated via formal management options. Of this waste, the majority (85%) is generated in rural areas. For all settlement types, the most common waste management option for unserviced households is a private dump, with the remaining proportion of waste either dumped illegally or managed through alternative treatment such as uncontrolled burning. The quantification of informal waste flows not only contributes towards a more realistic representation of national waste flows and management practices, but further, given the potentially adverse social and environmental consequences of informal waste practices, clearly indicates the lack of a standard for domestic waste management in rural settings as a major problem.

The waste generation rate is a key parameter within the model. While the waste generation rates used in this model take into account differences in household income, no data were available to distinguish between those in rural and urban areas. The lack of reliable South African specific waste generation rates reflects the paucity of focused waste generation studies undertaken in the region. Therefore, given the sensitivity of this parameter to a variety of factors including settlement type, in order to improve the accuracy of the model, further investigation into waste generation rates reflecting both income and settlement type should be undertaken.

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Authors' contributions

C.R.: Conceptualisation, methodology, data collection, data analysis, and writing. P.N.: Student supervision. H.v.B.: Conceptualisation and student supervision.

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Tourism and poverty in rural South Africa: A revisit

Debates about the value of pro-poor tourism indicated a need to revisit the links between the dynamics of tourism and hospitality enterprises and community poverty in rural South African towns. The numbers of tourism and hospitality enterprises in these towns are related to population numbers by a power law with a sub-linear exponent. The residents of smaller South African towns are more dependent on the tourism and hospitality sector than are the residents of larger towns. Measurement of the enterprise dependency indices (EDIs) of these towns provides a valid measurement of their wealth/poverty states. Their EDIs are directly and negatively associated with the strength of their tourism and hospitality sectors. Communities in towns with more tourist and hospitality enterprises are overall wealthier, and vice versa. This finding contrasts with a previous view about tourism and poverty reduction in South Africa. Debates about the benefits of pro-poor tourism should include information about the impact of tourism on community wealth/poverty. The EDI is a simple, yet powerful, measure to provide poverty information. Expressing the number of tourism and hospitality enterprises per 1000 residents of towns enables comparisons of towns of different population sizes. Based on ideas of the 'new geography of jobs', it is clear that tourism is part of what is called the traded sector and results in inflows of external money into local economies. Tourism is a driver of prosperity and a reducer of poverty in South African towns.

Significance:

- The application of different quantitative techniques demonstrates enterprise orderliness in the tourism and hospitality sector of towns in semi-arid South Africa.
- Smaller towns are particularly dependent on the tourism sector. Analyses indicate that tourism strength decreases overall community poverty.
- Leadership provided by individuals and location of towns can contribute to tourism success and poverty reduction.
- Community wealth/poverty should form part of the pro-poor tourism debate.

Introduction

Poverty and unemployment are two major perennial problems in South Africa.[1] Increased tourism is expected to contribute to the solution of these problems. For instance, the National Development Plan[2] frequently mentions tourism as an important component of economic growth and job creation, also for rural areas, and calls for the expansion of the tourism industry. Tourism is a major economic sector worldwide and is potentially important for pro-poor growth in poorer countries.[3]

Pro-poor tourism is defined as tourism that generates net benefits for the poor.[4] It is not a specific sector or product. Benefits may be economic, but they may also be social, environmental or cultural, and affect livelihoods in multiple indirect ways. Yet, paradoxically, the poor in South Africa are thought to benefit very little in the short term from additional tourism income.[5] This view, however, ignores impacts on community wealth/poverty and focuses on individual poverty.

Tourism gradually became a mass phenomenon during the post World War II period and by the new millennium it was one of the fastest growing industries in the world.[6] The direct gross value added in South Africa by tourism increased from about ZAR99 billion in 2015 to nearly ZAR114 billion in 2016.[7] The tourism sector directly employed 686 596 persons in 2016 – an increase of 17 945 employees compared to 2015. The share of tourism of the total employment in South Africa increased to 4.4% from 2015 to 2016. The number of employees in the tourism sector outnumbered the respective workforces of utilities (118 000 employees) and mining (444 000 employees).[7]

Since the 1990s, pro-poor tourism has been promoted as a means of alleviating poverty.[6,8] Tourism offers potential pro-poor economic development because it: highlights natural resources and culture; provides opportunities to diversify local economies possessing few other export and diversification options; enables opportunities for selling additional goods and services; offers labour-intensive and small-scale opportunities; and offers a high proportion of low-skill, domestic-type jobs that increase accessibility to the labour market for women.[9] A large part (29.33%) of tourist expenditure in China went directly or indirectly to local households.[10] Poor people, however, did not gain much of the benefit.

Despite its popularity, pro-poor tourism sparked a heated debate concerning its real capacity to combat poverty.[8,11] Hall[11] remarked:

> *In one sense, the focus on providing tourism employment to the presently unemployed is perhaps not far removed from the goals of any regional development programme. PPT* [pro-poor tourism] *advocates tend to suggest that there are qualitative differences with respect to its approach with respect to the poor …. However, some critics of PPT suggest that it is another form of neo-liberalism that fails to address the structural reasons for the north-south divide within developing countries.*

The quantitative dynamics and relationships of the tourism and hospitality (hereafter called T&H) enterprises with other enterprises were not considered.

The southern African tourism sector is large.[12] Consequently, tourism research in South Africa is multidimensional and extensive. This is illustrated by the papers selected for a recent geography-based theme collection of tourism contributions on southern Africa.[13] The collection addresses a diverse set of themes including greening and tourism, business tourism, visiting friends and relatives travel, second homes tourism and tourism development issues. The role of tourism in poverty reduction was not specifically considered.

In South Africa, conventional social investment approaches to poverty reduction (e.g. in education, health and targeted income support) have largely been unsuccessful.[4,14] Many southern Africans are poor.[4] Tourism has been promoted as a pro-poor strategy to promote community and sustainable development.[2,3,14-17] Nevertheless, poverty reduction is normally not at the heart of the tourism agenda.[4] Some small South African towns on the urban fringe have, however, benefitted from tourism development[17] and case studies of two towns (Utrecht and Still Bay) left no doubt that jobs had been created, people had been empowered and poverty had been alleviated[16]. Statements about the pro-poor benefits of tourism have, however, not been based on quantitative data about the wealth/poverty of communities but rather on perceived benefits to individuals. The extent to which tourism in South Africa impacts on community poverty, also in rural areas, needs to be reassessed.

In order to do so, it is necessary to pay attention to quantitative data about the enterprise dynamics of the T&H sector because this is where tourism-related jobs are created. However, South African reviews such as the Tourism Satellite Accounts of the tourism sector[7] supply no specific information about the kinds and location of tourism-related enterprises, despite the fact that thousands are surveyed. However, quantitative research of the demographic–socioeconomic–entrepreneurial nexus of urban settlements provides a way to revisit the issue of the pro-poor benefits of tourism in South Africa.

The demographic–socioeconomic–entrepreneurial nexus of urban settlements

In the early 2000s, the analogy between biological network systems and urban and corporate structures led researchers at the Santa Fe Institute in the USA to investigate if the same kind of analyses used to understand biological network systems, could be used for studying cities and companies.[18] This research group obtained empirical evidence that indicated that the processes relating urbanisation to economic development and knowledge creation are: very general; shared by all cities belonging to the same urban system; and, sustained across different nations and times.[19-21] Cities are complex systems whose infrastructural, economic and social components are strongly interrelated.[18] Quantitative information about human settlements is important and should be considered. In fact, Bettencourt and West[22] suggest that a new quantitative understanding of cities may well be the difference between creating a 'planet of slums' or finally achieving a sustainable, creative, prosperous, urbanised world expressing the best of the human spirit.

Power laws (i.e. log-log mathematical expressions) are central to the unravelling of the relationships of the demographic–socioeconomic–entrepreneurial nexus of urban settlements. The power laws reveal that many properties of cities scale with population size. Their scaling exponents fall in distinct universality classes: sub-linear, linear and super-linear (terms used by West[18]). Measures of the physical extent of urban infrastructure increase more slowly than city population size, thus exhibiting economies of scale. They scale sub-linearly (their exponents are <1). Regardless of where a city is located and regardless of the specific metric used, only about 85% more material infrastructure is needed for every doubling of city populations.[20] On the other hand, various socioeconomic outputs increase faster than population size and thus exhibit increasing returns to scale. They scale super-linearly (exponents are >1), which is typical of open-ended complex systems.[23] Large cities are environments in which there are more sustained social interactions per unit time. These generic dynamics, in turn, are the basis for expanding economic and political organisation, such as the division and coordination of labour, the specialisation of knowledge, and the development of political and civic institutions.[24] Cities are, therefore, approximately scaled versions of one another.[20] The extraordinary regularities observed open a window on underlying mechanisms, dynamics and structures common to all cities.[22] Enterprise regularities observed in urban settlements pave the way to derive a deeper understanding of enterprise dynamics.

