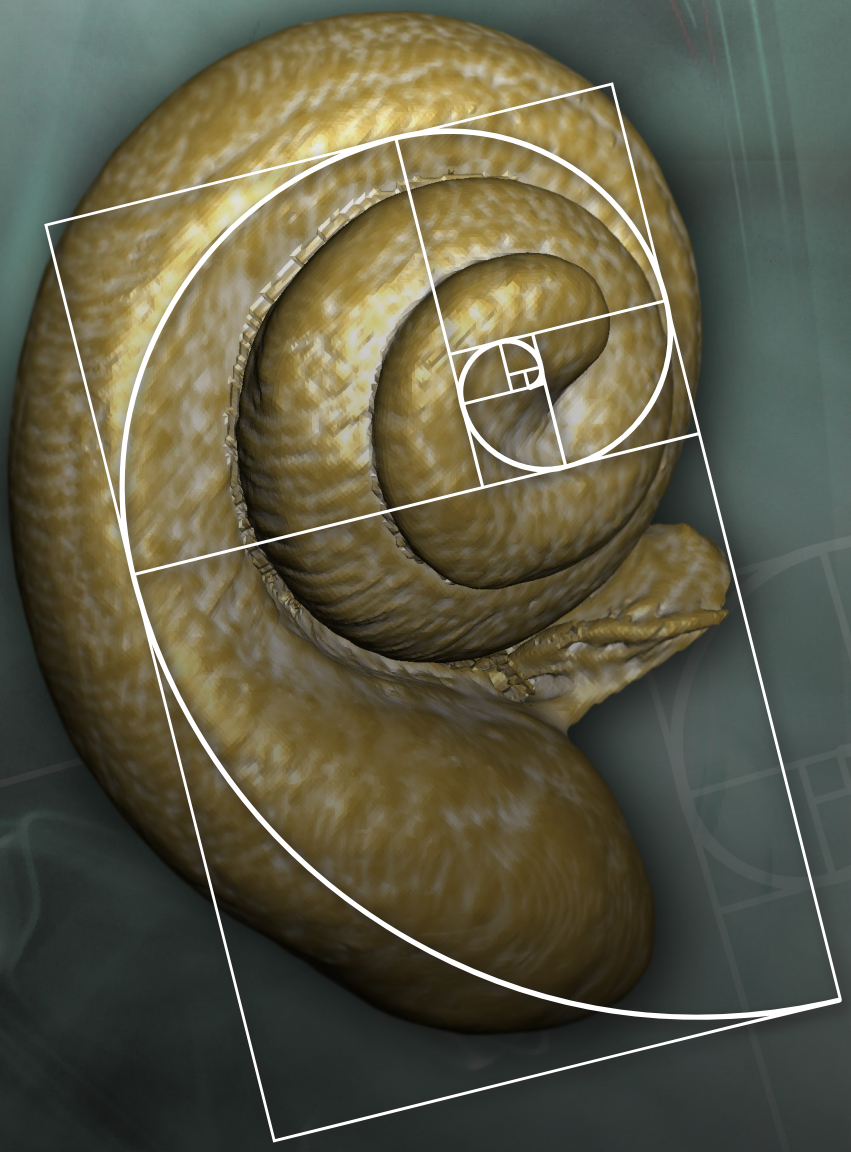
SOUTH AFRICAN
Journal of Science

The Golden Ratio: From space-time to biological structures

Can invasive alien plants be harvested for energy?

Crop pollination services in South Africa

An industry-directed training and research programme



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Science and education as antidotes

On 23 March 2014, the World Health Organization (WHO) was notified of an outbreak of the Ebola virus disease in Guinea. By 8 August, the WHO had declared the epidemic to be a public health emergency of international concern. By then, the number of reported cases had reached 1440 with 826 deaths recorded.

Just 4 weeks later, the reported cases had more than doubled to 3069 and the deaths almost doubled to 1552. By then, the most affected countries were putting major efforts into campaigns aimed at control and awareness, with the support of WHO, the UN, Médecins Sans Frontières (MSF) and Western countries. But it was only when the number of reported cases had reached 9911 and the deaths numbered 4868, in October 2014, that the Chair of the African Union (AU) Commission, Nkosazana Dlamini-Zuma, set off to West Africa to visit the three countries at the heart of the Ebola crisis. Her visit came 6 months after the crisis began, and despite widespread concerns across Africa and the world that the epidemic could very quickly spread out of control. Well before the AU visit, the US Center for Disease Control and Prevention (CDC) estimated that infections could reach 1.4 million by February 2015. And in September 2014, at the end of a history of suspicion and violence, eight health and medical workers were killed in Guinea by a mob whose members believed that the workers were spreading Ebola. It is difficult, under these circumstances, to understand why the AU took so long to respond to a regional crisis that could easily become a continental disaster.

It is not surprising, then, that there has been a focus on the importance of science and education, on information and understanding, as ways of facing not just this, but other epidemics. Sound, functioning systems of public health and good information are clearly essential. But the roles that science and education can play should contribute to prevention and cure and, where necessary, to stemming the rates at which epidemics spread.

Closer to home than the centres of concern (although her speech was given in New York in late October), Minister of Science and Technology Naledi Pandor pointed to the role that science has played in eradicating polio and smallpox through the development and widespread use of drugs and vaccines. Her view is that without major efforts to promote, support and invest in the development of science, technology and medicine in Africa, the countries of the continent will not be able to assist in the effective transfer of technology into the continent from outside, nor will there be a drive to develop local innovation aimed at meeting 'local' needs. Of equal importance are the roles that science and technology need to play in ensuring that the Millennium Development Goals are met, so that the underlying causes of the spread of disease, including poverty and very low levels of medical care, are addressed.

Much the same can be said for education. Development sites tend to focus on immediate, crisis educative solutions, which are inevitably short term: radio broadcasts (a good idea for the most part); house-to-house dissemination of materials (possibly useful for literate households); and the provision of mobile phones and solar-powered tablets (an expensive option in countries without sufficient funds to deal with crises in the first instance). The more serious considerations are those that mirror Minister Pandor's call for science and technology to be taken seriously across the continent – taking primary education and literacy seriously. Both are expensive, but have longer-term, potentially preventative benefits. Primary school attendance rates in the three most affected countries – Guinea, Sierra Leone and Liberia – are difficult to determine but would seem to be 74%, 70% and 41%, respectively. This means that, in Guinea, a quarter of the children in the relevant age cohort are not in primary school, in Sierra Leone 30% and in Liberia almost 60%. Adult literacy rates are worse.

Nor is it just inadequate formal education that presents challenges. Community and tradition are closely interwoven so that deep-rooted cultural practices sometimes override the benefits that could possibly come from better education (especially public health education). Extended families share homes, cooking implements and facilities – so cultural norms have, in fact, contributed to the rapid spread of the virus. Yet it is also true that the school and adult education data are closely tied to poverty and joblessness, and imply an urgent need to address these shortcomings as part of a long-term programme aimed at ensuring that diseases are more quickly and easily controlled.

The various needs to drive rapid growth in science, technology, health and education are, however, drawn together into a critical nexus at the level of higher education – both on the African continent and in countries of the South and North that have the will to develop knowledge and skills that can feed directly back into the continent.

The Ebola epidemic has, as a consequence, received attention not just from the expected organisations (WHO, the CDC, the UN and MSF) but also from major international universities that are providing expertise in scientific, medical and public health areas. Yale has scientists from its Schools of Public Health and Medicine working in Liberia, while, in August 2014, researchers from the Broad Institute and Harvard published (in *Science*) their findings on 99 Ebola genomes, identifying mutations important for diagnostics and treatment. Oxford has made available, free of charge, research on Ebola published in 13 of its medically orientated journals, while the London School of Hygiene and Tropical Medicine, teamed with the Institute of Tropical Medicine in Antwerp, is assessing whether or not treatment with antibodies in the blood of Ebola survivors could help infected patients to fight off the disease.

These are all critical contributions of the kind that science and technology can make in limiting the effects of the current epidemic. The calls for, and implementation of, intensive public health and general education are equally important. In the longer term, the unknown consideration is whether or not the Ebola crisis, and the deaths of as yet unknown numbers of people in Africa and elsewhere, will be sufficient to ensure that Minister Pandor's words will be taken seriously and put into practice.

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Rough and tumble

BOOK TITLE:
Rough and tumble: Aggression, hunting, and human evolution

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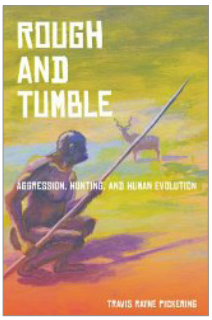

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Rough and tumble

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Human beings comprise a peculiar species on this planet with their multitude of behaviours, morphologies and proclivities. What we humans all have in common is our deep ancestry, just like all other species that have their own peculiarities. One need not look further than the daily newspaper to find examples of our worst inheritance: human-on-human aggression. It raises the question as to whether such aggression can be tied to our unique evolutionary history, particularly with regard to our prehistoric habit of hunting game for food. Questions about the relationship between the evolutionary origins of hunting behaviours and contemporary human aggression have been asked for decades, if not centuries, in one form or another. To dissect the myriad of ideas and hypotheses, none could have done a better job than Travis Rayne Pickering.

Pickering is a Professor of Anthropology at the University of Wisconsin, but his professorial skills extend over a wide gamut in this book – from historian to science philosopher, from palaeontologist to behaviourist. I might add in journalist as well. Despite taking pains at every turn to honestly portray his science with the utmost rigidity and fealty, he manages to keep the pace of the book moving like a gripping novel.

The first full chapter begins with a narrative about C.K. 'Bob' Brain – an icon of South African palaeontology and taphonomy, which are the topics that pervade the book. Biographical vignettes of Bob Brain are peppered throughout the book. I find this appropriate, as it is clear that Brain's scientific body of work and personal experiences have helped to shape Pickering's views, as they have for so many of us over multiple decades.

For those of you who are not familiar with the science of taphonomy, it is literally the study of the grave – the study of what happens to something after it dies. It is of critical importance to understanding the very nature of the fossil record, and Pickering, like Brain before him, is a master of the science. He uses it to tease through every bit of evidence, minute through grand, to formulate a cogent, plausible and testable notion of the relationship, if any, between our hunting origins and our current aggressions. Like any intimate relationship, it turns out to be, well, complicated.

Pickering goes to great lengths to push back the origins of human hunting to an earlier phase than most currently accept. He builds a strong case that early members of the genus *Homo* (as currently defined) may have been more than passive scavengers. I cannot say I fully agree with all of his arguments, particularly in Chapter 4 when he focuses on lion habits rather than those of other carnivores. But he puts his ideas out there with research data, and makes it clear that he is ready, and more importantly open, for debate.

Some readers might have wanted the book to come to a more succinct and defined conclusion. As much as I enjoyed reading *Rough and Tumble*, it has no crescendo at the end. The positive side of that reflects what I noted at the beginning of this review – Pickering is a careful and meticulous scientist, not prone to grandiose proclamations about how life used to be in our evolutionary past.

I will assign this book to my graduate students, as there is a lot of fodder for discussion for those seeking higher degrees; it has copious notes at the end for the serious scholar. I think that *Rough and Tumble* will interest undergraduates and the general public as well, given the high quality of writing. But I also hope that this book stays on the record as being representative of excellence in science and the scientific method. Some of the conclusions may change, but that is the nature of science and the science of nature. Pickering's approach is among the best I have seen.

Documenting a lost ecosystem

BOOK TITLE:
Historical incidence of the larger mammals in the Free State Province (South Africa) and Lesotho

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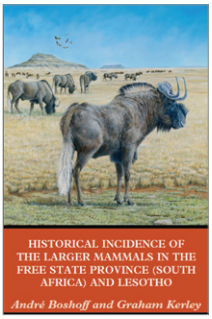

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The relatively recent, and ongoing, destruction of earth's wildlife is an unfortunate feature of today's world. Over large areas of South Africa, once plentiful populations of wild mammals have been eradicated or reduced to small relict populations in protected areas or on privately owned land. These changes have not been trivial, and it is often difficult to conceive the degree to which ecosystems have been transformed in a relatively short time. To have a concise, authoritative and comprehensive account of the conditions that prevailed in the recent past is an important step to understanding the ecology of any given region. In the case of the Free State and Lesotho, André Boshoff and Graham Kerley have produced a record for this region's grassland ecosystems, based on the eyewitness accounts and the illustrations of early literate travellers. Their book follows the publication of two volumes on a similar topic by C.J. Skead, one that dealt with the Eastern Cape and one with the Western and Northern Cape.[1,2] The two volumes compiled by Skead had the benefit of the often detailed and good quality distributional information recorded by early naturalists, including the Swedes Sparrman and Thunberg, the Englishmen Barrow and Burchell, the Scotsman Patterson, the Frenchman Le Vaillant and the Dutchman Gordon. By contrast, the historical distributions of the 59 larger mammal species that occurred in the Free State and Lesotho had to be reconstructed almost entirely from the records left by people other than competent naturalists or scientists. To construct maps of the historical distribution ranges of each species, the authors surveyed almost 100 texts describing travels in the 19th century. They classified any references to mammals by locality (either a precise locality was given or the locality was imprecise) and by species (either the species could be positively identified or the identity of the species referred to was not conclusive). Based on these accounts, it was possible to reconstruct the distributions of most large mammal species, although for some, uncertainty remains. For example, evidence for the occurrence of cheetahs was 'frustratingly vague'. Although there is evidence of the historical occurrence of cheetahs to the north, south and west of the Free State, and although the habitat was clearly suitable and appropriate prey species were abundant, no mention of cheetahs was found. Nonetheless, the picture that emerges is one of a remarkably diverse and unique large mammal fauna that occurred on the grasslands of the South African Highveld less than 150 years ago.

More remarkable are the accounts of the numbers of herd-forming plains game that existed in the 19th century, as well as the reconstruction of their precipitous demise. Early texts repeatedly refer to mixed herds of tens of thousands of animals that covered vast areas. Typical examples include: 'The number of wildebeest feeding on the flats is almost incredible'; 'the number of wild animals [blesbuck, springbuck, wildebeest and quagga]….almost realised fable'; and 'herds of gnus from 30 to 200 each, hartebeests and blesbucks….in larger numbers, and springboks in countless numbers'. Records show that these animals were systematically annihilated, both for sport and commercial gain, between the 1850s and 1870s. Trade records show that up to 300 000 hides were exported *per year* in the 1870s. Of 26 larger mammal species (7 carnivores and 19 herbivores, including 11 antelope species), 17 had been exterminated, 5 had been nearly exterminated, and 4 had experienced marked reductions in range and numbers by 1920. The book also presents some evidence for historical migrations in the area, although the herds were regrettably destroyed before these seasonal movements could be properly documented. The spectacle presented by vast migrating herds of antelope and other species, and accompanying predators, would have rivalled or eclipsed those on the famous Serengeti Plains. There are numerous illustrations, drawn by travellers from life, that help the reader to form a picture of the historical situation.

Where they still occur (or where they have been re-introduced), indigenous mammals can be a valuable source of income, both for venison and for ecotourism (hunting and game viewing). Given the value and growth potential of tourism, many private and government landowners have also re-stocked land with large mammals outside of their historical distribution ranges. The widespread redistribution of many species to areas outside of their natural ranges can have negative impacts on the biodiversity of ecosystems, and can lead to the genetic homogenisation of mammal populations. While these impacts have not been widely documented, a precautionary approach would seem advisable, and re-stocking of areas should be restricted to those mammal species that occurred there historically, and to which the ecosystems where they are being returned are adapted. This book will certainly be a valuable guide to the appropriate re-establishment of extirpated species.

This book has a wealth of well-organised information, and its production at a reasonable price was made possible by generous sponsorships from a number of sources. This book, and its two companion volumes, should therefore be of wide appeal, and I would recommend it to ecologists, conservationists, farmers and historians, as well as collectors of Africana.

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The University of East Africa: Anatomy of a failed experiment?

BOOK TITLE:
Politics and higher education in East Africa: From the 1920s to 1970

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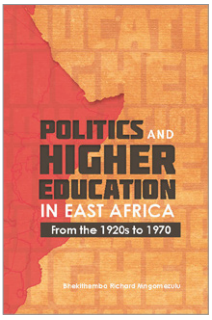

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In this book, Bhekithemba Mngomezulu offers a useful historiography of higher education in East Africa. He discusses the role played by politics in colonial Britain and in the East African colonies, and the involvement of missionary and American philanthropic organisations in the development of higher education in Africa, specifically in East Africa. The specific focus of the book is the rise and fall of the University of East Africa (UEA). It is this distinct focus on the UEA that distinguishes the book from earlier historical accounts of higher education in Africa such as Ashby's *African Universities and Western Traditions* (1964), Ajayi, Goma and Johnson's *The African Experience with Higher Education* (1996) and Lulat's *A History of African Higher Education from Antiquity to the Present: A Critical Synthesis* (2005).

The book consists of three parts, which are further subdivided into seven chapters. The first part (Chapter 1) provides a broad overview of the development of higher education in the British Empire. Further, it traces the development of higher education in Africa from the early 1920s to the 1960s. This chapter, through the reports of the various commissions, conferences, working parties, missionary and philanthropic organisations, demonstrates, inter alia, that the origin and development of higher education in Africa was a contested process; a process that was steeped in political wrangling, negotiations, suspicion, compromises and differing interests. The chapter illustrates that – while the demand for higher education by African constituencies was inseparable from the struggle for *uhuru* and the promotion of nationalism and pan-Africanism – for colonial authorities, missionaries and philanthropic organisations, the drivers for higher education in colonial Africa ranged from evangelism, colonial control, acculturation and, towards the end of colonial rule, the production of elites to whom the colonial authorities would 'handover the responsibility for administration, the technical services and for taking of political decisions' (p.9).

Part II (Chapters 2–4) explores the process of establishing the UEA from the early 1920s to 1963, located within the broader context of British imperial policy, and the roles played by the British government in London, British governors in East Africa and East African politicians and academics in the establishment of the UEA. The author traces the establishment of the UEA through the reports of various committees, commissions and working parties – such as the Permanent Advisory Committee on Native Education in the British Tropical African Dependencies (1923), the De La Warr Commission (1936) and the Asquith Commission (1943). He then explores the evolution of the UEA, beginning with the establishment of Makerere University College in 1949 as an inter-territorial university serving the entire East African region (Uganda, Kenya, Tanganyika and Zanzibar), and later the establishment of the Royal Technical College, Nairobi (1952) and University College, Dar-es-Salaam (1961), which in 1963 became the constituent colleges of the UEA. Towards the end of this part of the book (Chapter 5), the author presents important debates by East African politicians and academics around the role of the university, the relationship between the university, state and society, Africanisation of the curriculum and staff, academic freedom and university autonomy.

Part III (Chapters 5–7) examines the factors that led to the demise of the UEA in 1970. According to the author, 'the university started falling apart as it was being instituted, thus leading to the conclusion that it was like a stillborn child' (p.165); that is, there were indications already during the process of establishing the university that it was eventually going to collapse. While several factors conspired against the success of the UEA, the main reason for its collapse seems to be territorial and inter-territorial tensions among the three East African states, manifested mainly by agitations by these countries for the establishment of national universities and the pursuit of national interests.

Overall, the book offers an enlightening historical account of the development of higher education in East Africa. An important strength of the book is the detailed discussion of the various processes and roles played by different constituencies that led to the introduction of higher education in East Africa and the establishment of the UEA. The book is not just a historiography of higher education in East Africa, but, as is the case with good historical accounts, provides a useful context for understanding some of the issues confronting higher education in Africa today, such as the often problematic relationship between higher education, society and the state, the varied understanding of the roles of higher education, curriculum and the question of relevance, diversity and differentiation. Further, even though the author makes no attempt to link the historical development of higher education in East Africa to some of the practices that are characteristic of higher education in East Africa today, several path dependencies are discernible. A good example is the practice of aspiring universities entering into a 'special relationship' with an established university before attaining a fully fledged university status. In Kenya, with the exception of Moi University which was established from the outset as a fully fledged university, all public universities started as constituent colleges of an established university; a practice borrowed from the 'special relationship' of the UEA and the University of London.

A key limitation of the book is the largely descriptive nature of the discussion. While this is understandable given its historical focus, the author misses the opportunity, especially in the last chapter, to provide some critical analysis and tease out some key issues that still resonate in higher education debates today. For instance, despite the UEA being the first experiment with differentiation in African higher education, the issue is neither mentioned nor discussed. In this regard, the section on lessons from the experience of the UEA is the weakest in the book.

Number theory and the unity of science

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Within recent millennia, sentient representatives of the species *Homo sapiens* have explored science with a sense of curiosity. Currently there are schoolchildren, university students and academic researchers, in Africa and elsewhere, asking questions about relativity, mass, space, particles, waves, space-time and the nature of constants in the fields of mathematics, physics, chemistry and biology.[1] Recently, questions have been raised about whether an irrational mathematical constant – designated by the Greek symbol Φ with a value of about 1.618 – can be related to a biological species constant (T), based on morphometric analyses of modern mammalian skulls, and explored in the context of probabilities of conspecificity of Plio-Pleistocene hominin fossils.[2-4] We suggest that there is a strong case that this so-called 'Golden Ratio' (1.61803...) can be related not only to aspects of mathematics but also to physics, chemistry, biology and the topology of space-time.[1]

A convincing case for assuming a cosmic character of the Golden Ratio can be made based on the ubiquity of logarithmic spirals. Spectacular examples include the Whirlpool Galaxy (M51), ammonites, the shape of *Nautilus* shells, Hurricane Katrina and the distribution of planets, moons, asteroids and rings in the solar system (Figure 1). The logarithmic spiral is firmly related to the Fibonacci series and the Golden Ratio of number theory. A familiar aspect of Fibonacci spirals is the way they feature in botanical phyllotaxis, the shape of kudu (*Tragelaphus strepsiceros*) horns and the curvature of elephant tusks. Less well known is the way in which the crystallographic structure of DNA, stress patterns in nanomaterials, the stability of atomic nuclides and the periodicity of atomic matter depend on the Golden Ratio.[1] Apart from the Golden Ratio, a second common factor among this variety of structures is that they all represent spontaneous growth patterns. The argument that this amazing consilience ('self-similarity') arises from a response to a common environmental constraint, which can only be an intrinsic feature of curved space-time, is compelling.[1]

Sources: (left to right) NASA and The Hubble Heritage Team (Wikimedia Commons); Chris 73 (Wikimedia Commons); US National Oceanic and Atmospheric Administration (Wikimedia Commons); kongsky (FreeDigitalPhotos.net)

Figure 1: Examples of logarithmic spirals found in nature: (from left to right) the Whirlpool Galaxy, a *Nautilus* shell, Hurricane Katrina and an ammonite.

In the context of biology, Thackeray[3] has identified what he claims to be a species constant, based on the log-transformed standard error of the m-coefficient (log se_m), in regression analysis of cranial and other measurements from pairs of specimens of extant biological species (vertebrates and invertebrates), associated with regression equations of the form $y = mx + c$, where m is the slope and c is the intercept, using measurements of specimen A (x-axis) and specimen B of the same species (y-axis), or vice versa. Remarkably, an absolute mean log se_m value of ca 1.61 has been obtained for conspecific pairwise comparisons of extant vertebrates (mammals, birds, reptiles) and invertebrates (Coleoptera and Lepidoptera).[3]

An almost identical absolute mean log se_m value has been obtained from pairwise comparisons of conspecific Plio-Pleistocene hominin crania representing *Australopithecus*, *Paranthropus* or early *Homo.*[5]

An absolute mean log se_m value of 1.61 for pairwise comparison of dental measurements of hominin species has been calculated by Dykes[6]. In modern primates such as humans, chimpanzees, gorillas, orangutans and *Colobus* monkeys, the absolute mean log se_m value for pairwise conspecific comparisons of crania is approximately 1.6.[7] The empirical evidence for a biological constant with central tendency of an absolute value of 1.61 is strong.

Transformation of the equations for relativistic quantum theory from curved space-time to Euclidean space coordinates was derived by Veblen and Hoffmann[8] without realising the significance of the factor $\sqrt{5} = \Phi - 1/2$ that correlates the electromagnetic potentials in the underlying curved space-time and tangent space. Examined more closely, the curvature of a Fibonacci spiral, $\pi/2(2\sqrt{2}) \simeq \sqrt{5}/2$, hence constitutes a convincing measure of space-time curvature.

Also demonstrated at an early date by Harkins[9] was the fact that stable nuclides occur in a limited region defined by convergence to the proton:neutron ratio (p/n) from unity to a value of 0.62, later interpreted[10] as $p/n = 1 \rightarrow \tau$, where $\tau = 1/\Phi$. By the same reasoning, the remarkable observation that the structure of the periodic table of the elements is a function of environmental pressure[11] can now be accounted for in detail, as a response to space-time curvature. The stability of atomic nuclides varies from $p/n = 1$ at a black-hole singularity to $p/n = 0.58$ in Euclidean space.

The time has come to recognise that relativity and quantum theories can be integrated, and linked numerically to the value of a mathematical constant – whether in the context of space-time[1] or biology[3].

Acknowledgements

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Realising the value of continuous monitoring programmes for biodiversity conservation

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There is an increased need for support for continuous biodiversity monitoring programmes in commodity production landscapes; the pressure for such supports arises from a variety of sources. We highlight our rediscovery of a presumed extinct dung beetle species, last recorded in 1975, to accentuate the value of local-scale ecological monitoring approaches for modern conservation planning practices in South Africa. We believe this perspective could help articulate further growth in support for such infrastructure.

Advances in biodiversity conservation in production landscapes

In recent times, there has been a global increase in awareness of the important function of biodiversity conservation in commodity production landscapes.[1] We now better understand that many aspects of biodiversity, such as insects responsible for pollination, or certain plants that purify water in wetlands, are extremely valuable in production landscapes.[2] To allow for the sustainable use of these ecosystem goods and services, many environmental schemes were initiated worldwide, which encourage and provide financial help for land-users to implement 'ecoagricultural' systems.[3] A well-documented example is the European Agri-Environment Schemes. When these schemes are implemented appropriately (with the right knowledge base; involving collaboration between scientists, policymakers and practitioners; and effective on-site supervision), this modern production paradigm can have great reward for both the land-user, and local species diversity.[4,5] However, across the global commodity production landscape, the incentives for environmentally conscious initiatives, and their subsequent implementation and monitoring, do vary considerably.[6] In some instances such initiatives are legislated, while in others, environmentally conscious commodity production is guided by trade standards (voluntary 'user-pays' participation). These trade standards are usually ushered by modern consumer pressure (such as a need for more ecologically sensitive production), and essentially bridge the lack of local environmental legislation in a country (e.g. international commodity production regulatory bodies such as Global Good Agricultural Practice and the Forestry Stewardship Council (FSC)). For some land-users, producing goods in an environmentally sensitive way can also be motivated by a desire to be naturally sensible (e.g. for aesthetic reasons or because of a personal conviction).

In the timber industry specifically, the FSC provides a global certification framework whereby adhering to certain production standards, and thus being certified under this trademark, not only increases your company's status as an environmentally responsible land-user, but also offers socio-economic advantages (such as access to certain markets). For the past few years, as ecologists who consult independently of agricultural regulatory bodies, we have been involved in the environmental monitoring process for a FSC certified plantation forestry company in South Africa. Our involvement came about as the FSC auditors requested corrective actions to address the lack of knowledge (or acknowledgment) of rare, threatened or endangered species within the production landscape. During this time, we have learnt that requirements for continuous biodiversity monitoring as part of trade standards certification schemes, such as FSC, may act as a barrier to participation for companies or individuals who are unwilling or unable to resource such monitoring indefinitely. This has raised the issue of the role of *continuous* biodiversity monitoring and its potential in local (on-site) environmental sustainability initiatives.

Continuous monitoring programmes for biodiversity conservation

The value of implementing the principles of monitoring in conservation programmes, for example with the use of indicator species, was identified early on as contributing to more ecologically sound on-site managerial decisions.[7] In most managed semi-natural open spaces, the continuous monitoring of biodiversity is probably the most crucial aspect in verifying and ultimately determining conservation success.[8] In fact, continuous monitoring can be one of the most critical strategies to help reduce uncertainty (e.g. from imperfect biological or ecological knowledge of species) when practical managerial recommendations have to be made for the long-term success of managed populations.[9-11] As highlighted by Magurran et al.[9], it is imperative for an environmentally conscious land-user who is serious about contributing to the conservation of a landscape to (1) initiate biodiversity inventories, using a standardised approach, on all the different habitats or biotopes on their properties and (2) commit to implementing follow-up monitoring of these sites (for long-term data sets). This approach would eventually provide useful scientific insights into observed increases or decreases in specified fauna and flora, especially regarding which environmental variables could have determined these patterns (such as changes in agricultural management practices in the matrix, e.g. pesticide usage), and how to subsequently adapt the conservation management in local habitats or biotopes.[12,13] This process will also increase the chance of discovering those rare, threatened or endangered species (or even just the abundant but highly localised ones).

The rationale for this perspective

There is a vast literature showing the benefits to biodiversity for European countries when implementing agricultural environmental programmes, such as European Agri-Environment Schemes, at local scales (i.e. the scale of management intervention such as fields, farms or catchments).[14,15] However, we have also learnt from European Agri-Environment Schemes that at the scale of policy intervention (national measures of diversity or species abundance), there is little evidence of success in showing national biodiversity benefits.[16] A similar trend was observed regarding invasive alien plants and the overall impact of policies on curbing global biodiversity declines.[17] These trends illustrate the spatially varied application of local-scale conservation management and policy interventions. Fundamentally, the more evidence we can obtain that shows positive impacts of local-scale conservation initiatives on biodiversity, the more we should be able to influence national policy objectives to

further support such initiatives, thereby reducing the implementation gap. Indeed, Donald et al.[18] accentuated the enormous importance of available empirical evidence to help formulate bird conservation policies in Europe, which would support the proof of feasibility and efficacy of current conservation recommendations.

South Africa is a major commodity producing country, and needs to stay competitive in a more environmentally conscious market. Therefore, given the global idiosyncrasies in biodiversity conservation initiatives in agri-landscapes worldwide, we provide here some compelling evidence as to the value of continuous monitoring programmes in privately organised commodity production landscapes in South Africa. We aim to convey a plight for an increased awareness and appreciation of such programmes in helping environmentally conscious parties to obtain critical *evidence-based* (more scientifically accurate) conservation planning, as well as to help articulate support for such infrastructure in commodity production landscapes in South Africa.