The demographic–socioeconomic–entrepreneurial nexus of South African towns

South African towns and local authorities also have strong enterprise regularities enabling predictability about enterprise dynamics and some socioeconomic characteristics. The regularities include linear relationships between population and enterprise numbers of South African towns[25-27] and power law relationships between total enterprise numbers and the number of enterprise types (i.e. enterprise richness)[28,29]. Regional studies included towns of the Eastern Cape Karoo[25,30,31], towns and municipalities of the Free State[32,33] and population and enterprise distribution in three South African regions[34]. Importantly, the T&H sector of South African towns also exhibits enterprise regularities, e.g. for towns in arid South Africa[35] and Karoo towns in the area where shale gas development might potentially occur[36,37]. In addition, examination of the demographic–socioeconomic–entrepreneurial nexus of South African towns successfully quantified the impact of poverty on the demographic–entrepreneurial relationship in some South African towns.[38] These studies provided information and methods to investigate if tourism has pro-poor benefits in rural South Africa. First, one must consider the issue of poverty.

Why are some regions poor and others wealthy?

Hausmann and colleagues[39] concluded that the levels of productive knowledge (i.e. the specific and tacit knowledge of how to produce specific products or deliver specific services) of countries determine their levels of wealth or poverty. More prosperous countries have more productive knowledge than poor countries, and vice versa. Toerien[31,38] argues that if the level of the productive knowledge of countries determines their economic fates, the same should be true for local economies and populations of towns. The productive knowledge embedded in South African towns could, therefore, influence success in the T&H sector and its influence must be examined.

Can the productive knowledge embedded in towns be measured?

Toerien and Seaman[28] coined the term 'enterprise richness' for the total number of different enterprise types present in a town and developed a method to quantify it. Enterprise richness enumerates the number of times businesses of types that have not been present before have been successfully founded in a town. It is thought to serve as a proxy for the level of productive knowledge.[31,38]

Can one differentiate between wealthy and poor towns?

The enterprise dependency index (EDI) (i.e. the population number/total number of enterprises), has been successfully used as a measure of the wealth/poverty states of communities in towns.[25,31,38] It measures the number of people 'carrying' the average enterprise (defined as the population divided by the total number of enterprises) of each town. The EDI provides a simple and effective means to assess the wealth/poverty status of communities in South African towns[25,31,38] and is used as such in this contribution.

Purpose of this study

The purpose of this contribution is to demonstrate that tourism success does reduce community poverty in rural South African communities. A case study approach is used in the analysis. Firstly, a group of towns is selected. Secondly, to confirm the presence of orderliness in the enterprise structures of the selected towns, the enterprise richness of all selected towns is determined and related to their enterprise numbers. Thirdly, the EDIs of the towns are calculated and used to examine the T&H strengths of two groups of towns: a richer group and a poorer

group. Finally, the impacts of geographical location, national roads and tourist routes on the T&H strengths of towns are examined.

Methods

Selection of case study towns

Route tourism refers to initiatives to bring together a variety of activities and attractions under a unified theme and thus stimulate entrepreneurial opportunity through the development of ancillary products and services.[40] The clustering of activities and attractions, and the development of rural tourism routes, stimulates cooperation and partnerships between local areas.[41] When the pro-poor benefits of rural tourism are to be analysed, it is sensible to examine towns of recognised tourism routes. For this contribution, towns of Route 62 in the Little Karoo and of the N1 and N9 national roads were selected. Karoo towns potentially associated with shale gas development and of which the T&H enterprises have previously been quantified[36,37] were also included. This procedure limited the analysis to enterprise and demographic data of the 2015/2016 period. A total of 38 towns formed part of the case study (Figure 1 and Table 1).

Demographic–entrepreneurial relationships

The enterprises in 2015/2016 of the 38 towns were identified, classified and enumerated by the methods of Toerien and Seaman[26]. The East London telephone directory for 2015/2016[42] and the Port Elizabeth and Eastern Cape directory for 2015/2016[43] were used to identify the enterprises associated with the towns. The enterprises were classified into 19 different business sectors[26] (Table 2) and enumerated.

The population numbers in 2015/2016 of the towns were extracted from the German website 'Citypopulation' (undated).[44] This website's information is based on official South African census data for 2001 and 2011. The 2011 census population number for each town was extended to 2015 by its annual population growth rate between 2001 and 2011. Normalisation of data enables comparisons of towns of different sizes. The T&H sector strengths of towns were identified by expressing their T&H enterprise numbers per 1000 residents. Higher values indicate greater dependencies on the T&H sector, and vice versa.

Linear per capita indicators are generally used to characterise and rank cities. However, these indicators implicitly ignore the fundamental role of non-linear agglomeration in the life history of cities.[45] To ensure that non-linear population agglomeration impacts (i.e. scaling impacts) are not ignored, the power law relationships between population numbers and (1) total enterprise numbers and (2) the number of T&H sector enterprises were determined. Microsoft Excel software was used.

Table 1: The selected towns and their estimated 2015 population sizes

Town	Population	Town	Population	Town	Population
Aberdeen	7524	Somerset East	20 056	Barrydale	4873
Burgersdorp	17 368	Steynsburg	7509	Beaufort West	35 918
Cradock	39 682	Steytlerville	4177	Calitzdorp	4684
Fort Beaufort	27 592	Willowmore	8112	De Rust	3833
Graaff-Reinet	37 047	Carnarvon	7249	Ladismith	7725
Hofmeyr	3948	Colesberg	18 862	Laingsburg	6433
Jansenville	5919	Fraserburg	3319	Merweville	1814
Klipplaat	2997	Loxton	1189	Montagu	14481
Lady Frere	5391	Noupoort	8284	Murraysburg	5426
Middelburg	21 098	Richmond	5576	Oudtshoorn	63 076
Nieu-Bethesda	1823	Sutherland	3260	Prince Albert	7724
Pearston	4772	Victoria West	9528	Uniondale	4663
Queenstown	105 605	Williston	3544		

Impact of productive knowledge

The enterprise richness of each town was determined by counting the number of different enterprise types according to Toerien and Seaman[28]. A database of more than 600 different enterprise types encountered in South African towns was used. Power law (log-log) analyses between enterprise richness and total enterprise numbers as well as enterprise richness and population numbers were carried out. Microsoft Excel software was used.

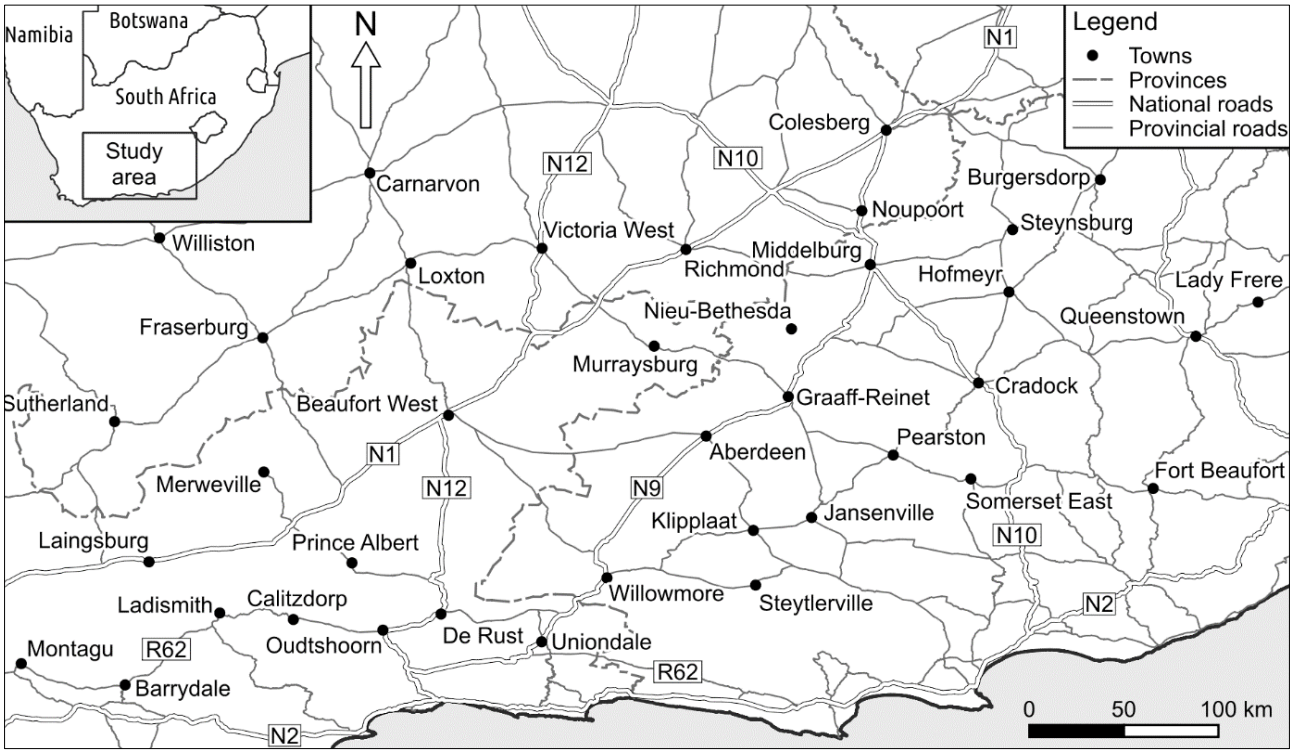

Figure 1: Map showing the towns selected for this analysis.