Hidden on the forest floor – A continuous monitoring success story

Mountainous areas in South Africa are considered centres of high endemism, in which conservation research is seen as a priority.[19] Since 2012, monitoring sites have been set up on fragments of threatened Afro-montane (African mountain) forest patches in a plantation forestry matrix in the Tzaneen area (Limpopo Province, South Africa). These forest patches are part of the Northern Mistbelt Forests vegetation type. We specifically chose the Northern Mistbelt Forests in this area, as it is an extensive agricultural area (major producers of fruit and timber in South Africa), with very few of these forest patches continuously monitored with regard to such encroaching threats. As a result of continuous follow-ups on these sites, in late 2013, we rediscovered a dung beetle that had been presumed to be extinct.

We have now confirmed the presence of *Gyronotus glabrosus* (Scarabaeidae) on one of the higher elevation forest sites on the estate. All species in this genus seem to be very sensitive to habitat disturbance and their presence can indicate good habitat quality.[20] *G. glabrosus* is a flightless, medium-sized and slightly flattened black beetle (about 12 mm long) which was first described in 1987 (Figure 1).[21] From the literature, this species was last recorded in 1975 from the Nerina Nature Reserve in Magoebaskloof (adjacent to the town of Tzaneen).[21] This area was, however, cleared of natural vegetation for extensive commercial *Eucalyptus* forestry. During 2000, extensive surveys in the area failed to record this species and it was therefore presumed to be either critically endangered or extinct.[22] It is currently only known from seven museum specimens. The collection of six specimens (three mating pairs) during this survey on the margins of this high elevation forest site therefore represents not only the rediscovery of this species, but also currently its only known locality.

The presence of this very sensitive species in the area is therefore indicative of good current habitat integrity with little disturbance. From this, at least, we can now argue that all efforts should be made to maintain the future integrity of this habitat in order to ensure the long-term survival of this very rare species. In fact, the ecological and economic importance of smaller animals is often ignored, but when ecological imbalances result from their exclusion, their significance cannot go unnoticed. For example, in Australia, Uruguay and the USA, the importance of dung beetles in organic recycling and pest management became very apparent after large losses in cattle industries as a result of outbreaks caused by dung-breeding nuisance and blood-sucking pests.[22] Many dung beetles are specialised to particular soils, vegetation food types etc., which also makes them very good indicators of ecosystem health. The loss of specialised species and an increase in non-specialists, for example, is a good indication that ecosystem integrity is compromised. Furthermore, southern African Afro-montane forests, one of the most endangered vegetation types in Africa, house the largest number of endangered dung beetle species.[22,23] How many more rare or localised species could be found in these remaining forest patches within major production landscapes?

The way forward

Creating awareness

The popular philosophical question, 'If a tree falls in a forest, and no one is there to hear it, does it make a sound?', challenges our perception of reality in absence of observation. We can also ask: If a dung beetle strolls on the forest floor, and no one is there to observe it, does it exist? The plain answer is that we need to prove its existence, and this is where we most often fall short, as without evidence, it becomes impossible, or at best circumstantial, to infer life. It can be argued that, in general, only when one allocates a name and value to an entity, one would be more inclined to accept responsibility for that entity, and can therefore better perceive a loss (and act upon it). Thus, in a production landscape context, without a biodiversity monitoring programme, many land-users would not be aware of the value of their natural capital, and would therefore not perceive any problem, or expect any future ecosystem failure. When we take into account the enormous lack of taxonomic knowledge of species in existence today, and their yet unknown dispersion patterns, the reality of starting monitoring programmes should become a natural response for the environmentally conscious parties which underwrite sustainable commodity production landscapes. Essentially, we have created these ecosystem fragments without knowing what we have left in our wake (the collateral damage). It would be naïve to accept that remnant natural (or semi-natural) patches are by default inhospitable to all living things, no matter what the size of these fragments, or their appearance (perceived health). With so many fragments (natural and semi-natural) left on private properties (mostly situated within a matrix of commodity production activities) with no properly structured *continuous* monitoring initiatives, a natural step would be to stress the importance of such programmes in these often overlooked areas. In doing so, we should have a better chance of finding new or presumably lost species and detect changes in ecosystem functioning. We can therefore extend our philosophical question posited above to a more applied tier: Will these unknown species continue to be? This we can *only* infer when we know what exists, where it exists, what it is doing there (niches), and how it responds to change. If we do not provide clear evidence of this nature, we would inherently fail in making more land-users aware of the value of remnant biotopes or habitats in commodity production landscapes, and therefore fail in gaining the relevant local policy support.[18] We believe that philosophical questions of this nature are highly relevant to most agricultural landscapes today, and can therefore be used to advocate awareness of biodiversity beyond the known.

The necessary infrastructure

South Africa is seen as a developing country. It is therefore positive to see that more and more people, academic or not, are becoming aware of the benefits of biodiversity conservation for humanity. For example, most universities in South Africa today provide degrees in conservation biology, or some course work in environmental management, and from our personal experience, we have seen these classes growing in student numbers in the past decade. As environmental education within the infrastructure improves, there should be an increase in knowledge that can be applied to environmental problems in agri-landscapes in South Africa. Of course, one can only apply knowledge if we are aware of a specific problem. In particular, we would want to see these environmentally interested parties being made more aware of how their knowledge can be applied to biodiversity inventorying, and, most importantly, continuous monitoring of these inventories. With the advent of environmental regulations (FSC, for example), and their (theoretical) future permanence in production landscapes, more opportunities for ecology professionals will eventually arise. Hill and Arnold[24] highlighted the enormous growth in opportunities for entrepreneurial endeavours in ecological consultation – information that these budding professionals should be made cognisant of.

Outside of conservation professionals, many other stakeholders could help with continuous monitoring protocols. Magurran et al.[9] reviewed the current trend in which more and more people are becoming interested in environmental matters, which creates a valuable opportunity for

Figure 1: One of the rediscovered *Gyronotus glabrosus* individuals (Scarabaeidae). This genus belongs to the Canthonini tribe, which is considered to be of substantial biodiversity and conservation value.[20]

citizen science in aiding the continuous monitoring ideal. For example, a farmer who has always been interested in the natural aspects of their farm, often possesses great knowledge of what species occur or have occurred on the property. This local knowledge would not only add great value to past recollections, but would also help to improve the chances of observing more species. Moreover, we can now better determine the factors that influence ecological processes at a local scale.

From an economic perspective, it is known that we live in a world of trade-offs. Given the high monetary value of ecological services, we cannot circumvent the role that business strategy would have in providing such infrastructure.[24] Someone has to pay for professionals to render continuous assessments, and land-users may want something in return (something of monetary value to them). We know there are many idiosyncrasies in incentives for performing continuous monitoring – for example, if a land-user is liable by law, certification, or through personal conviction. Although we provide no direct solution for the chronic funding debate here, we can re-appreciate the value of an evidence-based approach to help argue for support for continuous monitoring. We can relate species evidence as biological capital, to argue for conservation capital from companies for such initiatives.[25] Lindenmayer et al.[13] also argued that improved biodiversity monitoring is often constrained by poorly articulated objectives. In this light, seven critical topics are apparent to help stimulate discussions on the value of continuous monitoring programmes in South African production landscapes:

1. Continuous monitoring and subsequent maintenance of local open spaces *will* eventually help us create fairly stable indigenous refuges that are important for the welfare of a variety of indigenous biota, especially the rare and endemic ones.
2. Long-term on-site (local) observations on the different biotopes in a given landscape are the *only* reliable way to determine changes in community dispersion patterns. Any biotope could provide the unique niche resources for diverse biota, and detecting changes to biotic communities (for which we now have baseline data), would enable conservation biologists to more accurately predict which variables (natural or anthropogenic) significantly influence observed changes.
3. We can obtain far more *focused* or *goal-orientated* conservation planning. For example, an increase in *x* disturbance may lead to a decrease in *y* species.
4. For current and proposed production landscapes, implementing biodiversity monitoring programmes is highly relevant considering South Africa ratified the Convention on Biological Diversity's 2020 Aichi Biodiversity Targets. The vision of these biodiversity targets is essentially to 'live in harmony with nature'. When a country agrees to strive towards these targets, they agree to make sure that the biodiversity of their country is valued, conserved, restored where needed, and ultimately sustainably used for the well-being of all citizens, and, of course, the planet as a whole (see www.cbd.int for more information).
5. Locally organised continuous monitoring programmes, given the right communication structures, would *complement* already

established national or regional monitoring initiatives, such as the South African Environmental Observation Network.[26]

6. There is an established marketing incentive for adhering to voluntary responsible land-user programmes, such as access to niche markets (for example, the Biodiversity and Wine Initiative in South Africa). The land-owner gets information of unexplored territories on their property, which may increase eco-tourism, cultural or aesthetic value.

7. There is a feel-good factor involved. The idea that one adds to life and living, and not only resource extraction. That a new or 'lost' species was discovered on a property, at least for some people, could be highly thought provoking (hinting again at awareness). Given the right communication channels, interesting stories from the field can inspire and awe the general public, especially educational institutions such as schools.

With regard to specifically asking for funding for such continuously running tasks, we feel that some early recognised insights of Lindenmayer[8] are still highly relevant today: to be innovative and contemporary – relating to a modern, technologically and environmentally conscious people (how does this aid in the health of families and through which interesting media can this message be conveyed); to reveal the strong scientific base behind long-term data gathering; be experts – or state their involvement; and, finally, be explicit in how you will ensure these data are implemented (discuss the feasibility of conservation management recommendations for the land managers[10]). Essentially, it is clear that, at present, there is expert consensus on the high value and logic of continuous monitoring programmes in modern conservation practices, worldwide. It is even clearer that the necessary infrastructure for such programmes needs redress.[13]

To conclude

In this modern ecoagricultural context, many land-users accept some responsibility for severely transforming the earth's surface. To perhaps paraphrase a land-user for whom we consulted:

> *I did not know I should plan for conservation; my father never taught me this value as being essential to farming practice, but I now recognise its worth for the sustainability of my business, and the local landscape from which it derives.*

This is just one anecdote, but, essentially, environmental consciousness *is* increasing, numbers of skilled professionals *are* correspondingly increasing, and we are slowly *becoming* more aware of the increased scope for entrepreneurial growth in applied ecological science. The basis of promoting continuous monitoring programmes is a derivative of these factors, and would unquestionably complement current national or regional observation strategies, for which continually monitoring so many sites is an enormous task. Moreover, increasing continuous monitoring infrastructure would demonstrate a deep realisation of the Convention on Biological Diversity's 2020 Aichi Targets on all facets of commodity production (large-scale, small-scale and subsistence farmers). Unfortunately, the mitigating efforts to rectify bad management practices are not consistently distributed across producing countries. For South Africa, the rediscovery of this critically endangered dung beetle species within a major commodity production landscape, specifically on areas previously never subjected to biodiversity monitoring, should serve as a wake-up call for improved continuous monitoring infrastructure, across all hierarchies (legislation, certification, private companies and citizen science). Increased awareness and realisation of the value of applied ecological approaches to farmland conservation, would rightly position a country, especially developing countries like in southern Africa, to advance in a time when biodiversity conservation forms an integral part of the commodity production landscape.

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A symbiotic glance at the complexities of signature microbiomic interventions: Infusing balance

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We're not individuals, we're colonies of creatures.

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The Common Fund's National Institutes of Health Human Microbiome Project launched in 2007 is the first major genomics-based effort to reveal the influence of human microbiota, or resident microorganisms, on the health and disease status of humans. The first phase of the Human Microbiome Project (FY2007–2012) focused on characterisation of the composition and diversity and evaluation of the metabolic potential of microbiota that inhabit five major mucosal surfaces of humans: the oral cavity, gastrointestinal tract, nasal passage, skin and urogenital tract. The second and current phase of the Human Microbiome Project (FY2013–2015) is dedicated to data integration of the microbe–host biological properties extracted from cohort studies of microbiome-associated diseases.[2]

The Human Microbiome Project has provided a few major breakthroughs in understanding the complexity and diversity of human microbiota and their role in human health and disease. At present it is estimated that humans encompass approximately 20 million genes that encode the entire microbiota. In addition, the microbiota in humans contributes immensely toward the micro-xenobiotic and non-xenobiotic interventions inherent to microbiome-associated diseases. However, there are several issues that require thorough consideration before the scientific community can decide on the therapeutic potential of targeting microbiota. This commentary provides a detailed incursion into the complicated inter-microbiome associations and interventions that are related to the five most researched microbiota in humans: (1) the role of the butyrate-producing microbiome in colorectal cancer therapeutics, (2) the protective/defensive microbiome related to inflammatory bowel disease, (3) the risk associated with probiotic delivery in obesity, (4) the antimicrobial-based microbiome disproportion leading to/arising from skin diseases and (5) the maintenance of microbiome loads and confinement to the vaginal mucosa.

Microbiomic intervention in colorectal cancer therapy

Muco-adherent pro-inflammatory microbes have been associated with the prevalence of colorectal cancer (CRC).[3] These microbes are carcinogenic and influence the host's metabolism and function via signalling pathways and genotoxicity and by inciting immune responses.[3] The colonic microbiome in CRC functions via two specific mechanisms – muco-adhesion and muco-inflammation. The muco-adhesion mechanism can be disrupted by surgical procedures and the prophylactic administration of antibiotics while the muco-inflammatory mechanism may be reduced by the regular use of non-steroidal anti-inflammatory drugs (NSAIDs).[4] The prophylactic administration of antibiotics also has a negative effect on the beneficial commensal microbiota of the gut. Although controversial, the involvement of short-chain fatty acids such as butyrates has been proposed because they act via cell-cycle arrest that results in increased apoptosis of carcinogenic cells. Therefore, the introduction and preservation of the butyrate-producing microbiome can intervene in CRC therapy.[5] Furthermore, it has been suggested that carcinogenic (specific to CRC) microbiota have inflammatory niches and hence are further influenced by introducing an anti-inflammatory commensal bacterium that is capable of blocking NF-kB expression and IL-8 secretion.[6] Certain probiotics produce antibacterial peptides that are capable of protecting the host from pathogenic commensals and can significantly reduce the occurrence and recurrence of CRC in conjugation with a probiotic that is an adhesion competitor (Figure 1). In conclusion, CRC therapy can be effectively intervened by administering (1) antibiotics that are selective toward *Enterococcus*, *Streptococcus* and *Fusobacterium* species, (2) NSAIDs and (3) anti-inflammatory and butyrate-producing probiotics.

Inflammatory bowel disease and the microbial imbalance

Inflammatory bowel disease (IBD) is associated with an imbalance (preferentially known as dysbiosis) between the aggressive and protective microbiome in the gut. This imbalance is mainly an increase in *Bacteroides* and a decrease in *Bifidobacterium* and *Lactobacillus* species.[7-11] The latter species are prescribed as probiotics in the treatment of IBD and their administration may help in correcting the imbalance. However, the efficacy of these probiotics in an already compromised inflammatory environment is doubtful and an immediate reduction of the aggressive species is required to reverse the imbalance. An interventional strategy involving the administration of a purified form of polysaccharide A (a molecule from *Bacteroides fragilis*) was reported by Mazmanian and co-workers[8], wherein it was proposed that polysaccharide A can suppress the pro-inflammatory responses in IBD.[8] However, in a recent study, Hueber and co-workers[9] stated that suppression of such pro-inflammatory responses attained no benefit in severe inflammatory Crohn's disease even after administering highly potent therapeutic agents such as secukinumab. Therefore, broad-spectrum antibiotics such as a combination of ciprofloxacin and metronidazole are still the drugs of choice as they are capable of treating IBD complications such as abscesses, inflammatory phlegmon, fistulae, fissures, bacterial overgrowth secondary to strictures, prophylactic postoperative infections and secondary infections. Furthermore, antimicrobial peptides such as α-defensin 1-4, α-defensin 5, β-defensin 1-3, lysozyme, sPLA2, Reg3A/HIP/PAP and lipocalin 2 are significantly effective against Gram-positive and Gram-negative pathogenic microbes. They have also shown significant activity against lectins and selective bacteria. These antimicrobial peptides can further enhance the composition of the colonising defensive microbiota in the gut.[10,11]

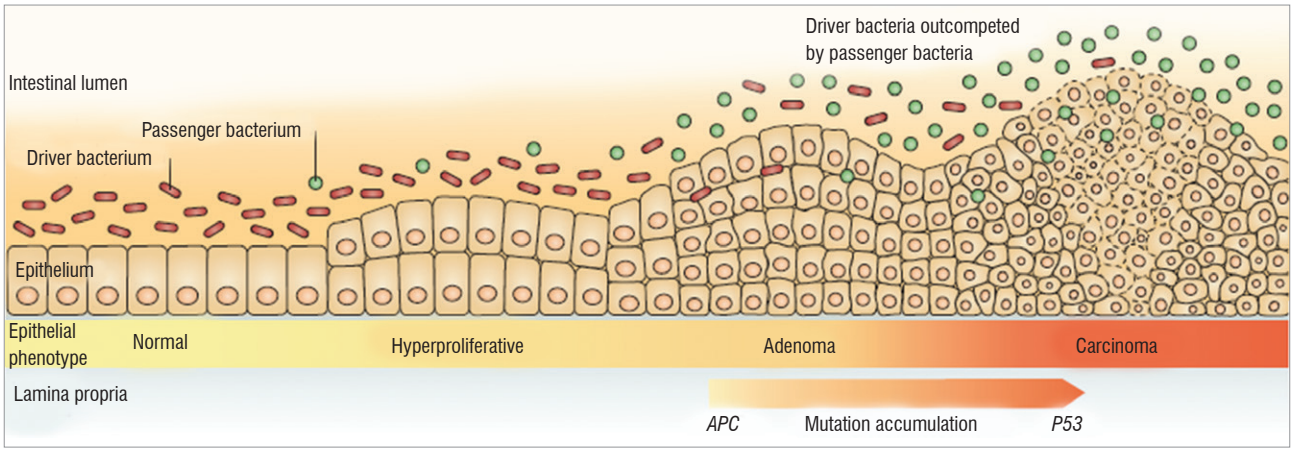

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Figure 1: A bacterial driver–passenger model for colorectal cancer (CRC). The colonic mucosa of patients who are at risk of CRC is intrinsically colonised by pathogenic members of the genus *Bacteroides* (Enterobacteriaceae) or by bacteria that function as 'drivers' of CRC that cause inflammation, increased cell proliferation and/or the production of genotoxic substances that contribute to the accumulation of mutations during the adenoma-carcinoma sequence. The oncogenic process is accompanied by the rupture and bleeding of the cancerous tissue that alters the micro-environment and the selective pressure on local microbiota. These changes facilitate the gradual replacement of 'driver' bacteria by 'passengers', consisting of tumour-foraging opportunistic pathogens, commensal or probiotic bacteria, or other bacteria with a competitive advantage at the tumour. Tumour progression may be either suppressed (by probiotic 'passenger' bacteria) or promoted (by pathogenic 'passenger' bacteria) as a result of these microbial colonisation shifts.

Microbiota associated with obesity – The probiotic risk

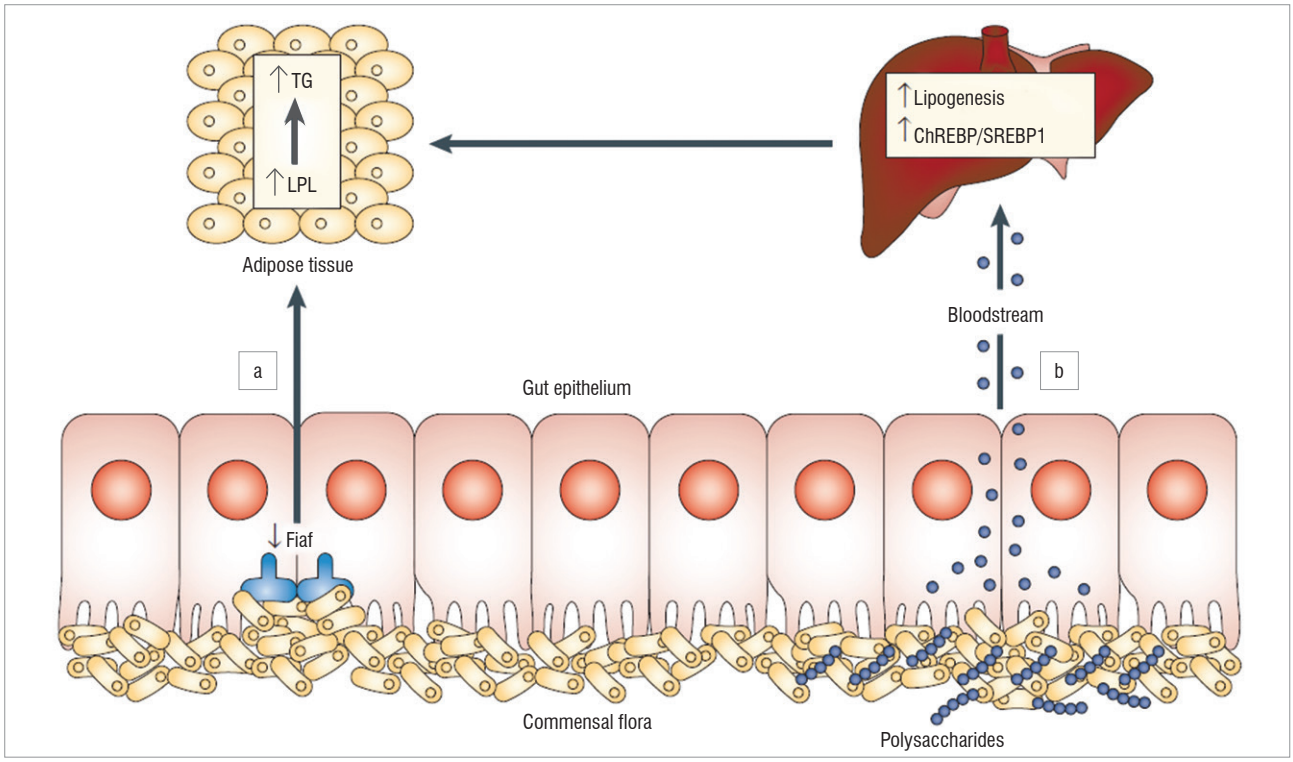
Although controversial, obesity in humans has been microbiotically related to the changes in the ratio of Gram-positive Firmicutes and Gram-negative Bacteroidetes. However, these studies were performed in subjects on restricted diets and hence their findings can be debated.[12,13] In studies with no dietary restrictions, it has been reported that Bacteroidetes significantly differed in obese patients, confirming the role of diet in the prevalence of microbiota and obesity.[14] It should be noted that Firmicutes such as *Lactobacillus* spp., *Bifidobacterium* spp. and *Enterococcus* spp. form the majority of functional food and therapeutic adjuvants added to farm products as probiotics or prebiotics (Figure 2).[15] Furthermore, the concentration of live *Lactobacillus* spp. and *Bifidobacterium* spp. in these functional foods is in the range of that used in animals as growth promotors. Surprisingly, the level of these adjuvants – especially *Lactobacillus acidophilus* – in probiotic-containing dairy foods was enough to cause weight gain in experimental piglets. The same is applicable to the weight gain in children on prebiotic supplements which contain *Lactobacillus rhamnosus* – independent of disease intervention.[16] These findings lead to the conclusion that controlling and maintaining the relative abundance of these two bacterial species – along with the less researched but dominant archaeon *Methanobrevibacter smithii* – may provide future researchers with drug targets for the treatment and prevention of obesity and related disorders.[17]

Therapeutic intervention of the skin microbiome

The skin microbiome, constituting mainly Actinobacteria and Proteobacteria, is distributed throughout the human body and differs considerably with respect to external factors such as type of occupation, hygiene and climate as well as intrinsic factors such as skin temperature, humidity and degree of glandular secretions. For example, sebaceous glands are inhabited by Propionbacterineae species, moist areas of the skin are colonised by *Staphylococcus* and *Corynebacterium* spp., while the drier regions are inhabited with Proteobacteria.[18] Unique to the skin microbiome is the relative inverse abundance correlation among various microbial species such as (1) the bacterial deficiency of *Propionibacterium acnes* in the presence of staphylococcal species and (2) the relative scarcity of *Staphylococcus aureus* as a result of the abundance of *Staphylococcus epidermidis*. The staphylococcal species and *S. epidermidis* can be useful probiotics against *P. acnes* and *S. aureus*, respectively, while also providing prognostic information related to these slow dwelling infections.[19] However, this entirely symbiotic interaction has been adversely affected by the overuse of antibiotics, leading to the generation of the highly pathogenic strain of methicillin-resistant *S. aureus* that has acquired genes which are further resistant to the antimicrobial peptide released from *S. epidermidis*.[20,21] The skin microbiome is responsible for various dermatological disorders such as atopic dermatitis (*S. aureus*) and psoriasis (*S. pyogenes*) caused by bacterial infection and seborrheic dermatitis and tinea versicolor caused by fungal infection.[22] Although antimicrobial interventions have shown to be an effective approach for the treatment and prevention of these skin disorders, the recovery of the symbiotic microbiome may take several weeks and some populations of the microbial community, such as *S. epidermidis,* may never recover to their original concentration.

Vaginal microbiome and related lactobacilli abundance and transport

The lactic acid producing microbiome in healthy women consists of one of the four species of *Lactobacillus,* namely *L. crispatus*, *L. iners*, *L. gasseri* or *L. jensenii*.[23] The lactic acid produced provides various benefits such as acidification of the vaginal milieu (hence preventing growth of pathogenic microbes) and modulation of the host vaginal membrane and biochemical environment.[23] A change in this protecting mechanism may lead to the prevalence of pathogenic anaerobic and facultative bacteria such as *Gardnerella vaginalis,* leading to the well-known condition bacterial vaginosis (BV).[24,25] Another important opportunistic infection is vaginal candidiasis in which the vaginal epithelium is asymptomatically colonised with *Candida*. These bacterial species are also responsible for preterm birth as a result of the passage of bacteria to the upper genital tract, for the infrequent problem known as vulvovaginal pain, and for increased susceptibility to HIV and other sexually acquired infections. Therefore, therapeutic opportunities related to the vaginal microbiome should be focused on maintaining the *Lactobacillus* load in the vagina as well as preventing its passage to the upper regions of the reproductive tract.[26] Antimicrobials can be an effective intervention for containing the aggressive vaginal microbiome. However, they should be avoided in pregnant women. Although the administration of metronidazole for BV results in the back shift of microbial profiles, this back shift results in replenishment of *L. iners* in abundance but fails to recover the *L. crispatus* levels.[27,28] The use of oestrogen replacement therapy has also shown potential for treating urogenital infections caused by the increased colonisation of the upper



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ChRE BP, carbohydrate response element binding protein; SRE BP1, sterol regulatory element binding protein 1; TG, triglyceride.

Figure 2: Schematic of how the gut microbiota affects fat storage in the host. The gut microbiota increases lipoprotein lipase (LPL) activity in adipocytes to promote storage of calories harvested from the diet into fat through two mechanisms. In the first mechanism, (a) the gut microbiota selectively suppresses fasting-induced adipocyte factor (FIAF, also known as ANGPTL4), a member of the angiopoietin-like family of proteins, leading to the up-regulation of LPL. In the second mechanism, (b) the gut microbiota metabolises the non-digestible polysaccharides and induces *de novo* hepatic lipogenesis via the absorption of resulting monosaccharides.

genital tract by *Lactobacillus* species.[29] Readers are encouraged to refer to a recent review by MacPhee and co-workers[30] in which they discuss the possibility and efficacy of using topically applied vaginal probiotics under regulations characterising their use as drugs or intravaginal devices.

Impact of the Human Microbiome Project in South Africa

The human microbiome forms one of four pillars that has a health impact in Africa; the other three being genetics, socio-economics and environmental factors.[31] Figure 3 effectively displays the role and importance of the human microbiome in delineating the health-and-disease model in African populations. However, South Africa (and in fact the African continent) has been neglected and hugely under-represented in the Human Genome Project and its status in the Human Microbiome Project is not any different.