Tourism and the wealth/poverty of the selected towns

The EDIs of towns were simply calculated by dividing the number of people of each town by the number of its enterprises. To examine the impact of poverty on entrepreneurial development, Toerien[38]: (1) ranked towns on the basis of their EDIs, and (2) binned them into different EDI groups. The power law between the enterprise richness and population numbers of each of the binned groups was then determined and the results were graphically and numerically compared. This method was also used here on two groups of towns, those with: (1) EDIs less than 100 and (2) EDIs more than 100.

The enterprise strengths of the T&H sector (the percentage of T&H enterprises, termed tourism%) and the EDIs of the selected towns were used to assess the relationship between tourism and community wealth/poverty.

Influences of geographical location, roads and tourist routes

The impact of the locations of towns (e.g. on a tourist route or on or close to a national road or in a specific region) on their tourism–poverty profiles was tested in three ways. Firstly, the tourism strength and EDIs of the towns of Route 62 were compared with those of towns on the N9 national road and that of Nieu-Bethesda on the Owl Route. Secondly, a comparison was made of the profiles of Eastern Cape towns. Thirdly, the same profiles for towns on or adjacent to the N1 national road and towns in the western part of the study area were compared.

Results

Selected towns, their demographics and entrepreneurial relationships

Correlations between characteristics form a central part of the results presented here. Pearl and Mackenzie[46] remark: '[T]he mantra "Correlation does not imply causation" should give way to "Some correlations do imply causation"'. The results presented here, are viewed in this way.

The population sizes of the selected towns (Table 1) range from about 1200 (Loxton in the Northern Cape) to nearly 106 000 in Queenstown (Eastern Cape). The total enterprise numbers vary from 17 (Loxton) to 1000 (Oudtshoorn) (Table 2).

Table 2: The enterprise numbers and the enterprise richness of the selected towns

Town	Enterprises	Enterprise richness*	Town	Enterprises	Enterprise richness*
Aberdeen	44	26	Merweville	13	11
Barrydale	82	30	Middelburg	174	70
Beaufort West	489	104	Montagu	269	94
Burgersdorp	94	50	Murraysburg	26	14
Calitzdorp	72	33	Nieu-Bethesda	58	21
Carnarvon	78	36	Noupoort	38	23
Colesberg	154	55	Oudtshoorn	1000	206
Cradock	289	98	Pearston	17	11
De Rust	54	24	Prince Albert	155	59
Fort Beaufort	108	53	Queenstown	882	186
Fraserburg	35	21	Richmond	44	17
Graaff-Reinet	396	118	Somerset East	200	81
Hofmeyr	21	14	Steynsburg	42	23
Jansenville	75	28	Steytlerville	43	24
Klipplaat	14	7	Sutherland	52	22
Ladismith	124	55	Uniondale	61	35
Lady Frere	35	20	Victoria West	88	43
Laingsburg	67	36	Williston	32	21
Loxton	17	8	Willowmore	90	36

**Enterprise richness = number of different enterprise types in town*

Enterprise richness varies from 8 (Loxton) to 206 (Oudtshoorn). T&H enterprises range from just over 79% of total enterprises in Nieu-Bethesda to just over 7% in Klipplaat (Table 2). The variation in population and enterprise numbers enables examination of the pro-poor value of tourism in the selected group of towns.

Regularities occur in the enterprise dynamics of the towns. Their enterprise numbers scale sub-linearly with population numbers. The power law relationship between these entities is:

$$\text{Enterprise numbers} = 0.049(\text{population numbers})^{0.7275} \quad \text{Equation 1}$$

with $r=0.91$, $n=38$, $p<0.01$. The exponent indicates a strong sub-linear scaling of enterprise numbers relative to increases/decreases of population numbers. Larger towns with larger populations have disproportionately fewer enterprises than smaller towns with smaller populations.

A weaker power law:

$$\text{T\&H enterprise numbers} = 0.0328(\text{population numbers})^{0.7119} \quad \text{Equation 2}$$

$r=0.61$, $p=0.05$, $n=38$ describes the relationship between population size and T&H enterprises. Only 37% of the variation is explained.

These analyses show that orderliness is also present in the demographic–enterprise dynamics of the T&H sector of the selected towns. T&H enterprises scale in a similar fashion with population to that of the total enterprises. Smaller towns have disproportionately more T&H enterprises than larger towns. In other words, they have a greater economic dependence on the T&H sector.

Impact of productive knowledge

Enterprise richness serves as a proxy for productive knowledge. The power law between enterprise richness and the number of enterprises in the selected towns is statistically highly significant ($p<0.01$), and explains virtually all the variation and indicates strong super-linear scaling of enterprises relative to increases/decreases of enterprise richness (Figure 2). Towns with more productive knowledge have disproportionately more enterprises, and vice versa.

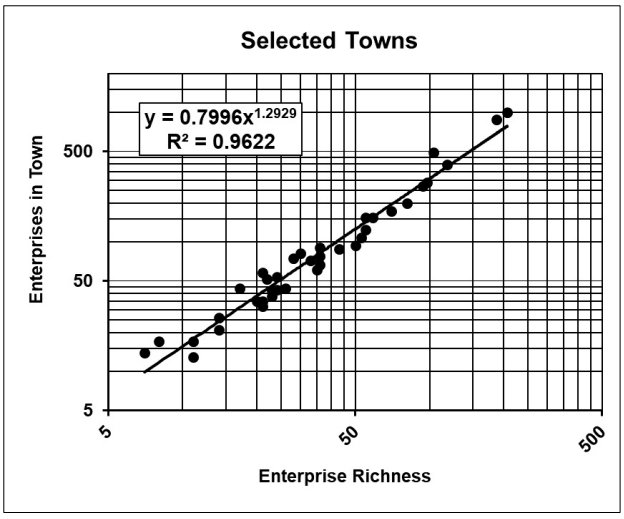

Figure 2: The power law (log-log) relationship between enterprise richness and the number of enterprises in the towns selected for this investigation.

The power law between enterprise richness and population numbers is also statistically significant ($p<0.01$) (Figure 3). Towns with higher enterprise richness are more populous. The spread of datapoints around the regression line in Figure 3 is more diverse (compare with Figure 2) and only some 81% of the variation (compared to 96% in Figure 2) is explained. Does poverty play a role in this phenomenon?

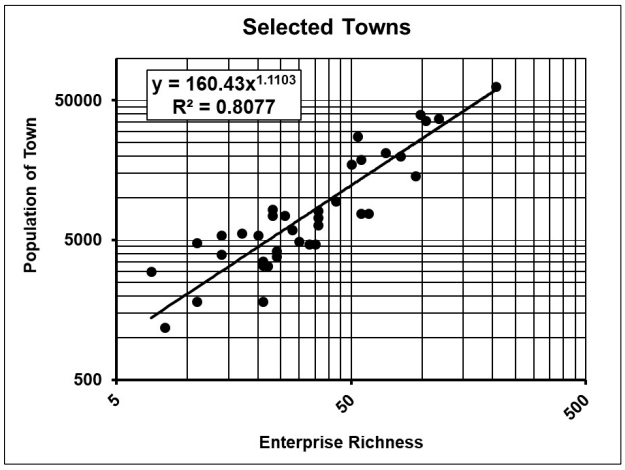

Figure 3: The power law (log-log) relationship between enterprise richness and the population numbers of enterprises in the towns selected for this investigation.

Enterprises and community wealth/poverty

The influence of poverty is examined in Figure 4. Separation of the towns into two groups on the basis of their wealth/poverty states results in two different power laws: one for the richer towns and another for the poorer towns. The exponents of the two power laws are super-linear and very similar. However, the constants of the power laws differ substantially (i.e. 64.4 versus 225.9). Increased poverty moves the regression line (see Figure 4) upwards and results in a numerically higher constant. For the same enterprise richness, a poorer town needs more people to support the same number of enterprises. Wealth/poverty plays a role in enterprise dynamics. But does it also impact upon the T&H sector?

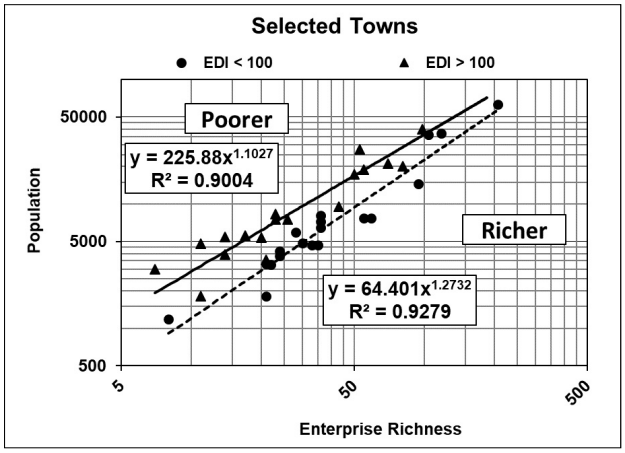

Figure 4: The enterprise richness–population numbers power law of a group of richer (EDI < 100) towns versus that of a group of poorer (EDI > 100) towns.