The role of human microbiota discussed earlier in this commentary covers all three major physiological areas of microbiome research – the surface of the skin, the gastrointestinal tract and the urogenital tract. In addition, one lifestyle disorder (obesity) and an infectious factor (the vaginal microbiome) affecting metabolism and immunity, respectively, are also discussed. This commentary explains the importance of microbiome research to understand specific physiological phenomena and disease susceptibility. A better understanding of (1) the lifetime stability of human microbiota, (2) the similarity and diversity of microbiota among individuals, their families, the community and the entire population, (3) the possibility of founding a universal microbiota database and, finally, (4) the microbiomal adaptation and mutation with changing lifestyles and environmental factors, can provide important insights into novel therapeutic targets and diagnostic biomarkers for various illnesses.[31]

According to a recent study, covering 188 countries over a period of 33 years (1980–2013), published in the *Lancet* (29 May 2014), South Africa has the highest overweight and obesity rate in sub-Saharan Africa with 40% of men and 69% of women overweight or obese.[32] The major reasons for obesity in South Africa are (1) easy access to a low-cost calorie-rich diet, (2) sedentary lifestyles because of fast-growing urbanisation and (3) the social stigma associating 'being-fat' with health and wealth and 'being-thin' with HIV infection. However, the role of the gut microbiome in obesity cannot be overruled as the obesity-associated gut microbiome, e.g. Firmicutes, is significantly more capable of extracting energy from food than the microbiota of lean individuals and hence may indirectly increase the risk of concomitant cardiometabolic diseases such as diabetes and hypertension. Therefore, a complete array of experimental and analytical tools need to be generated nationally and regionally via a thorough gut microbiome investigation.[33]

Another microbiomic factor impacting the South African health system is the vaginal microbiome imbalance. In a recent study published in *PLOS Medicine*, it was reported that BV, due to the prevalence of pathogenic anaerobic and facultative bacteria such as *Gardnerella vaginalis*, is associated with a threefold increased risk of female-to-male HIV-1 transmission. High BV prevalence in women has been associated with lower socio-economic status (hygiene) and in South Africa may further be associated with race (black women have a higher incidence of BV because of lower dominance of lactobacilli), sexual practices (women with multiple sex partners have a higher incidence), trichomoniasis, HIV-1 infection (leading to BV and vice versa), recent antibiotic use, and the absence of lactic acid and peroxide producing lactobacilli. The introduction of antibiotics against *G. vaginalis* and *Atopobium vaginae* and/or the use of lactobacilli probiotics as an adjuvant/alternative to antibiotic intervention may subdue the impact of BV on HIV-1 transmission. However, maintaining a lactobacilli-predominant flora in the vagina appears longer lasting and more effective because of the

ability of *G. vaginalis* and *A. vaginae* to form biofilms recalcitrant to antibiotic treatment.[34,35] As stated by Cohen and co-workers[34]:

> *A lactobacillus-predominant vaginal flora might not only reduce the risk of HIV-1 acquisition in women, but also HIV-1 transmission to male partners, and points to the potential benefits of using the human microbiota to prevent disease.*

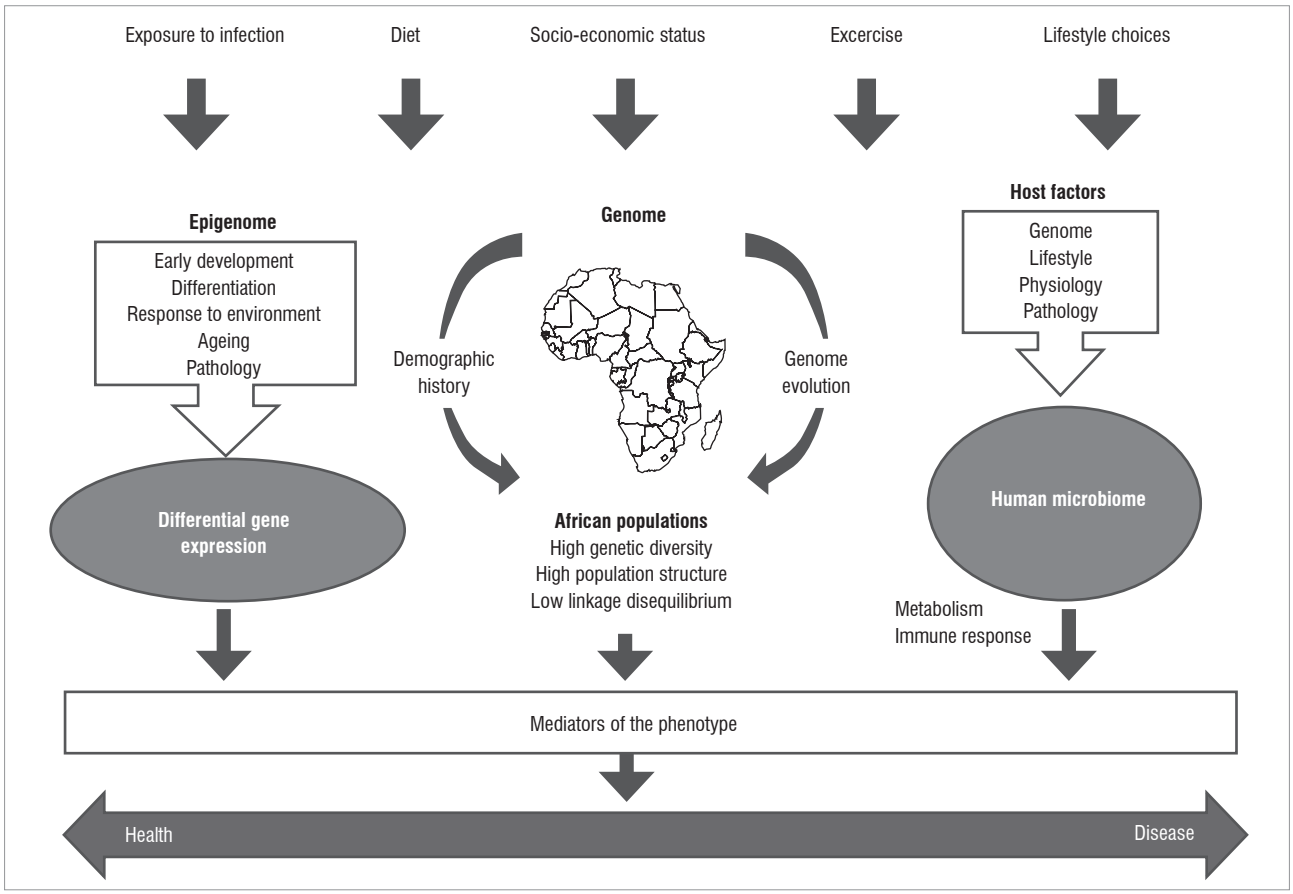
South Africa is struggling with a food allergy epidemic among black children. This expression or suppression of food allergy is attributed to the differences in intestinal microbial populations between allergic and non-allergic infants caused by an alarming increase in the rate of caesarean sections, socio-economic status and changing diet, as well as the frequent use of antimicrobials. The mutation and modification of the maternal intestinal microbial milieu may also affect the child's microflora. In addition, environmental factors such as exposure to soil/dust in close vicinity to migrant populations may lead to hand-to-mouth transmission of harmful microbiota in children. Although this theory requires further experimentation and explanation, the role of the microbiome in food allergy in black South African children cannot be ignored.[36]

Various factors such as genetic polymorphism, pathogenic infection, poor nutrition and hygiene can also significantly affect the efficiency and efficacy of oral vaccines against pathogenic gut microbiota. In a typical example, the altered gut microbial composition in the case of IBD leads to the disruption of mucosal integrity and function, which in turn compromises mucosal immunity. This significantly altered gut physiology may directly or indirectly affect vaccine efficacy and obstruct the development of effective and durable mucosal immune responses.[37]

The human microbiome will continue to alter with age, health status, sickness frequency and type, and hormonal variations, as well as under changing physico-chemical, environmental and social factors.[38] The above-mentioned specialised conditions represent merely the tip of the 'microbiomic iceberg' impacting health in South Africa. Since inception of the USD100 million Human Microbiome Project in 2007, only a handful of studies have covered the South African microbiome paradigm, with the majority of studies conducted overseas. We urge the South African biomedical research community to join hands to unfold the African microbiome landscape which, given the disease prevalence in Africa, might prove to be the most diverse, challenging and disease predisposing microbiome known to humankind.

Concluding comments

The microbiome-associated diseases discussed in this commentary can act (in future) as a guidance point for other related or unrelated conditions with emphasis on the fact that the microbial supplements (probiotics), facilitators (prebiotics), terminators (antibiotics) and bacteriocins should be linked to form an effective synergistic therapeutic paradigm. The microbiomic interconnection between various continuous systems such as the gastrointestinal and respiratory systems should be considered and studied for their co-therapeutic potential. Furthermore, the very confusing and complicated scenarios arising from probiosis and dysbiosis as well as from probiotics and synbiotics need thorough laboratory and clinical investigation in order to complete the phenotypic profiling of related microbiome-associated diseases. From a South African, sub-Saharan and African perspective, the role of xenobiotic interventions via prebiotics, probiotics and synbiotics in special cases such as immunocompromised patients, neonates and children must also be carefully studied by taking their safety considerations into account.



Source: Ramsay[31]. Reprinted with permission of the Federation of the European Biochemical Societies.

Figure 3: A complex set of interdependent and parallel processes that govern health and susceptibility to disease. They include the role and function of genetic variation (central panel), epigenetic remodelling (left panel) and the microbiome (right panel), with the latter two significantly affected by the environment and acting as mediators of the phenotype.

Acknowledgements

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Industry-directed training and research programmes: The BMI experience

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Universities are academic institutions with the primary objectives of teaching students a particular academic discipline and for conducting research related to that discipline. Traditionally, very little collaboration existed between universities and industry with respect to training and research in the mathematical sciences. Because of funding pressure, more and more universities are forced to find external sources of income. In this paper, we discuss a framework for designing and implementing career-oriented training programmes and industry-directed research programmes with a statistical science core. This framework was used as the basis for designing and implementing a highly successful training and research programme at North-West University's Centre for Business Mathematics and Informatics® (Centre for BMI), with the active support of industry partners Absa and SAS Institute. We believe that the lessons learnt from its implementation could form valuable guidelines for other, similar initiatives.

Introduction

We propose a management framework for training students for professional careers in business and industry as well as for conducting industry-directed research in the mathematical sciences, with a specific focus on a statistical science core. The framework has been designed and implemented by us at North-West University's (NWU) Centre for Business Mathematics and Informatics® (Centre for BMI) where the training and research programme is referred to as the BMI programme. Note that although statistical sciences constitute the core of our programme, several mathematical sciences are included in the programme, namely the disciplines of pure mathematics, applied mathematics and operational research. In addition, information technology is incorporated because it provides the environment for the effective implementation of the framework.

The framework will be explained in generic terms and the BMI programme will be used to illustrate the implementation thereof. The BMI programme was launched in 1998 with an intake of 11 first-year students and has grown to nearly 400 registered students in 2013. To date, 297 BMI MSc students have been delivered of which about 15 have chosen to follow academic rather than professional careers. Students who complete the honours and master's programmes find work easily and are employed before or soon after completing their studies. Absa has supported the programme since its inception by donating funds for capacity building and student bursaries whilst the SAS Institute has supported the programme since 2001 and recently donated USD300 000 to expand the programme to include an MSc BMI course in Business Analytics/Data Science. The current 5-year contract with Absa (the fourth since inception) commenced in 2011 and involves an annual donation of approximately ZAR3 million to ensure the sustainability of the Centre, ZAR4 million towards BMI student bursaries and ZAR1.5 million towards conducting applied risk research projects for Absa. Over the years a host of industry-directed research projects have been delivered by the MSc students as well as a number of technical research reports by BMI staff under the Absa applied research programme. The popularity of the graduates amongst companies and recruiting agencies as well as the industry involvement in the training and research programmes are testimony to the success of this flagship programme of the NWU. Some further achievements of the Centre for BMI are provided in the Online Supplementary Material.

Background

The Centre for BMI was established in 1998 as a joint venture between the erstwhile Potchefstroom University for CHE and Absa Bank. The main reason for the establishment of the Centre for BMI by the university management was twofold: a need to increase the number and quality of postgraduate students in mathematical sciences, and the success of the BMI programme at the Vrije Universiteit van Amsterdam (VU). The Dutch programme carried the same name (BMI, or in Dutch, BWI – Bedrijfswiskunde en Informatica) and had been developed in close cooperation with the RABO bank in the Netherlands. Based on this concept, the university convinced Absa to enter into a similar relationship. Boersma et al.[1] provide greater detail regarding the establishment and initial implementation of the Centre for BMI from a university management and transformation perspective. In this article, we focus on the implementation of the framework at an operational level.

We were appointed during 1997 with the mandate to design and implement a training programme along the lines of the existing BMI programme at the VU. The VU BMI programme was essentially an operational research programme, which consisted of subjects such as mathematics, operational research, statistics and computer programming, with the distinguishing addition that students were required to do a 'stage' or MSc project on-site at a company in industry. Our first attempt at designing a curriculum, largely based on the VU BMI curriculum, was rejected by Absa at the end of 1997 because it did not meet their requirements. This led to a fundamental reconsideration of the curriculum design, specifically to add a focus on risk management in banking. The NWU BMI curriculum then developed independently and separately from that of the VU (although it did include the 'stage' concept), and changes were effected annually in order to continuously improve it in line with industry requirements. It is interesting to note that the VU recently changed the name of their BMI programme to Business Analytics, suggesting that the VU BMI brand name did not receive the same widespread industry recognition in the Netherlands as its offspring did in South Africa.

Overview of relevant statistical literature (1998–2000)

Our approach was shaped mostly by relevant statistical literature in circulation between 1997 and 2000. At the turn of the century it was clear that the subject of statistics was becoming extremely popular in many application areas such as finance, health care and pharmaceuticals, manufacturing and quality-management marketing and service improvement, environmental sciences, and risk management. In finance, the first version of the Basel Accord in 1988 prescribed the use of statistically based risk measures and procedures as regulatory requirements to guard against bank failure, which has led to a significant rise in the demand for risk-management expertise ever since. Major developments in communications and computer technologies such as e-commerce and e-intelligence began to have a considerable impact on the way of doing business and data were collected and stored in massive amounts. Hand[2] warned the statistical community of several new challenges inherent to the statistical analysis of massive data sets. Companies are interested in utilising these huge data sets (presently referred to as big data) to improve, amongst others, their marketing campaigns, customer relationships, pricing strategies and risk management. According to Lambert[3] and Nelder[4], it was clear that the definition of statistics as a subject was widening, that many new application areas were increasingly making use of statistics, and that many open problems and challenges remain in evidence. Lawless[5] made an important observation that the definition of statistics is changing from scientific enquiry to one of problem solving, while Hahn and Hoerl[6] stated that there was a growing awareness of the value of and need for statistics in US business and industry.

The growing need for statistics resulted in a corresponding demand for appropriately trained people in the discipline. However, many authors (for example see Billard[7]) expressed concerns, because the typical academic training received by students did not prepare them adequately for business and industry. Several authors[5,6,8-10] felt that statisticians were not highly regarded in business and industry because they generally did not possess the necessary skills to function effectively in that environment and also did not have enough knowledge of the area in which they applied their skills. These and other authors[5,6,8-12] reported that students trained in the mathematical sciences were lacking skills such as subject matter expertise, creative problem solving, project planning and management, problem structuring and formulation, meeting management, group and team dynamics, as well as technical writing, presentation and persuasion skills.

During the course of our interaction with academia, we were often struck by the lack of understanding amongst some academics regarding the needs of business and industry. This perceived lack of understanding may be partly because of unwillingness to show interest in the problems faced by business and industry. Gnanadesikan and Kettenring[12] made the same observation: 'Instructors need to have industrial experience. Would a medical student want to learn surgery from professors who have never done it?' Further contributing factors to the tendency of academics to shy away from the problems faced by industry are the performance appraisal system and promotion criteria employed by many universities. This system exerts a great deal of pressure on researchers to produce publications and perform research purely for the sake of research and does not necessarily reward research aimed at improving business competitiveness. Therefore one of the greatest challenges faced by a successful industry–university alliance is the requirement to break through these barriers which may exist between academia and industry.

Iman[13] expressed a concern about the demise of statistics departments and claimed that most academic departments in the mathematical sciences had difficulty attracting young people to pursue an academic career, mainly because of poor salaries and a lack of funding. (Today the South African Statistical Association (SASA) is involved with a strategic initiative that is aimed at resolving a national crisis in academic statistics. At many universities, the statistics departments have difficulty offering postgraduate programmes in statistics and internationally acclaimed researchers in the field can be counted on one hand.) Government funding is limited and universities are forced to generate non-governmental sources of income to balance their books. External funds are difficult to acquire and industry increasingly expects return on their investments in higher education. Furthermore, universities are facing increased competition from foreign universities and other institutions as a result of globalisation. It is therefore of the utmost importance that universities should design programmes that are globally competitive and have the potential to earn income from non-governmental sources. This principle guides the design of our industry-directed training and research programmes.

It is interesting to note that all the views expressed a decade ago are still true today, as demonstrated by the presidential addresses of the most recent presidents of the American Statistical Association, namely Geller[14] and Rodriguez[15]. The subject of statistics is more popular than ever, and although some progress has been made, the issue of industry-relevant training of statisticians has not been resolved and statistics departments still struggle to appoint appropriately trained staff.