Tourism enterprises and community wealth/poverty

The share of the T&H enterprises of the total enterprises (tourism%) in the towns (Table 2) is negatively correlated with their EDIs:

$$EDI = 180.7 - 2.04\ (tourism\%) \qquad \text{Equation 3}$$

with $r = -0.56$, $n = 38$, $p < 0.01$. Trend lines fitted to the two characteristics (Figure 5) show clearly their contrary behaviour: as the tourism% increases, the EDI (poverty) decreases, or vice versa. In general, strength in the T&H sector in towns is associated with a reduction of poverty in their communities.

The large fluctuations in EDI and enterprise richness in Figure 5 indicated a need to examine if enterprise richness influences or is influenced by the EDI–tourism% relationship. Towns with reasonably similar enterprise richness values in Table 2 were identified and grouped (see groups in Table 3). Three groups were identified and each group was examined. The first group have enterprise richness values ranging from 20 to 30. Its enterprise numbers and enterprise richness remained reasonably constant, but as its tourism% declined, poverty (measured as EDI) increased (Figure 6 illustrates this relation). Similar trends were also observed for two additional groups: those with enterprise richness values between 33 and 36, and those with enterprise richness values between 50 and 59. In each case, enterprise richness (productive knowledge) did not influence the relationship between tourism% and EDI. This makes sense because an increase in the number of T&H enterprises is unlikely to increase the number of enterprise types (i.e. productive knowledge).

Table 3: Towns with similar enterprise richness values. Tourism% indicates the share of the enterprises of the tourism and hospitality sector of the total enterprises in the towns.

Town	Enterprises	Enterprise richness	Population	Enterprise dependency index	Tourism%
Lady Frere	35	20	5391	154.0	8.6
Nieu-Bethesda	58	21	1823	31.4	79.3
Williston	32	21	3544	110.8	31.3
Fraserburg	35	21	3319	94.8	8.6
Sutherland	52	22	3260	62.7	59.6
Noupoort	38	23	8284	218.0	21.1
Steynsburg	42	23	7509	178.8	14.3
De Rust	54	24	3833	71.0	59.3
Steytlerville	43	24	4177	97.1	32.6
Aberdeen	44	26	7524	171.0	20.5
Jansenville	75	28	5919	78.9	30.7
Barrydale	82	30	4873	59.4	65.9
Calitzdorp	72	33	4684	65.1	45.8
Uniondale	61	35	4663	76.4	31.1
Laingsburg	67	36	6433	96.0	37.3
Willowmore	90	36	8112	90.1	36.7
Carnarvon	78	36	7249	92.9	29.5
Victoria West	88	43	9528	108.3	26.1
Burgersdorp	94	50	17 368	184.8	18.1
Fort Beaufort	108	53	27 592	255.5	8.3
Colesberg	154	55	18 862	122.5	29.2
Ladismith	124	55	7725	62.3	25.8
Prince Albert	155	59	7724	49.8	52.9

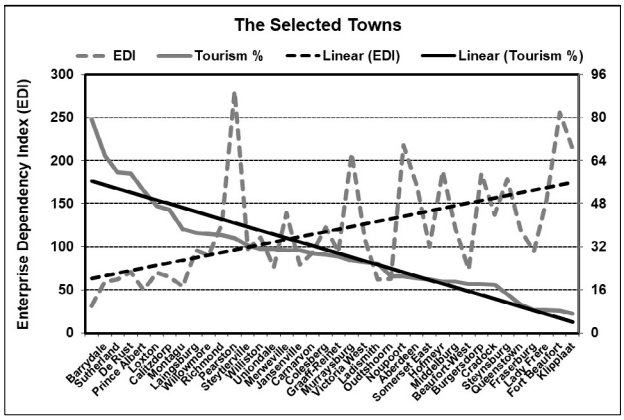

Figure 5: The share of the tourism and hospitality sector as a percentage of the total enterprises (tourism%) of the 38 selected towns in relation to the enterprise dependency indices of the towns. Trend lines were fitted for both characteristics.

Influences of geographical location, roads and tourist routes

The strength of T&H sectors and wealth/poverty levels of towns on different routes in the study area differs widely (Figure 7). Nieu-Bethesda on the Owl Route has an exceptionally strong T&H sector, based primarily on the art of Helen Martins and the reputation of the author Athol Fugard.[47,48] Its community poverty (EDI) is relatively low.

The T&H sectors of the Route 62 towns (Montagu, Barrydale, Ladismith, Calitzdorp, Oudtshoorn, De Rust, Prince Albert, Uniondale), located in the Gouritz Cluster Biosphere Reserve[49], are clearly stronger and their EDIs are lower than those of towns of the N9 national road (Willowmore, Aberdeen, Graaff-Reinet, Middelburg, Noupoort, Colesberg) (Figure 7).

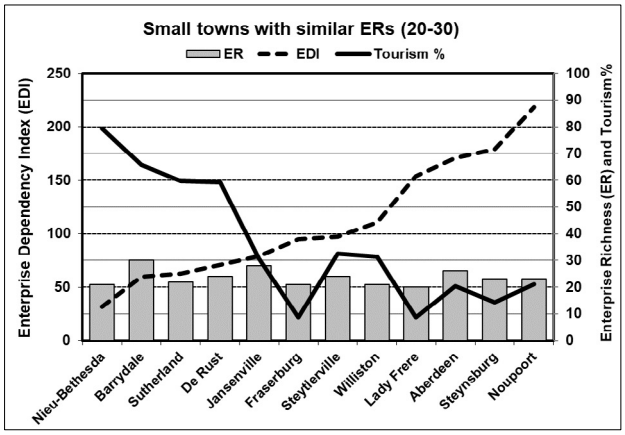

Figure 6: The share of the tourism and hospitality sector of the total enterprises (tourism%) and the wealth/poverty states (EDI) of towns with enterprise richness (ER) values between 20 and 30.

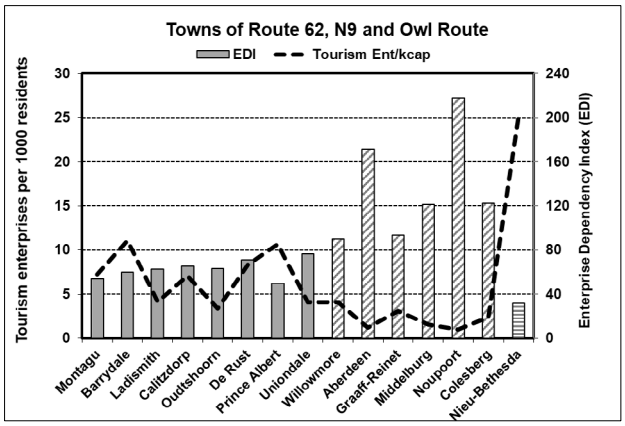

Figure 7: Comparison of the tourism sector strength (tourism enterprises per 1000 residents and abbreviated as Tourism Ent/kcap) and enterprise dependency indices (EDI) of the towns of Route 62 (even coloured), of the N9 national road (diagonal stripes) and the Owl Route (Nieu-Bethesda, horizontal stripes).

The tourism strength of the R62 towns resulted from sustained efforts of two persons, Gert Lubbe, owner of a hotel in Montagu, and Jeanetta Marais, a former CEO of the Breede River Valley District Council. They initiated the efforts to develop Route 62 into an internationally known tourist destination.[49] Surprisingly, Graaff-Reinet, which is generally touted as an important tourist destination in the Eastern Cape Karoo, has a weaker T&H sector than the Route 62 towns (Figure 7). As a larger town, it has probably developed strength in enterprise sectors other than T&H.

The T&H sector strengths of Willowmore, Steytlerville and Jansenville (Figure 8) are generally lower than those of the Route 62 towns (compare Figures 7 and 8), but are stronger than those of other towns of the Eastern Cape (Figure 8). The aforementioned three towns have lower EDIs (less poverty) and form part of the 'Small Town Paradox', i.e. small towns that paradoxically fare economically much better than their peers.[31] Visionary leadership by a mayor in the case of Willowmore and Steytlerville, and a civic leader in the case of Jansenville, that strengthened their T&H sectors, contributed to their success.[31] Other Eastern Cape towns (i.e. Burgersdorp, Queenstown, Steynsburg, Lady Frere, Klipplaat and Fort Beaufort) have low T&H strengths and high community poverty rates (high EDIs).

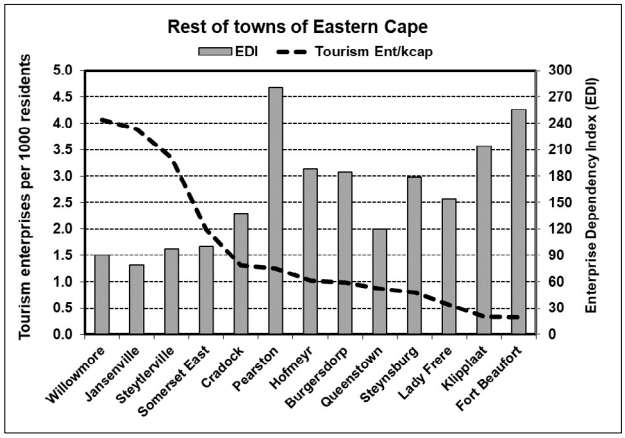

Figure 8: Comparison of the tourism and hospitality sector strength (tourism enterprises/1000 capita and expressed as Tourism Ent/kcap) and the enterprise dependency indices (EDIs) of other towns in the Eastern Cape.