We used the views expressed in this section as drivers for the design of our framework and for monitoring the successful implementation thereof.

Designing a framework for industry-directed training and research

In order to design a generic industry-directed training and research framework, we had to consider the following key aspects:

- the application and focus areas for training and research,
- the design concept for implementing the career-oriented training and industry-directed research programmes, and
- management and governance structures and processes required.

The application and focus area

Consider the so-called 'BMI Triangle' shown on the left side of Figure 1. This triangle formed the basis of the VU BMI programme, which we altered slightly by incorporating a specific focus, as depicted in Figure 1b. (When the Centre for BMI was established, we chose business economics as the application area and quantitative risk management as our focus area.) The basis of the triangle is made up of the mathematical sciences at one corner and computer/information science at the other. As stated by Kettenring[9], the mathematical sciences and computer science should form the basis of any career that is built around a statistical science core. The above-mentioned sciences should then be applied in a preselected application area, such as health sciences or economic sciences. It is interesting to note that this triangle allows you to plot many of the 'non-pure' disciplines, such as econometrics, on one side of the triangle, moving to the inside of the triangle allows you to depict application or focus areas that require an interdisciplinary problem-solving approach.

As stated previously, many application areas are possible, and the particular choice depends on the following factors:

- The likelihood of obtaining industry partners or sponsors requiring graduates who understand the particular industry, are highly skilled in the mathematical sciences and computer science, and have the necessary problem-solving and business skills.
- The professional career opportunities in the particular industry.
- The support that the programme will receive from the university, especially senior management.
- The likelihood of obtaining lecturers with the necessary technical qualifications and business experience.
- The experience, expertise and interests of the employed academics at the particular university.
- The relationship that exists between the departments involved (i.e. statistics, computer science and the application area), in particular how far apart they are in the university organisational structure.

- The existence of similar programmes at the university in other departments that could act either as a barrier or as support.
- Proximity and standing of the university with the particular industry.

It could well happen that the application area is too broad, which then requires defining a focus area within the broader spectrum to ensure the required focus for a successful implementation. This scenario is depicted in the 'focused BMI Triangle' in which we decided to place our focus – quantitative risk management – in the middle of the triangle. The important concept to note is that the three corners of the triangle provide the basis upon which one or more such focus areas could be built.

The importance of forming constructive partnerships within the university cannot be overstated. In this regard one should involve the mathematics, applied mathematics, statistics and computer science departments when developing the career-oriented training programmes. Of course, given the application area, another department may have to be involved as well, for example if the application area is business economics with risk management in banking as the focus area, the Department of Economics/Accounting should play an important role. One of the most important design considerations is to formulate a vision for the chosen application/focus area upfront that will serve to grow into a Centre of Excellence or something similar. This vision then has to be unpacked into a clear mission statement, which will drive its implementation.

The design concept for implementation of the framework

Working forward from the basis established by the triangle concept, the next step is to define an implementation framework or operating model that can be used to operationalise the concept. To illustrate our implementation framework we use Figure 2, which is a Venn diagram consisting of three overlapping circles depicting a set of 'Training', 'Research' and 'Industry' activities that will be described in more detail below.

At first, let us consider the set of activities indicated as 'Basic Training' in Figure 2. After deciding on the particular application area (including a focus area if applicable), a decision has to be made regarding the careers for which we aim to prepare the students. When determining the content and delivery method of the training, we need to consider the needs of industry in the particular focus area. Based on the type of problems experienced by the particular industry, the characteristics (skills, subject matter knowledge, etc.) required by these careers can be determined. These characteristics then provide the specific focus for the career-oriented training programmes and give the necessary input to design the curricula, as well as the training methods to develop the required skills. This design should be done in close collaboration with one or more industry partners, but with the understanding that one is embarking on a process which will require continuous improvement as the needs of industry and your understanding thereof evolve.

Meetings and work sessions may be held initially to determine particular requirements in the form of the skills and knowledge that the students should possess in order to function effectively in the chosen focus area. The curricula of other universities and international training programmes in the particular area may also be referenced when designing your own curriculum. In order to incorporate all the requirements, the career-oriented training programme, in our opinion, should span at least five academic years, as is the case with most professional training programmes. For the duration of the undergraduate studies (the first three years), focus should still be placed on the important theoretical concepts and principles of the mathematical sciences, but courses in the selected application area should be gradually incorporated. These activities are carried out in the area designated as 'Basic Training' in Figure 2.

Next, consider the set of activities indicated as 'Integration Training' where the 'Training' and 'Industry' diagrams overlap. In the graduate programmes (BSc Hons and MSc), specific courses should be included to train students in the non-technical skills that were mentioned earlier and to integrate their knowledge to solve real-world problems. Most of the training should preferably be of an 'on-the-job' nature and occur concurrently with the students working on a particular project. During the fourth and fifth years, the programme should focus on the integration of subjects and the students should solve various practical problems using the knowledge and skills they have acquired. The heart of the programme is the set of activities labelled 'Student Industry Projects' where all three circles overlap in Figure 2. These activities represent the 'stage' idea, which we adopted from the VU programme. Using our industry experience, we[16] developed a detailed procedure for conducting and executing the student projects in industry. The basic idea is that all MSc students in the programme are required to complete an individual, substantial (6-month) industry-directed research project under the mentorship of an assigned client project officer (who is employed by industry and assumes responsibility for the business success of the project) and an academic supervisor (who is employed by the university and is responsible for the academic/technical quality of the project). (Note that, in the university structure, the industry-directed research project is classified as a mini-dissertation.) The particular project should be carefully chosen in collaboration with the client so as to solve a problem faced by the client, whilst simultaneously encompassing the requisite academic content. The students, who are able to bid for

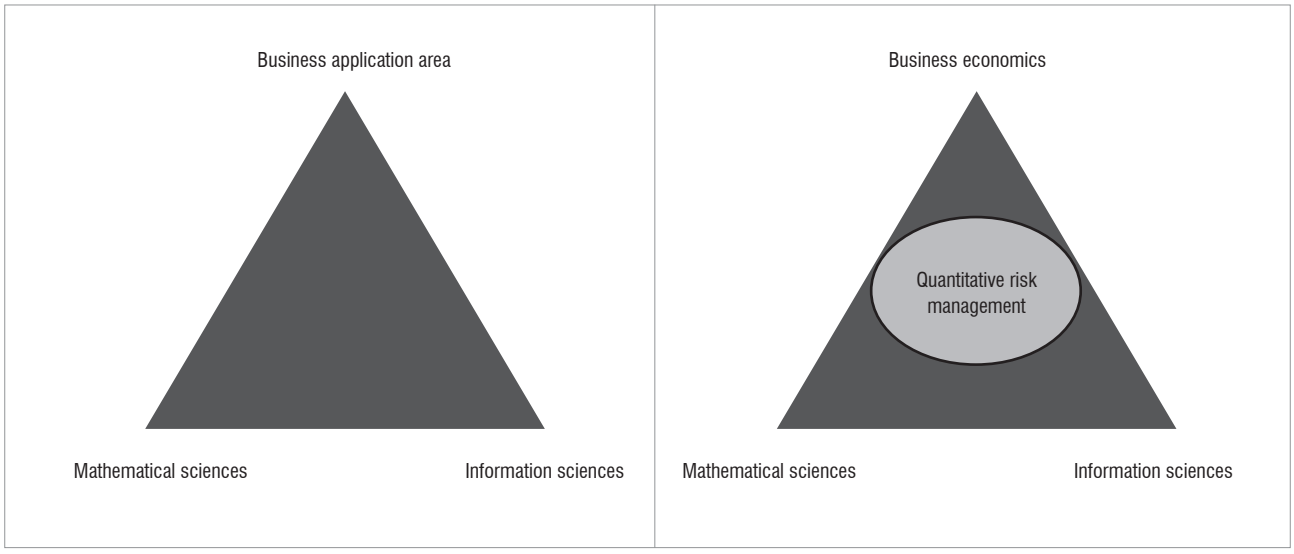

Figure 1: (a) The BMI Triangle and (b) our focused BMI Triangle.

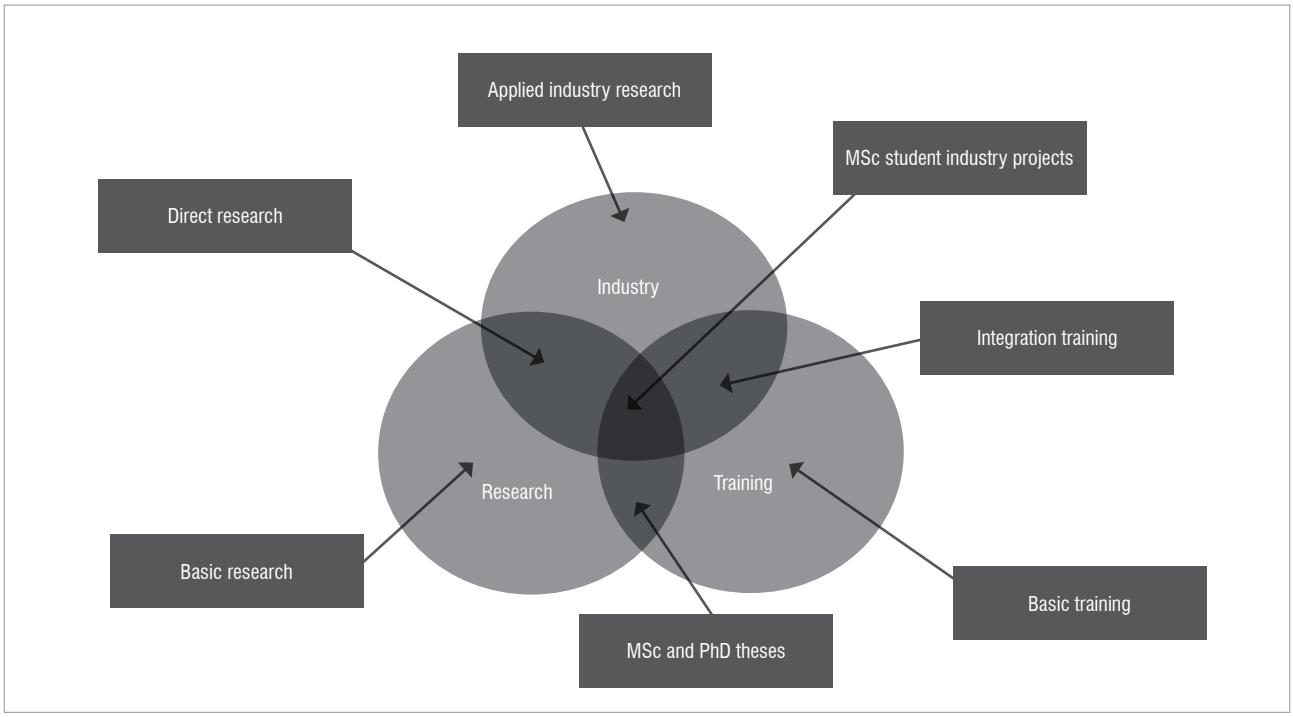

Figure 2: The design concept for implementation of the framework.

projects, should work on-site on the project to ensure that a first-hand knowledge of industry is obtained, and at least five formally organised meetings are required at the physical place of work to ensure that the academic supervisor experiences the business environment and interacts with the client organisation.

This process serves as a natural way of marketing the training and research programmes, as students have better job opportunities and supervisors have the opportunity to market their skills. This approach presents opportunities for the university to earn income from non-governmental sources and for supervisors to direct their research towards the needs of industry. Also, from a marketing perspective, industry is exposed to the academic environment and the skills that exist there. Consequently, the gap between business and industry and the academic environment is naturally narrowed. Although the student industry-directed research projects essentially form part of a training activity, they also form part of research, which provides the link between industry and the university research programme.

The activities indicated as 'Basic Research' in Figure 2 are those involving traditional research activities by staff in the basic mathematical sciences, e.g. research on the improvement of statistical methodology such as the bootstrap. This type of research is usually of a 'technology push' nature, in the sense that research is usually based on the work of peers as observed in the open literature.

The activities labelled as 'Directed Research' are those activities carried out by staff in the chosen application area. Here researchers apply their research skills in the basic mathematical sciences to solve problems or develop methodologies in the chosen application area. Although the research is directed to the application area, it is also primarily of a technology push nature and predominantly based on the work of peers in the application area. The directed research programme was recently extended to include transdisciplinary research activities which entail directed research projects between industry and academia, but which are longer term in nature.

Unlike the projects undertaken under 'Directed Research', the activities in 'Applied Industry Research' are of a 'market pull' nature and are directly related to the needs of industry. Here staff tackle a specific problem posed by industry in order to generate income for the university, usually measured against short- to medium-term milestones. It should be noted that these activities have to be managed carefully against the specified milestones and should be conducted from an applied research perspective and do not take the form of pure consulting work per se. The nature of the work carried out is more medium term in nature rather than the very short-term milestones typically faced by consulting companies. As soon as the 'Applied Industry Research' projects are completed, a special effort is needed to generate transdisciplinary research papers co-authored by academics and clients as part of the 'Directed Research'. Figure 3 provides an illustration of the types of research activities in the knowledge-production chain – the long-term success of the research part of the framework is critically dependent on the alignment of the 'push' and 'pull' part of the chain, which requires active management from the research director.

The remaining training activities, depicted as MSc and PhD theses in Figure 2, are all the traditional training and research activities that result in theses written by students who study the basic mathematical sciences.

Management and governance issues

At this stage it should be clear that the activities carried out in the various areas of the implementation framework are quite diverse and that different people with different skill sets are involved in these activities. For example, the researcher operating on activities classified as 'Applied Industry Research' should have significant experience in solving business problems in the particular application area or should work under someone who has the relevant experience. Similarly, the researcher operating on 'Basic Research' activities should have experience in researching methodology in the basic mathematical sciences. The framework could also serve as a tool for the career planning of staff, because one could plot the progress of someone wishing to develop from 'Basic Research' to 'Applied Industry Research' or vice versa.

The diverse nature of the above-mentioned activities require that the university should seek to employ people well equipped for the particular task at hand, in particular to manage the interfaces between the different areas in the framework, as well as the framework as a whole. This in turn dictates different compensation and promotion strategies for the staff involved.

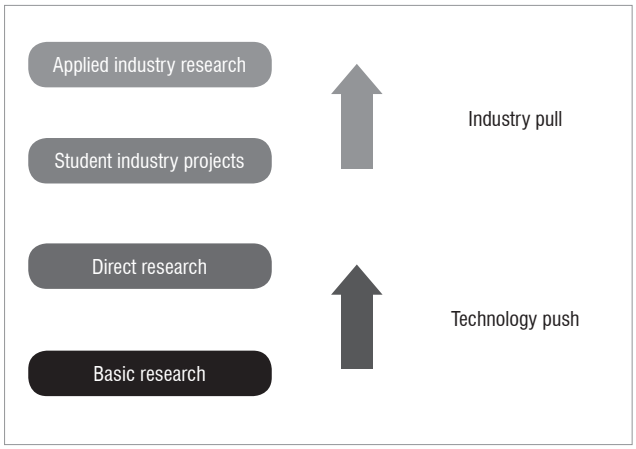

Figure 3: The knowledge-production chain.

The establishment of the capacity to conduct activities such as Directed Research and Applied Industry Research will most likely require some time before it reaches fruition. It is our recommendation that one should start by involving academics in the student industry projects in a supervisory capacity. By becoming involved in these projects, they will quickly grasp the problems faced by industry and identify the nature of the research required. At the same time, academics could acquaint themselves with the literature relevant to the emerging field and initiate directed research in the new application area.

Some academics may initially exhibit resistance to a change in their focus for obvious reasons, such as the time it will take to come to grips with the new research area. Management will have to adapt performance appraisal systems and promotion criteria so that industry-directed research is rewarded appropriately. Another issue is that industry-directed research projects are mostly classified as confidential, because of data issues and the possibility of commercialisation. Therefore it is important that universities address intellectual property issues upfront in these projects.

Appropriate governance structures are required for each set of the activities mentioned in the Implementation Framework. Most of these structures already exist at most universities for the 'Training' and 'Research' activities, but not for the 'Industry' activities in which the management of the industry–university relationship is of critical importance (for example see Edmonson et al.[17]). The governance and management structures of the BMI programme will be discussed in the next section, but in this case, separate management structures were required for each of the four sets of 'Industry' activities. Note also that separate governance structures are needed for each set of the 'Training', 'Research' and 'Industry' activities. At our university, the Centre for BMI has the responsibility for managing the 'Industry' activities, including the overlapping ones; the School for Statistics, Mathematics, and Computer Science for the non-overlapping 'Training' activities; and the Research Unit for BMI for the non-overlapping 'Research' activities.

The BMI programme

In this section we use the BMI programme as a case study to illustrate the implementation of our framework. We focus on the implementation of the BMI programme as far as the 'Industry' activities are concerned and discuss 'Integration Training', 'Directed Research', 'Student Industry Projects' and 'Applied Industry Research' separately in terms of implementation experience and the management and governance structures implemented.

Early in 1998 we formulated the vision of the Centre for BMI as follows:

> *To be a recognised player in the South African industry and the international academic world, and to obtain, develop and disseminate financial risk management expertise in close collaboration with the industry and public sector.*

We defined our focus area as 'Quantitative Financial Risk Management' (which has recently been extended to include Business Analytics/Data Science). Therefore, in the early years of the Centre for BMI, the drive was to become a Centre of Expertise in Financial Risk Management solutions. Much of what is reported here focuses on the development of career-oriented training programmes and industry-directed research programmes for this field, but it is important to note that the same principles may be followed for other fields such as Data Science.

Integration training

Implementation experience

In order to ensure the introduction of subject-matter expertise into the programme, we liaised with the NWU School of Economics to introduce economics and finance courses within which the concepts of finance, banking and risk management are covered. These subjects were later replaced by courses in financial risk management which the School of Economics presented as part of a qualitative risk management programme. In the postgraduate programmes, several specialised courses in quantitative financial risk management had to be developed. In the end we settled on a mixture of material originating from the syllabi of the Institute and Faculty of Actuaries, the Global Association of Risk Professionals (GARP), the Professional Risk Managers' International Association (PRMIA) and books on related topics.[18-20] The BMI curricula may be viewed on our website (www.nwu.ac.za/bmi) and contain courses in Quantitative Risk Management, Business Analytics/Data Science, Financial Mathematics and Actuarial Science. The latter programme was acquired in 2000 from the Department of Statistics, when departmental management chose not to be troubled with the administrative burden of managing the exemptions and accreditation requirements of the Institute/Faculty of Actuaries. This was an important strategic decision, which paid tremendous dividends in recent years when the actuarial profession decided in 2008 to expand their global syllabi to include enterprise-wide risk management as part of their Certified Enterprise Risk Actuary qualification. At this time, and because of the widespread perceived excellence achieved in risk management training and research, the Centre for BMI was approached by the Actuarial Association of South Africa (ASSA) with a request for assistance with this initiative. It is important to note that the BMI courses include many programming courses, in particular SAS, while courses are presented in R, C# and Java (only for the data-mining curriculum). (Note that we have found SAS skills to be a job-differentiating factor in that students with these skills have a definite advantage when applying for jobs.) Great care has been taken to incorporate industry-relevant software systems training into our curricula, in particular, risk-management systems such as Risk Watch by Algorithmics, Front Arena by SunGard, and the portfolio risk management system BARRA on campus.

Another challenge was to ensure integration of the student's knowledge, in particular, to teach them how to use their mathematical and computer programming skills to solve real-world problems. To this end, we introduced BMI integration courses at first-year, third-year, honours and master's levels. In the first-year course, students are taught the basics of financial mathematics and are then required to develop a so-called retirement calculator utilising either MS Excel, C# or Visual Basic. This calculator can then be used to plan a fellow student's retirement. The problem statement is presented to the students in the first class to allow them to experience how the theoretical concepts that they are taught build up to the point at which they are able to solve the problem. They are also given the opportunity to systematically develop a software system which can be designed and tweaked in order to handle changes in inputs. At the end of the year, the students present their system and are then required to solve some of the problems posed in the exam. In this way they learn how to present and market their system. We have found that this course goes a long way in assisting the student to develop a problem-solving mindset. The courses introduced on the other levels are similar in terms of the integration of mathematical formulation and computer programming skills, but a different and more challenging problem in the focus area has to be solved. We also realised that students at master's

level had to be properly prepared for their industry-directed research project, and introduced a 32-credit integration-training module.

Management structures

A special effort had to be made to make the BMI programmes accessible to students from a previously disadvantaged background. In 2003, because of the language policies at the NWU's Potchefstroom Campus, we negotiated with the Dean of the School of Modelling Sciences at the Vaal Triangle Campus to present the undergraduate BMI training programme in English and changed the presentation language of all postgraduate BMI programmes to English. Absa's BMI bursary programme contributes annually to students following this programme. Absa manages the bursary programme in collaboration with the Centre for BMI and the progress of bursary holders is monitored closely through a Bursary Committee which has been established via a formal agreement. Each year, three formal meetings are scheduled at which representatives from Absa and BMI manage, inter alia, student progress, the allocation of new bursaries, employment within Absa, and repayment of bursaries by defaulters.

Directed research

Implementation experience

In order to properly focus research in the new field of quantitative financial risk management or risk analytics, we distinguish between basic-directed and transdisciplinary-directed research. Basic-directed research is defined as systematic study directed toward a more comprehensive knowledge or understanding of the fundamental aspects of risk management and analytics. This type of research is typically generated by researchers and depends largely on their personal interests and skills. This type of directed research is similar to basic research, with the difference being that the research is directed towards the particular field of interest, in this case risk management as opposed to, say, basic research in statistics or mathematics. On the other hand, the aim of transdisciplinary-directed research is to explore a theoretical or experimental research problem in order to achieve a defined industry goal in collaboration with industry.

In order to stimulate research in the new field of financial risk management, we decided to appoint a top-rated retired researcher in 2001. This appointment was made with the objective of gaining momentum for the basic-directed research programme. At present, the Centre for BMI contracts five retired researchers almost exclusively to do basic research in risk analytics and to supervise PhD students. As part of a recent memorandum of understanding signed between the Department of Science and Technology (DST) and Absa, the directed research programme received funds that are primarily used for transdisciplinary-directed research, but also for basic-directed research. At first, most of the funding was earmarked for basic-directed research projects which focused on the fundamental theory and aspects underlying (financial) risk analytics. As the programme matures, the emphasis is shifting to transdisciplinary-directed research projects with specific goals. The goals of these projects will typically be defined by industry (Absa and other financial services companies), the Reserve Bank and the NWU's Centre for BMI. During the first two years of running this virtual research programme, we managed to involve researchers from the University of Johannesburg, University of KwaZulu-Natal, University of Pretoria, University of South Africa and Stellenbosch University. Apart from Absa, where we held a workshop to formulate some transdisciplinary-directed research themes, we have attracted the interest of the Reserve Bank, National Treasury and Standard Bank with respect to our transdisciplinary research projects.

Management structures

Although formal project management procedures had to be implemented to manage the 'Applied Industry Research' projects, these procedures were used as guidelines and project management principles guided us in managing the directed research projects. Here we implemented the principle of goal-focused research for which we rewarded researchers who focused their research on the goals of the directed research programme, in line with predefined criteria and goals. The criteria were derived in collaboration with Absa and the DST and have been selected to support the Absa Applied Risk Research Programme.

The funds available for allocation among research projects is determined by an Assessment Committee comprising representatives from Absa, the DST and the Centre for BMI. Informal management structures exist for the selection and allocation of PhD applicants to supervisors, which are organised in an ad-hoc manner with the supervisor and student.

Student Industry Projects

Implementation experience

During the second semester of their master's degree, students are placed at a specific company for 3 or 4 days per week, where they are required to apply their knowledge and skills in solving a real industry problem with the requirement that value is added to the company. This process is well structured and managed according to a specific methodology and is very popular in the financial services industry. We have documented the methodology as part of a procedure guide[16] which contains details on the project management process, documentation packs, minutes of project meetings, responsibilities of the Project Steering Committee members, preparation for meetings, report templates and structure, project close out procedures and assessment details.

As mentioned previously, a module has been introduced in the first semester of the MSc in order to prepare the student for the second semester industry-directed research project. This module contains lectures on creative problem solving, project management, meeting administration, report writing and business communication. Typically, two students are assigned to a project, which is concerned with solving a problem for a local client (e.g. from within the university, local industry, municipality or the defence force). These problems are typically of a management consulting nature and usually involve developing a decision support system, which is typically computer based. The problems are specifically chosen to fall outside the risk management field to force the student to think 'out of the box' and to learn to apply the project management processes and principles properly. As instructors we follow a hard and provocative line during the Project Steering Committee meetings at which students are required to answer the typical why, what, where and how questions. The objectives are to drill students in question answering and persuasion techniques and in thinking 'on their feet' when answering questions, in order to prepare them to deal with any personality type they may encounter when they do their industry projects in the second semester.

Overall, this process has several benefits: students find work easily and the feedback from industry allows us to ensure that the training and research programmes remain highly relevant to industry. This process also has several advantages for industry partners, such as:

- An opportunity to complete those projects that never seem to make it to the top of the priority list.
- Access to the skills of a nearly qualified student, with the backing of an academic mentor, at a very low cost.
- An opportunity for a 6-month on-the-job evaluation of a prospective employee, before deciding to offer them a job. (This option is far more cost effective than working through a placement agency.)

Management structures

Each student project is managed by a Project Steering Committee, which comprises a client project sponsor, client project manager, client project officer, director of the Centre for BMI, academic project supervisor and the student. A detailed list of the responsibilities of each person is provided in the procedure guide.[16] In short, the client project officer and academic project supervisor are required to meet with the student and discuss project progress on a weekly basis. These meetings usually take

place on Mondays (with the client project officer at the client company) and on Fridays (with the academic project supervisor at the university). The client project officer is responsible for managing the business relevance to the company, while the academic project supervisor is responsible for monitoring the academic/technical quality. Regular meetings require the student to keep informal minutes and are necessary to keep the project on track. Four formal Steering Committee meetings – referred to as the Business Case, Project Proposal, Progress Review and Project Close-out – take place at the premises of the client and require formal documentation packs and minutes of meetings. The evaluation of the final report follows a rigorous process which is very similar to the formal theses assessment process, with the exception that slightly modified evaluation criteria are used. One aspect of the extra criteria included is the consideration of the value and benefits provided by the project to business. To date, about 90% of the student projects delivered have received a high to very high rating. (Based on our experience in the consulting environment, this rate is much higher than the success rate experienced by consulting companies.)

Applied Industry Research

Implementation experience

In the years prior to the commencement of this programme in 2006 it became clear that a business value-adding activity was required to motivate the continued contractual relationship between Absa and the Centre for BMI. Although Absa had acknowledged the substantial benefit of the students and the industry-directed research projects delivered, they had provided bursaries to the students and by then had invested a large amount of capital for the capacity-building phase. The BMI training programme was well established, but other companies in the financial services were also benefitting from the programme – in fact, only 35% of the BMI MSc graduates are employed by Absa. As a result, it became clear that an additional service had to be introduced to ensure renewal of the contract. During 2005, an important strategic initiative was launched to involve staff in Absa applied research projects, subsequent to which Absa decided to renew their contract in 2006, this time with the inclusion of an umbrella contract for Applied Industry Research projects. Today the value of this contract is just over ZAR1.5 million and a number of research reports have been delivered – an average of 13 projects are completed each year. Most of the projects were done for clients in Absa middle management, which, together with the student projects, ensured that BMI staff obtained high visibility in Absa. Other institutions also came to know about the BMI capabilities, and today a number of companies are interested in using the Centre for BMI as independent evaluators or validators of their models.

Management structures

Although the management of the programme started off in an ad-hoc way, the processes have now been formalised. A project management procedure, similar to that employed during the course of the student projects, has been instituted in an augmented form to ensure a proper audit and reporting trail for the completion of projects in terms of the initial client requirement as well as to ensure business value. An Absa Risk Research Steering Committee manages the process with the responsibility to ensure good governance in terms of value and funding and to make sure that follow-up work is done. Each year a report is issued which contains the value-added ratings by the clients of the various projects performed in the previous year. Although BMI staff salaries were augmented by Absa funds, it was difficult at first to motivate BMI personnel to become involved in the Absa projects, mainly because of the profit sharing policy of the university, which rewarded personnel who worked on projects conducted on a one-to-one basis and not those under an umbrella contract. As soon as the profit sharing policy was adjusted to also incorporate the Absa umbrella project, personnel became motivated to take part in the Absa projects.

As stated earlier, the Centre for BMI is involved in two long-term contracts with industry partners Absa and SAS. Both contracts are managed by Steering Committees consisting of representatives from Absa, SAS and NWU. An Advisory Board manages the Absa interface with executive representation from Absa Human Resources, Absa Financial Services, Absa Group Risk, SAS, the DST and NWU. The Advisory Board meets once a year and provides strategic level direction and oversight to the activities of the Centre for BMI. Recently, the Board tasked us with designing a framework for measuring the success of the relationships between the NWU and Absa. In order to do this, we adapted the industry–university evaluation framework suggested by Perkman et al.[21] for our purposes.

Concluding remarks and lessons learnt

In the process of designing the BMI programme, several important lessons were learnt. Some of the most important ones are:

- The people responsible for managing the university–industry interface should be good managers who understand the process of problem solving, should have industry experience in applying the mathematical sciences to solve business problems and should understand research and the associated difficulties. Managing this interface with industry is a full-time job, and cannot be expected from an academic on an over-and-above basis.
- It is important to focus on a particular area of application. We initially worked from the generic BMI base, trying to 'be all things to all people'. You cannot have meaningful discussion with industry without a specific focus in a chosen application area. (In the end it turned out that our chosen focus, quantitative risk management, was anyway a massive field.)
- Without active support from senior (top) management within the university *and* the industry sponsor(s), the effort is a non-starter. On the other hand, university management who have no industry experience and are 'traditional academics' may find it difficult to cope with the demands, frustrations and speedy decisions that are required when managing the 'Industry' activities.
- Effective integration and co-operation across faculty and/or departmental boundaries is crucial – establishing a team spirit with a common vision and breaking down the traditional academic silos are essential.
- The Student Industry Projects, although they require extensive management and academic time investment, represent a critical success factor for the initiative, as it forces the two parties to engage with one another and move out of their comfort zones. Furthermore, they create frequent communication opportunities and act as a natural marketing activity.
- Active partnering with credible professional bodies (e.g. GARP, PRMIA, ASSA) and with relevant software companies (e.g. SAS, Sungard, Barra) lends further credibility to the initiative.
- It is important to note that the BMI programme focuses on the delivery of professionally trained students to industry and *not* on training academics; therefore, students who have completed a BMI MSc and wish to register for a PhD in the mathematical sciences (e.g. mathematics or statistics) will require additional advanced discipline-specific training.