The T&H sector strengths of the towns on the N1 national road (Figure 1) are somewhat lower than those of Route 62 towns but are higher than those of the towns of the N9 national road (Figure 9). The strengths of the T&H sector of the towns close to the Square Kilometre Array (SKA) development (i.e. Carnarvon and Williston) are somewhat higher than those of the N1 towns. Sutherland seems to be benefiting much from its astronomy attractions and Loxton from its association with Deon Meyer, a well-known Afrikaans crime novelist. These towns have relatively low community poverty (EDIs).

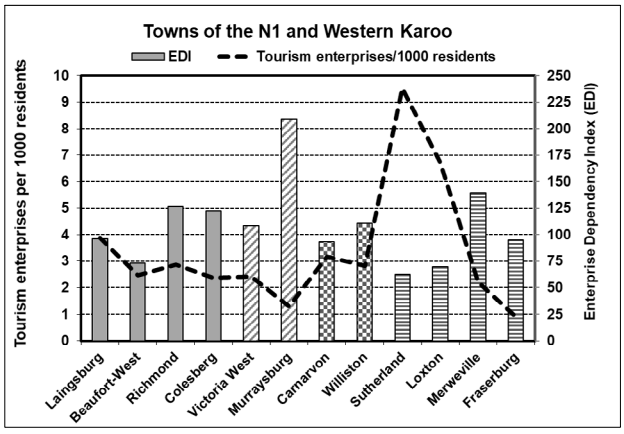

Figure 9: Comparison of the tourism sector strength (tourism enterprises per 1000 residents) and enterprise dependency indices (EDI) of towns on the N1 national road (even coloured) or closely linked to it (diagonal stripes) as well as towns close to the Square Kilometre Array development (square blocks) and other towns in the western part of the study area (horizontal stripes).

Infrastructure (the N1 national road, i.e. the main road between Cape Town and Gauteng, astronomy observatories in the case of Sutherland, the SKA development in the case of Carnarvon and Williston) and the influence of individuals (Deon Meyer in the case of Loxton) contribute to T&H sector strength and the reduction of community poverty.

Discussion and conclusions

Enterprise orderliness prevails in the T&H sectors of the selected towns. A power law (Equation 2) indicates that T&H enterprise numbers are disproportionately higher in smaller than larger towns. The residents of smaller South African towns are more dependent on the T&H sector than the residents of larger towns. The sub-linear coefficient of this relationship is similar to sub-linear exponents of power laws describing the relationships between the infrastructure needs of cities and their populations.[18,22,45]

In the selected towns, EDIs, and thus their wealth/poverty states, are directly and negatively associated with the strengths of their T&H sectors (Equation 3 and Figure 5). Communities of towns with more T&H enterprises are wealthier, and vice versa. This trend was observed in a number of different analyses and is not impacted by the enterprise richness (productive knowledge) of the towns (Figure 5, Table 2).

The debate about the capacity of tourism to reduce poverty[8,11] has focused more on benefits for poor individuals rather than the wealth/poverty states of whole communities. For instance, Saayman et al.[5] stated: 'The main finding [of their study] is that the poor [in South Africa] benefit very little in the short term from additional tourism income.' In contrast, this contribution shows that in the selected group of towns, the communities of towns with stronger T&H sectors are overall wealthier, and vice versa. Debates about the benefits of pro-poor tourism should include information about the impact of tourism on community wealth/poverty and not just focus on individual poverty. The EDI is a simple yet powerful measure to provide community-based poverty information (Figures 4 to 9).

T&H strength (T&H enterprises per 1000 residents) proved to be a very useful normalisation that enabled evaluation of the tourism scenes of the selected towns (Figures 7 to 9). This measure also helped to illuminate the impact of location on tourism success, e.g. being located on the N1, Route 62 or in areas close to astronomical observatories (e.g. Sutherland, Figure 9).

Why is tourism important to rural South African towns? It helps to reduce poverty but the 'new geography of jobs' should also be considered. Moretti[50] explained:

> [T]*he vast majority of jobs in a modern society are in local services. People who work as waiters, plumbers, nurses, teachers, real estate agents, hairdressers, and personal trainers offer services that are produced and consumed locally. This sector exists only to serve the needs of a region's residents.*
>
> *By contrast, most jobs in the innovative industries belong to the traded sector, together with jobs in traditional manufacturing, some services – parts of finance, advertising, publishing – and agricultural and extractive industries such as oil, gas, and timber. These jobs, which account for about a third of all jobs, are very different because they produce a good or service that is mostly sold outside the region…*
>
> *The paradox is that while the vast majority of jobs are in the non-traded sector, this sector is not the driver of our prosperity. Instead our prosperity mainly depends on the traded sector.*

It is necessary to add to Moretti's views that the T&H sector also belongs in the traded sector. Tourists are primarily from elsewhere. What they spend in a local economy represents an inflow of external money. In this sense, tourism is a driver of prosperity and a reducer of poverty in South African towns and should be strongly supported.

Acknowledgements

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Psycho-hormonal effects of aerobic fatigue on collegiate female soccer players

Up to 95% of a soccer match entails aerobic actions that may cause fatigue. Little is known about the effects of fatigue on the hormonal and psychological states of female players. Cortisol values (saliva sample), state anxiety (Spielberger State-trait Anxiety Inventory) and mood scores (Incredibly Short Profile of Mood States [ISP], comprising six subscales and total mood disturbances [TMD]) of 43 female players (aged 22.0±2.7 years) were taken immediately prior to and 15 min after an aerobic fatiguing test (AFT: Yo-Yo Intermittent Recovery [YYIR] test). Cortisol increased (d=0.7, p=0.007) and ISP–confusion and ISP–vigour decreased (d=0.5, p=0.01–0.02). At pre-AFT, a slight positive relationship between cortisol and anxiety-absence (r=0.3, p=0.05) was seen. TMD consistently demonstrated a strong relationship with all ISP and anxiety scores (r>0.4, p<0.01). Post-AFT results demonstrated a positive relationship between cortisol and blood lactate (r=0.3, p=0.04), between ISP–anger with maximal heart rate (r=0.3, p=0.03), ISP–anger and YYIR level as well as ISP–fatigue (r=0.4, p=0.04), and between perceived exertion rate and ISP–vigour (r=-0.4, p=0.008) as well as ISP–fatigue (r=0.3, p=0.05). Fatigue caused by prolonged activity may be a greater physiological than psychological stressor, although both may affect soccer performance. We recommend training players to increase their aerobic capacity to ensure maximal quality match-time before fatigue and its subsequent adverse physiological and psychological effects set in.

Significance:

- The YYIR-1 test is effective in producing significant changes in both the hormonal and psychological states of female soccer players.
- Conditioning staff can effectively implement a mood state questionnaire to predict possible psychological stress (increase in state or trait anxiety) prior to and after a stressor.
- A relationship exists between cortisol and the absenteeism of anxiety prior to this fatiguing test, as well as with blood lactate thereafter. Therefore, the State-trait Anxiety Inventory questionnaire can be administered and blood lactate samples can be collected as they may display sensitive information regarding hormonal state.
- A positive relationship exists between the maximal heart rate achieved following an aerobic fatiguing test and various mood subscales experienced. Thus, with an increase in heart rate (as frequently observed due to fatigue), it can be assumed that an increase in perceived negative mood state might take place.

Introduction

Soccer is characterised by players performing submaximally for a prolonged period, with fatigue commonly observed due to the inability to endure the required work rate for the entire match.[1,2] Most actions are executed at a submaximal exertion level, dominating up to 95% of the work-rate profiles during a match.[2-4] Thus, a large aerobic capacity is needed to maintain high performance throughout a 90-min match; in the absence of large aerobic capacity, fatigue may set in either at the peripheral (outside the central nervous system) or central (within the central nervous system) sites of the body, with debilitating physiological and psychological consequences.[1,3,5] Physiologically, fatigue (perceived as the 'sense of effort') reflects the dominance of the motor drive from the cerebral cortex to the motor neurons, whereas psychologically it reflects the exercise capacity.[5]

It is important when planning training sessions to determine when and why fatigue occurs during a match.[6] Fatigue usually arises during the second half of a game and is manifested by a decline in specific playing ability (less distance covered, sprints completed and ball contact) and, ultimately, physical performance.[1] There may be several physiological reasons for fatigue (such as depleted glycogen stores, hyperthermia, changes in muscle pH and muscle creatine phosphate concentrations, and increased muscle lactate concentrations),[6] although owing to the large load placed on the aerobic system during a match, it is argued that fatigue arises from effects on the aerobic system. During prolonged activities (when aerobic glycolysis is the primary energy source), a depletion in glycogen stores and an increase in glucose consumption by the muscle tissues take place.[5,6] Although the aerobic system is extremely taxed during a match, limited research is available regarding the fatigue experienced during training on the physiological and psychological domains. Hence, examining the effects of fatigue during exercise is an area of concern in studies of the physiology and psychology of sport.[5]

The effects of exercise on mood are influenced by various factors, among others neurobiological features, player characteristics, features of the exercise and psychological state.[7,8] Studies have reported increased positive and reduced negative mood (such as tension, anger, fatigue and confusion) and anxiety states following various aerobic exercises[9-11], partially due to the release of endorphins whilst training[8]. Furthermore, for every 30 min of training (≥60% $\dot{V}O_{2max}$), there is a progressive improvement in mood for various psychological states – including state anxiety, depression, confusion, fatigue and extent of mood disturbances overall.[7,10] However, when prolonged physical exertion becomes distressing, cortisol (the main stress hormone) is secreted.[12]

The secretion of cortisol is modulated by the hypothalamic-pituitary-adrenocortical axis[12], which is important for normal physiological functioning and cognitive and affective processes[12]. Physiologically, cortisol is involved in providing energy for muscle tissue by increasing blood glucose levels[12] and promoting/inhibiting inflammatory processes[13]. Psychologically, it is associated with various behaviours such as expression of mood and anxiety.[14] Because of the bidirectional relationship between hormones and behaviour[15], it is speculated that improvements in mood might modify the perception of stressors, which subsequently can alter the release of cortisol, and vice versa[16,17]. This has been reported previously with increased positive mood states reducing cortisol responses ($F_{(1,901)}=5.86$, $p<0.05$), compared to negative mood states raising them ($F_{(1,901)}=6.91$, $p<0.01$).[17] Furthermore, training has been shown to increase ($p<0.05$) cortisol secretion by up to 36%[18], although a larger increase (250%) was described after a soccer match[14]. This indicates the necessity to maximise the match components, and more specifically the aerobic basis, to minimise the incidence of increased negative psychological states and cortisol due to fatigue.

The influence of aerobic fatigue on the hormonal and psychological states of female soccer players is of practical interest in view of its large role during match play, and the importance of these components for maximal performance on the field. Based on an extensive literature review and searches, we found no published research on the effect of an aerobic fatiguing test (AFT) on the psycho-hormonal state of female soccer players in South Africa and, more broadly, in Africa. The aim of our study was, therefore, first to evaluate the effect of an AFT on the anxiety, mood and cortisol levels of these players; and second, to determine what associated relationships prevail between anxiety, mood and cortisol levels and/or the AFT. Such knowledge will aid coaches, sport scientists and sport psychologists in determining whether fatigue due to prolonged physical exertion may lead to physiological and/or psychological stress in players and whether it adversely influences their performance.

Materials and methods

Subjects

A total of 43 female university students who were soccer players at the time of the study volunteered to partake (age: 22.0±2.7 years; stature: 158.5±5.9 cm; mass: 54.1±6.2 kg, competitive playing experience: 8.2±4.8 years). They all reported being healthy at the start of testing and were excluded if they became injured or ill, or did not complete all the tests. They experienced normal day-to-day stressors as registered students committed to their academic tasks. The specific testing regime was compiled in accordance with their soccer training schedule (training 3–5 times/week) to prevent overtraining. Their internal training load was monitored during the testing period by means of their maximal heart rate (HR_{max}) and perceived exertion rate (RPE).

During the testing period they were in their competitive training phase, with average $\dot{V}O_{2max}$ values of 41.0±1.5 mL/min/kg. An average total sleep duration of 7.7±2.3 h the night before the tests was reported. The majority of participants was in the luteal phase of their menstrual cycle, and none was on oral contraceptives or prescribed medication, as testified in the information questionnaire.

Design

It was postulated that the AFT would result in a statistically significant increase ($p<0.05$, $d\geq0.8$) in salivary cortisol and total mood disturbances (TMD). A linear relationship between anxiety, cortisol and/or TMD was expected. A repeated measure, quantitative research design was adopted to test the hypothesis. Information was collected using various questionnaires and a test battery. Ethical approval was provided by the Health Research Ethics Committee of the North-West University, South Africa (NWU-00055-15-A1) and all principles of the Declaration of Helsinki were adhered to.

Methodology

The study was completed over two consecutive days, two weeks prior to the main tournament. On the first day, written consent was obtained and the testing procedures were explained to the participants. During this period, participants were granted the opportunity to ask questions. They were advised to obtain a good night's rest (at least 8 h sleep), to wake up between 6:00 and 7:00 and to have their last meal at least an hour before the start of testing.

Upon arrival on the second day, each student's body mass (BFW platform scale, Adam Equipment Co. Ltd., UK) and stature (Harpenden portable stadiometer, Holtain Ltd., UK) were recorded. Following a 15-min warm-up session comprising aerobic, stretching and sport-specific activities, the participants rinsed their mouths with lukewarm water to remove any food substances, and after a period of 10 min their saliva was sampled. In this period, they were fitted with a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland) to monitor the HR_{max} obtained post-AFT, and completed the psychological questionnaires. After 10 min, they provided a saliva sample (pre-AFT) and completed the AFT with the Yo-Yo Intermittent Recovery (YYIR)-1 test. Immediately thereafter, the players' RPE, HR_{max} and blood lactate (BLa^-) were recorded, with the last saliva sample and questionnaires completed 15 min post-AFT.

Saliva sampling

Saliva samples were collected using the passive drool test for the assessment of cortisol.[19] If needed, the participants could chew on a piece of Parafilm™ to stimulate saliva flow. Saliva was then collected through a plastic straw into a 20-mL collection vial, after which the sample was stored in a fridge (at 4±1 °C) and transported to a qualified laboratory for analysis.[19] The cortisol concentrations were determined from 20-μL saliva samples by using a luminescence immunoassay. The samples were transferred into a Berthold luminometer to determine the average relative luminescence units, after which they were converted to exact values by plotting against the cortisol concentrations. This method has a non-linear ($r=1.0$) and linear correlation coefficient ($r=0.8$) with serum cortisol values, with an intra-CV (correlation of variation) range of 0.4–1.7% and inter-CV range of 0.8–1.8%.[20] The first sample was collected following warm-up (immediately prior to the AFT), and the last sample 15 min post-AFT, as previous studies have demonstrated that mean cortisol values peak at 10–30 min following a stressor.[16]

Sport-psychology questionnaires

Mood states

Mood states were evaluated pre- and post-AFT by using the Incredibly Short Profile of Mood States (ISP) questionnaire derived from the original Profile of Mood States questionnaire[21] by Dean and colleagues[22]. The ISP consists of six questions targeting the same subscales (involving anger, depression, tension, confusion, fatigue and vigour). Correlations between the two questionnaires ($r=0.67$–0.82)[22], as well as between the six subscales ($r=0.72$–0.83), have been reported previously[23]. The participants rated the questions on a five-point Likert scale from 1 ('not at all') to 5 ('extremely'). Individual scores for each subscale were the rating indicated per question and the TMD score was calculated by adding the negative and subtracting the positive scales.

Anxiety

The participants' perceived anxiety levels pre- and post-AFT were estimated from the results obtained from the state-subscale (SAI) of the original State-Trait Anxiety Inventory.[24] The state-anxiety scale consists of 20 statements that evaluate how respondents feel 'right now, at this moment' on a four-point Likert scale, ranging from 1 ('not at all') to 4 ('very much so'). Trait anxiety was not measured, as it evaluates how a person feels 'in general' and was therefore not within the scope of this study. Total anxiety scores were determined by calculating the sum of the different scores; thereafter the two state-subscales (anxiety – present and absent) were calculated. The scores range from 20 to 80; the higher the score, the greater the anxiety perceived.[24] Internal consistency has been demonstrated for state anxiety ($r=0.91$) over a wide range of studies and participants.[25]

Aerobic fatiguing test

A YYIR-1 test was performed to tax the participants' aerobic system maximally to induce aerobic fatigue.[26] The test was executed as described

by Bangsbo and colleagues[6] to measure the participants' HR_{max} and $\dot{V}O_{2max}$ values while performing intervals over a prolonged period of time. The test was conducted on a flat, clearly marked 20-m stretch of a grass soccer field with the players wearing their soccer boots. The following measurements were made: total distance covered (m), YYIR-1 level completed, HR_{max}, BLa^- and RPE. There is a high correlation for female soccer players between BLa^- and the YYIR-1 test ($r=0.73$, $p=0.003$), the total distance covered ($r=0.64$, $p=0.014$) and the amount of high-intensity running ($r=0.83$, $p<0.001$) covered during a match.[4]

Immediately post-AFT, BLa^- (mmol/L) was measured by collecting a blood sample from a finger prick of the left hand and transferring this to a portable analyser (Lactate Pro, Arkray, Japan). Prior to collection, the portable analyser was calibrated according to the manufacturer's guidelines. This reading was measured as BLa^- and can be an indication of the degree to which the aerobic and anaerobic glycolysis systems are taxed during the test, and can confirm that the onset of fatigue occurred, as values above 8 mmol/L have been reported for soccer players.[27] The participants then indicated their RPE on a 10-point Borg scale, with 1 being the lowest and 10 the highest perceived exertion level.[28]

Statistical analyses

IBM SPSS (v. 24.0.0.0) was used to analyse the data. Descriptive statistics (means, maxima, minima and standard deviation values) were calculated at every time point for each variable. Linear mixed model analyses were then conducted to investigate time-point differences with an autoregressive 1 covariance structure.

Next, the variables were categorised into three rankings (low, average/neutral and high) as derived from the results for each time point. Prior to their ranking, the cortisol values were adjusted according to the awakening and sample collection times.[29] The score for each ranking at each time point was then expressed as a percentage of the total score for the specific variable as calculated by chi-squared analysis, with practical significance indicated by Cramer's *V* values.

Finally, Pearson's rank correlation, rho, determined the relationship between the variables (cortisol, TMD and anxiety) and AFT. A Fisher's *r* to *z* transformation was calculated to determine the 90% confidence interval (CI) from the correlation coefficient. The level of significance was set at $p \leq 0.05$. The strength of the correlation was categorised from ≤ 0.01 to ≥ 1 (perfect). In each case, magnitudes of standardised effects $\pm$ 95% confidence interval ($d \pm$95% CI) were calculated and interpreted as: $d \geq 0.8$ (large), $d \geq 0.5$ (moderate) and $d \geq 0.2$ (slight). Effect sizes with wide confidence intervals that overlap categorical classifications of effect were downgraded as 'unclear'.

Results

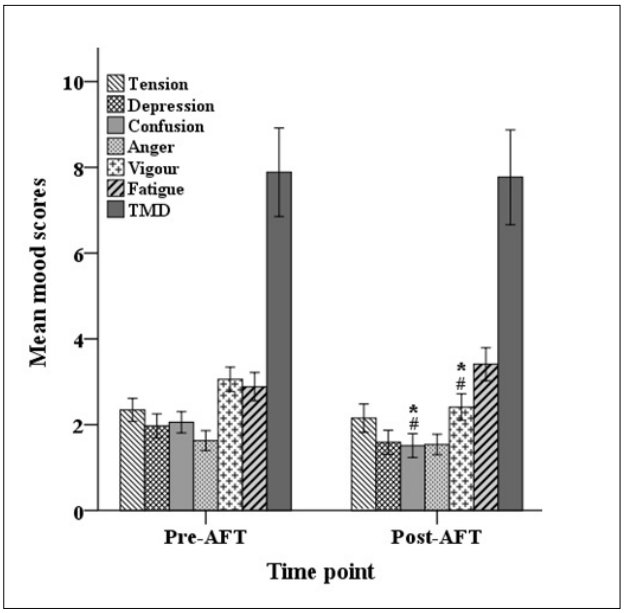
The average results for the AFT were: level: 14.1±0.9; total distance: 560.9±212.8 m; HR_{max}: 190.1±8 bpm; BLa^-: 10.9±3.6 mmol/L; RPE: 7.1±1.9. Only 36 complete sets (cortisol and full questionnaires at pre- and post-AFT) were used for analysis, with incomplete sets excluded.

Cortisol results

Cortisol increased significantly (52.2%) ($F_{(2.216)}=5.2$; $p=0.007$, $d=0.7$ CI: 0.3–1.2). The total number of cortisol values rated as 'high' increased significantly from pre- to post-AFT (pre-AFT: 28.2% to post-AFT: 59%, $p<0.01$, $V=0.4$).

Psychological results

Only the ISP subscales confusion (pre-AFT=2.1, post-AFT=1.5, $p=0.01$, $d=0.6$ CI: 0.2–1.1) and vigour (pre-AFT=3.1, post-AFT=2.4, $p=0.02$, $d=0.6$ CI: 0.2–1.1) showed moderate decreases from pre- to post-AFT (Figure 1). The subscale anxiety–absence was larger than anxiety–present (pre-present = 16.5±5.0, pre-absent = 21.6±6.0, post-present = 16.2±5.1, post-absent = 22.5±6.6), although a moderate effect was seen in the anxiety-present scores from pre- to post-AFT ($d=0.5$ CI: 0.07–1.0).



*#Moderate effect size (*d*≥0.5)*

**Significantly lower than pre-AFT (*p*<0.05); error bars: 90% CI*

Figure 1: Mood responses before and after an aerobic fatiguing test (AFT).

Hormonal and psychological relationship results

At pre-AFT, a slight positive relationship between cortisol and anxiety–absence ($r=0.3$, $p=0.05$) was seen. TMD demonstrated a strong relationship with all ISP and anxiety scores ($r>0.4$, $p<0.01$). Post-AFT results demonstrated a positive relationship between cortisol and BLa^- ($r=0.3$, $p=0.04$), between ISP–anger and HR_{max} ($r=0.3$, $p=0.03$), ISP–anger and YYIR-level as well as ISP–fatigue ($r=0.4$, $p=0.04$), and between RPE and ISP–vigour ($r=-0.4$, $p=0.008$) as well as ISP–fatigue ($r=0.3$, $p=0.05$).

Discussion

The most significant observation from the current study was the increase in cortisol with only two mood subscales (vigour and confusion) decreasing following an aerobic fatiguing test. This suggests that aerobic fatigue, as frequently observed during a match, primarily influences the individual's physiology and its underpinnings rather than the psychological state. In addition, a positive relationship between cortisol and anxiety–absence and between cortisol and BLa^- was observed. The mood and anxiety scores correlated strongly at all times, whereas some mood subscale scores correlated with the AFT measurements. We therefore propose that a connection exists between physiological and psychological states when dealing with a physical stressor.

The sensation of fatigue during training is common due to the increased training load and decreased energy stores of the athletes involved.[5] These sensations can be related to both psychological and physiological states, as exercise affects both a person's physiology and neuromuscular condition.[5]

Hormonal responses

The significant cortisol increase is similar to that reported previously[18,30], following either a 30-min treadmill run[18] or after a high-intensity resistance training session[30]. As evident in the results, a linear relationship exists between cortisol and physical exertion.[30] In this regard, training below 60% $\dot{V}O_{2max}$ decreases cortisol[31], whereas training above 60% $\dot{V}O_{2max}$ generally increases cortisol either to aid in the metabolism and mobilisation of energy sources in providing sufficient fuel, or as a consequence of its secretion exceeding its removal.[12,32] In addition, the high BLa^- and HR values recorded following the test might indicate a quicker onset of fatigue owing to the participants' training status (average rated $\dot{V}O_{2max}$ values), which has the ability to influence hormonal response patterns,[30] as seen from the correlation between cortisol and BLa^-.

Table 1: Correlation coefficient (*r*) at the 90% CI at pre- and post-AFT

		Pre-AFT										
	***r* (CI 90%)**	**Cortisol**	**TMD**	**ISP: Tension**	**ISP: Confusion**	**ISP: Depression**	**ISP: Fatigue**	**ISP: Anger**	**ISP: Vigour**	**Anxiety total**	**Anxiety absent**	**Anxiety present**
Post-AFT	**Cortisol**	–	-0.1 (-0.2–0.1)	-0.1 (-0.2–0.2)	-0.1 (-0.3–0.2)	-0.1 (-0.3–0.1)	-0.2 (-0.3–0.1)	-0.1 (-0.2–0.3)	0.1 (-0.3–0.2)	0.2 (-0.0–0.4)	0.3* (0.1–0.5)	0.1 (-0.1–0.3)
	TMD	-0.2 (-0.4–0.1)	–	0.6** (0.3–0.8)	0.7** (0.6–0.8)	0.8** (0.7–0.9)	0.7** (0.5–0.8)	0.6** (0.3–0.8)	-0.4** (-0.6– -0.2)	0.6** (0.6–0.8)	0.4** (0.2–0.6)	0.7** (0.5–0.8)
	ISP: Tension	-0.3 (-0.5–0.0)	0.5** (0.2–0.7)	–	0.5** (0.2–0.7)	0.4* (0.1–0.7)	0.3* (0.1–0.5)	0.1 (-0.1–0.3)	0.3* (0.0–0.5)	0.4** (0.1–0.7)	0.1 (-0.2–0.5)	0.6** (0.4–0.8)
	ISP: Confusion	-0.1 (-0.2–0.2)	0.7* (0.6–0.8)	0.2 (-0.1–0.5)	–	0.7** (0.7–0.9)	0.2 (-0.0–0.5)	0.5** (0.4–0.8)	0.0 (-0.2–0.3)	0.7** (0.5–0.8)	0.4** (0.2–0.6)	0.7** (0.6–0.8)
	ISP: Depression	0.0 (-0.2–0.3)	0.8* (0.7–0.9)	0.3* (0.0–0.7)	0.7** (0.4–0.9)	–	0.3* (-0.0–0.6)	0.8** (0.5–0.9)	-0.1 (-0.3–0.2)	0.6** (0.5–0.7)	0.4** (0.2–0.6)	0.6** (0.5–0.8)
	ISP: Fatigue	-0.2 (-0.3–0.0)	0.5** (0.2–0.7)	-0.1 (-0.4–0.2)	0.2 (-0.0–0.5)	0.0 (-0.3–0.3)	–	0.2 (-0.2–0.5)	-0.4** (-0.7– -0.1)	0.3* (0.0–0.6)	0.2* (-0.1–0.4)	0.4** (0.1–0.6)
	ISP: Anger	0.1 (-0.1–0.4)	0.6* (0.3–0.8)	0.2 (-0.2–0.6)	0.5 (0.3–0.7)	0.8** (0.7–0.9)	0.2 (-0.2–0.5)	–	0.0 (-0.2–0.5)	0.4* (0.2–0.5)	0.2 (0.1–0.4)	0.4** (0.2–0.6)
	ISP: Vigour	0.2 (-0.0–0.4)	-0.4* (-0.6– -0.1)	-0.1 (-0.3–0.3)	0.0 (-0.3–0.3)	-0.3* (-0.5– -0.1)	-0.4* (-0.7– -0.1)	0.0 (-0.2–0.4)	–	-0.1 (-0.4–0.2)	-0.2 (-0.5–0.1)	0.1 (-0.3–0.3)
	Anxiety total	0.2 (0.0–0.4)	0.7** (0.5–0.8)	0.2 (-0.1–0.5)	0.7 (0.5–0.8)	0.6* (0.5–0.7)	0.2 (-0.2–0.4)	0.4* (0.2–0.5)	-0.1 (-0.4–0.2)	–	0.9** (0.8–0.9)	0.9** (0.8–0.9)
	Anxiety absent	-0.1 (-0.1–0.4)	0.5** (0.3–0.7)	0.0 (-0.3–0.3)	0.4 (0.2–0.6)	0.4* (0.2–0.6)	0.2 (-0.1–0.5)	0.2 (0.1–0.4)	-0.2 (-0.5–0.1)	0.9** (0.8–0.9)	–	0.5** (0.3–0.7)
	Anxiety present	0.1 (-0.1–0.4)	0.7** (0.5–0.8)	0.4** (0.1–0.7)	0.7* (0.5–0.8)	0.6* (0.5–0.8)	0.0 (-0.3–0.3)	0.4 (0.2–0.6)	0.1 (-0.3–0.3)	0.8** (0.7–0.9)	0.4** (0.3–0.7)	–
	Yo-Yo level	-0.1 (-0.4–0.2)	0.2 (-0.1–0.5)	0.2 (-0.2–0.5)	-0.2 (-0.4–0.2)	0.0 (-0.3–0.2)	0.3* (0.0–0.6)	-0.1 (-0.3–0.1)	-0.3 (-0.5–0.0)	-0.1 (-0.3–0.2)	-0.1 (-0.4–0.2)	-0.0 (-0.3–0.2)
	Maximal HR	0.1 (-0.2–0.4)	0.2 (-0.1–0.5)	0.2 (-0.1–0.4)	0.2 (0.0–0.4)	0.2 (-0.1–0.5)	0.0 (-0.3–0.2)	0.3* (0.1–0.5)	0.1 (-0.2–0.3)	0.2 (-0.1–0.5)	0.2 (-0.1–0.4)	0.2 (-0.1–0.5)
	BLa^-	0.3* (0.1–0.6)	0.1 (-0.2–0.3)	0.1 (-0.2–0.3)	0.1 (-0.3–0.4)	0.1 (-0.2–0.4)	0.0 (-0.2–0.3)	0.0 (-0.2–0.3)	0.1 (-0.1–0.3)	-0.1 (-0.3–0.2)	-0.2 (-0.4–0.1)	0.1 (-0.1–0.3)
	RPE	-0.3 (-0.5– -0.1)	0.3 (0.0–0.5)	0.2 (-0.1–0.5)	0.0 (-0.1–0.2)	0.0 (-0.3–0.3)	0.3* (0.1–0.5)	-0.2 (-0.4–0.1)	-0.4** (-0.7– -0.1)	0.1 (-0.2–0.3)	0.1 (-0.2–0.3)	0.1 (-0.2–0.4)

AFT, aerobic fatiguing test; BLa^-, blood lactate; HR, heart rate; ISP, Incredible Short POMS; RPE, rate of perceived exertion; TMD, total mood disturbances

**p<*0.001; *p<*0.05*

Psychological responses

As seen from the negative correlation between ISP–vigour and RPE, fatigue caused vigour to decrease during the test. The significant reduction in the players' state of confusion might be attributed to them becoming familiar with the specific test, as it was completed regularly during the tournament season. Previous research reported a significant decrease in tension, anger, fatigue and confusion following a treadmill session at 61% HR_{max}.[9] During aerobic training the body releases endorphins (the natural mood-enhancing hormones), with a particular release threshold reached at higher training loads.[8] Although no significant changes in anxiety were reported, previous research demonstrated reduced anxiety levels following aerobic training.[10,33] This might be due to studies proposing training sessions of at least 30 min to stimulate the release of endorphins and provoke well-being improvements.[7,8,10] Finally, negative mood states did not increase as postulated, possibly due to the maintenance of a coherent mood state, as the training session offered a diversion from the tensions of normal life; alternatively, the positive feelings followed the accomplishment of a specific task, the AFT.[8]

The positive relationship found between the TMD and anxiety at all times is similar to that reported by Guszkowska and Sionek[34]. They reported a correlation between trait anxiety and various mood subscales (tension and vigour) following a training programme. Although not the sole measurement, an anxiety subscale was examined in the ISP questionnaire, which might explain this relationship. This noteworthy observation makes it possible to use this questionnaire to indicate a participant's state of anxiety.

Hormonal and psychological relationships

Not only is cortisol physiologically involved during exercise, but also psychologically.[15] Research indicates a link between the higher central nervous system's functioning and the neuroendocrine system, together with the psychological sense of training.[5] Whereas our findings demonstrated only a slight positive relationship between cortisol and the absence of anxiety pre-AFT, Haneishi and colleauges[14] described a higher positive correlation between cortisol and cognitive anxiety prior to training ($r=0.7$). However, they did not report the specific training regime, making it possible that more intense training was expected.[17] Our subjects, on the other hand, were familiar with the specific fatigue test, thus reducing their perceived anxiety.

Although anxiety questionnaires are primarily developed to detect anxiety changes, it is plausible that other variables, such as cortisol fluctuations, might be detected, as researchers believe that our emotions are influenced by physiological processes and vice versa.[35] A possible explanation for this relationship is the bottom-up approach – a stressful situation can result in various negative emotions, leading to erratic heart rates, taxing the nervous system, activating the hypothalamic-pituitary-adrenocortical axis (thereby resulting in the secretion of cortisol) and, subsequently, impeding the psychophysiological system.[35] Therefore, implementing a psychological questionnaire could be functional to detect not only underlying psychological states, but also physiological states needed to enhance performance.

Practical application

Aerobic fatigue elicits a greater physiological than psychological stress response (which might be due to the depletion of energy stores). Players and their coaches could therefore focus on maximising the aerobic component, as it may contribute to longer quality match-time for players before fatigue sets in.

Seven data sets were excluded – either due to saliva samples not being thoroughly analysed or because questionnaires were incomplete. Subjects acknowledged that the SAI is lengthy and that they did not complete all the questions. Therefore, future studies could instead implement the ISP questionnaire as it correlated strongly with the SAI. Furthermore, a thorough analysis of participants' sleep could be obtained for plausible explanations on the hormonal and/or psychological states.

Due to the circadian rhythm of cortisol, the saliva collection times should have been limited to a specific time period to exclude potential outliers. Additionally, the fitness levels of the subjects could have been a confounding factor, as fitness affects onset of fatigue. Future studies could take into account the current readiness level by making use of physical and/or psychological inclination questionnaires.

Conclusion

To our knowledge, this study is the first to evaluate the effect of an AFT on the hormonal and psychological states of female soccer players in South Africa and, more generally, in Africa. The investigation demonstrated that an AFT, such as the YYIR test, led to an increase in cortisol and a decrease in vigour. The easy administration of the YYIR-1 test, together with its soccer-specific nature, makes it a useful tool for future evaluations to monitor soccer-specific fitness and hormonal changes. The positive relationship observed between cortisol and anxiety–absence can enable coaches to use the questionnaire to anticipate cortisol responses as a reaction to aerobic fatigue. Our study affirms the negative effects of fatigue due to prolonged activity on the players' psychophysiological state.

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Authors' contributions

A.B. was responsible for conceptualising the research goals and aims, developing the methodology, data collection, applying statistical techniques to analyse the data and preparing and creating the published work as well as reviewing and revising the work. M.S. was responsible for conceptualising the research goals and aims, developing the methodology, data collection, validating the experimental process and results, overall project leadership and management, student supervision and reviewing and revising the writing. C.P. was responsible for conceptualising the research goals and aims, developing the methodology, data collection, student supervision and reviewing and revising the writing. D.E. was responsible for student supervision and reviewing and revising the writing.

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