In this paper, we proposed a framework that can be used to design and implement career-oriented training programmes with a statistical science core. The essential elements of the framework are that it is:

- Multidisciplinary – in our case, it consists of a sound undergraduate base in statistics, mathematics, computer science, banking and financial economics.
- Structured around a specific focus in the application area – in our case, quantitative financial risk management, recently expanded to data science.
- Career-orientated, with the curriculum reverse-engineered from the identified careers – in our case, financial risk manager, investment

manager, financial engineer, financial statistician/mathematician and data-miner.

- Practical, as facilitated by the specific selection of staff with the skills and experience to operate 'inside' the triangle in Figure 1, and involves active practitioners from industry in the training programme.
- Integrated, in the sense that there are specific courses incorporated in the curriculum – in our case, on first-, third- and fifth-year levels – to actively integrate the knowledge between the corners of the triangle, together with the non-technical skills discussed earlier.
- Backed by a well-structured research unit, with clearly defined goals and management responsibilities, and an applied research programme in financial risk analysis, which is aligned with the declared focus in financial risk management.

This framework has been used to successfully design and implement the BMI programme at the NWU. We believe that the mathematical sciences departments at any university should be able to use this framework to design and implement career-oriented training programmes. The key, however, is to choose the right application area and right champions, to find an interested and committed business partner, and to gain acceptance, approval and support from university authorities. Also, we should take care to not focus on the same area, but to rather collaborate, and share ideas to the benefit of all.

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Authors' contributions

Both authors contributed equally to the manuscript.

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Pollination ecosystem services in South African agricultural systems

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Insect pollinators, both managed and wild, have become a focus of global scientific, political and media attention because of their apparent decline and the perceived impact of this decline on crop production. Crop pollination by insects is an essential ecosystem service that increases the yield and quality of approximately 35% of crops worldwide. Pollinator declines are a consequence of multiple environmental pressures, e.g. habitat transformation and fragmentation, loss of floral resources, pesticides, pests and diseases, and climate change. Similar environmental pressures are faced in South Africa where there is a high demand for pollination services. In this paper, we synthesise data on the importance of different pollinators as a basis for services to South African crops and on the status of managed honeybees. We also focus on insect pollination services for the Western Cape deciduous fruit industry, which is worth ZAR9800 million per year and is heavily reliant on pollination services from managed honeybees. We discuss landscape and regional level floral resources needed to maintain sufficient numbers of managed honeybee colonies. In summary, the available literature shows a lack of data on diversity and abundance of crop pollinators, and a lack of long-term data to assess declines. We highlight key areas that require research in South Africa and emphasise the critical role of floral resource availability at the landscape and regional scale to sustain pollinators. We conclude that understanding the dynamics of how floral resources are used will help inform how landscapes could be better managed in order to provide long-term sustainable pollination services.

Introduction

Insect pollinators, comprising both managed (domesticated, e.g. honeybee *Apis mellifera*) and wild populations (species that exist as non-managed wild populations including wild *Apis* spp.), have become a focus of global scientific, political and media attention because of their apparent decline and the perceived impact of such declines on crop production.[1-8] Crop pollination by insects (predominantly by bee species)[9] is an essential ecosystem service that increases both the yield and quality of an estimated 35% of crop production worldwide.[10] Farmers depend on managed honeybees to pollinate crops in many parts of the world, including areas such as North America where honeybees have been introduced to provide this service.[5,8,11] The decline in honeybees, particularly in North America[2,12] and Europe[4,13], has focused attention on the need for alternative, non-honeybee pollination, particularly the role of wild pollinators and the ecosystem services provided by these pollinators[6] (but see the long-standing debate between Corbet[14,15] and Morse[11] and later between Aebi et al.[16,17] and Ollerton et al.[18] regarding the relative importance and effectiveness of honeybees versus other species). As a result, current pollination ecosystem services research focuses predominantly on conserving wild pollinators and their habitat within and adjacent to the agricultural matrix.[19-21] The original emphasis on managed honeybees for crop pollination was based on their convenience and effectiveness in intensive agricultural systems[5,11], which are typically characterised by relatively large crop areas with little or no natural vegetation within the agricultural matrix as well as a short time period for pollination as a result of the deliberately high level of flowering synchrony within a crop field[7]. Total reliance on wild pollinators would therefore appear to present risks for farmers in these intensive agricultural landscapes and it is still unclear if there are sufficient numbers of suitable wild (non-*Apis*) pollinators to provide effective pollination services.[22] There is a growing body of evidence showing that diverse pollinator assemblages provide better pollination services to crops.[3,23,24]

A recent global study investigated the role and contribution of wild pollinators and managed honeybees as a pollination service to a range of annual and perennial fruit, seed, nut, and stimulant crops across 41 sites worldwide.[25] This study indicated that crop fields with high numbers of both honeybees and wild pollinators resulted in sufficient pollen deposition. In contrast, it was shown that wild insect visitation alone significantly increased fruit set, by twice as much as honeybees did, suggesting wild pollinators provide more effective crop pollination. Moreover, fruit set was shown to increase consistently with visitation from wild pollinators and increased with visitation by a diverse assemblage of pollinators independent of honeybee visitation. The additive interaction between non-*Apis* pollinators and honeybees has been shown to increase fruit set.[26,27] Recommendations for optimal pollination therefore sometimes call for the integration of wild pollinators with managed honeybees.[25,28]

Despite the perceptions of global honeybee decline, long-term global data indicate an increase in managed honeybees,[29-31] except in the USA. However, agricultural demand could outstrip supply of managed honeybees[30] and greater demand for high value fruit and nut crops may further increase demand for pollination services.[32,33] This demand implies that pollination services may experience constraints even without a dramatic decline in honeybees and highlights the need for effective strategies to safeguard reliable pollination services for agriculture. Such strategies could include: improved health of managed honeybees; identifying possible substitutes for managed honeybees[14,34]; increasing and diversifying the suite of wild pollinators where possible (see Corbet[15]); and increasing the effectiveness of wild pollinators[26]. The latter includes conserving suitable food sources and nesting habitat for wild pollinators within the agricultural matrix and raises the question first posed by Ghazoul[35]: 'Is management to secure biodiversity benefits more rewarding for crop production than management less favorable to biodiversity?'

If so, then strategies to improve pollination services need to be aligned with strategies to conserve biodiversity in agricultural landscapes.

Within South Africa, there is a high demand for pollination services for many crops. At the same time, our pollinators are exposed to similar environmental pressures that have resulted in declines elsewhere in the world, e.g. habitat transformation or fragmentation[19,20], loss of diversity and abundance of floral resources[36,37], inappropriate use of pesticides[36,38], spread of pests and diseases[17], and climate change[5]. As a result, it is important to understand the current state of knowledge in South Africa relating to pollination services. In this context, we review the literature of South African pollination services in agricultural systems to highlight issues and identify areas where further research is needed. Firstly, we review the importance of different pollinator species as a basis for services to South African crop production. Secondly, we examine if South Africa is experiencing similar declines in managed honeybees. Thirdly, we focus on the Western Cape deciduous fruit industry, an industry worth ZAR9800 million per year, which is heavily reliant on the provision of pollination services.[89,90] Despite its economic importance, very little has been published on managed pollination services in South Africa. We review the current capacity, economic value and importance of the pollination services. Fourthly, we focus on the landscape and regional level dependence on floral resources to maintain sufficient numbers of managed honeybee colonies and what this may mean for sustainable pollination services.

Importance of pollinator species for South African crop production

One of the assumptions of the global focus on pollination ecosystem services is that a wide variety of species has the potential to contribute to crop pollination and that this diversity of pollinators can be promoted either as an alternative[3,23] or as an adjunct[24,27] to honeybees. The literature indicates that a shortage in the abundance and diversity of wild pollinators could jeopardise crop yields.[40-43] One of the main factors affecting the diversity and abundance of pollinators in the agricultural matrix is available habitat; declines in pollinator diversity in Europe and North America have been correlated with the loss of habitat through agricultural intensification.[3,44,45] In addition, isolation of crop fields from natural and semi-natural habitat has been shown to negatively impact on the stability of wild pollinator richness, visitation rate and fruit set in crops.[21,42,46]

There have been few comprehensive assessments of pollinator assemblages on crops in South Africa and no studies on declines in these assemblages such as that done by Biesmeijer et al.[4] for European systems. Nevertheless, studies on natural systems within South Africa have shown the negative effects of habitat fragmentation on plant–pollinator interactions within the agricultural matrix[47,48] as well as the breakdown of specialist plant–pollinator networks on smaller conservation areas (reserves <385 ha).[49] Furthermore, the impact of overgrazing on pollinators has also been shown to have negative impacts through the loss of host plants and trampling of nesting sites.[50-53] Interestingly, Vrdoljak and Samways[54] found that levels of flower visitor richness within agricultural mosaics can be similar to protected areas, suggesting the potential for natural or semi-natural habitat to facilitate movement of individuals and act as a repository for pollinators. Without long-term monitoring of pollinator populations to assess trends over time, little inference can be made about such changes in wild pollinator populations or their effects on pollination services.

Within South Africa, there have only been nine studies (Table 1), four published in peer-reviewed journals, assessing the importance of different pollinator assemblages as a basis for services to crop production. The contribution of pollinator richness to fruit or seed set has not been thoroughly investigated in South Africa, with a few notable exceptions on sunflower seed[55], mango[56] and rooibos seed[57] crops indicating the importance of pollinator richness. In the case of sunflowers and mangoes, even with a high abundance of honeybees, Carvalheiro et al.[55,56] found diversity of flower visiting insects to be the main contributor to crop productivity. In these two crops, pollinator richness and abundance decreased with distance from natural vegetation, which negatively affected production. In order to reduce these negative effects, Carvalheiro et al.[55,58] found that promotion of 'within-farmland biodiversity' (native flower patches in mango orchards and weeds in sunflower fields) increased pollinator richness which improved crop productivity. Promoting within-farmland biodiversity appears to offer practical cost-effective management options for increasing pollination services. These studies confirm the importance of pollinator richness for some crops and the concomitant need to maintain habitat within the agricultural matrix. Nevertheless, the evidence base linking pollinator richness to crop yield is still relatively weak for most South African systems. In addition, estimating the importance of pollinator richness can be challenging as not all flower visitors actually pollinate plants[57,59] and it is necessary to relate the biology of these species to their behaviour and pollen loads to distinguish flower visitors from pollen vectors[57,59-61]. Additionally, pollen delivery is only one of several factors resulting in successful pollination.[62,63] It is therefore important to determine the key pollen vectors in order for farmers to manage their land more effectively, e.g. providing nesting habitat for these key pollinators.[37,57,64,65]

Despite the findings indicating the importance of wild pollinators, the role and contribution of honeybees (both managed and wild) within South African agriculture should not be overlooked. All but one study (Table 1) on mangoes[55] found honeybees to be the most abundant pollinator (contributing on average 69.2±30.0% of observed insect visitors to flowers) in South African crop fields, including seed, deciduous fruit and tropical fruit crops. A high abundance of honeybees is not uncommon; honeybees are known to be present in many agricultural systems worldwide[25,66] – either because managed hives have been used or because there are wild or feral honeybees[55]. Honeybees in South Africa are indigenous and ubiquitous in natural[67-69] and agricultural systems[55,70] and are an important pollinator to a wide range of indigenous plant species[68,71]. Consequently, assessing the ecological importance of wild honeybees within the agricultural matrix and their contribution to sustainable pollination services is essential. However, doing so is not straight forward, as it would be impossible for researchers to distinguish between wild and managed honeybees as they are the same species.[56,57] In order to determine the relative contribution of wild pollinators, including wild honeybees, researchers would need to (1) account for the presence of managed hives in their experimental design and statistical analysis (see Carvalheiro et al.[55,56]), (2) use isolated fields (greater than 5 km from neighbouring farms), preferably surrounded by natural vegetation, that do not have managed honeybees or (3) close up managed hives once they have been brought into the orchard or crop field.

Honeybees are not efficient pollinators of some crops (as a result of their foraging behaviour and morphology), which is usually compensated for by increasing the number of managed hives.[11,72] Increased frequency of honeybee visitation has been shown to provide sufficient pollen deposition but poor or variable quality pollination.[25] It has been shown that rooibos seed[57], lucerne seed[73,74] and mango[56,58] in South Africa are pollinated effectively by other pollinators. In one study investigating potential pollinators for rooibos seed production, honeybees were abundant but were not considered to be important pollinators.[57] Instead, Gess and Gess[57] found Xylocopinae, Megachilinae and Masaridae were essential pollinators for rooibos seed production. Honeybees are also not considered to be the most efficient pollinators of lucerne[72], even though lucerne seed producers depend on them. Larger bees, such as the carpenter bee (*Xylocopa caffra*), are considered to be more suited to the large flowers of legumes and are more effective as a consequence of their foraging behaviour, during which they trip the flower and affect pollination.[68,73-75] However, in crops where honeybees are abundant, synergistic effects (increasing the movement and rate of visitation of honeybees) of non-*Apis* have been shown to improve pollination efficiency and the potential to increase crop yields.[26,27,55] These findings suggest the possible benefits of integrated management of non-*Apis* and honeybees.[25]

The limited amount of published research (Table 1) on the importance of different pollinator species highlights the need for further research on the diversity and richness of unmanaged pollinators (including

Table 1: A summary of research assessing the importance of different pollinator assemblages as a basis for services to crop production in South Africa

Crop	Citation	Dominant pollinator/flower visitor		Other pollinators/flower visitors recorded		Recorded use of managed hives at time of study	Distance from managed hives included in study	Location in South Africa
		Species	% Visits	Taxa	% Visit			
Apples (*Malus domestica*)	Mouton[76]	*Apis mellifera capensis*	98%	Lepidoptera Hymenoptera Diptera Coleoptera	2%	Yes	2 km	Grabouw, Western Cape
Avocado† (*Persea americana*)	Eardley and Mansell[77]	*Apis mellifera scutellata*	84%	Hymenoptera Coleoptera Lepidoptera Hemiptera Diptera	16%	Yes	No	Tzaneen, Limpopo Province
Litchi† (*Litchi chinensis*)	Eardley and Mansell[78]	*Apis mellifera scutellata* *Plebeina denoiti* *Ctenoceratina* spp. *Braunsapis facialis*	65% 9% 8% 8%	Hymenoptera Chrysididae Coleoptera Diptera Bombyliidae Syrphidae Muscidae	10%	Yes	No	Ofcalaco, Limpopo Province
Mango† (*Mangifera indica)*	Eardley and Mansell[79]	*Apis mellifera scutellata* *Rhyncomya forcipata* *Braunsapis* spp.	32% 16% 13%	Hymenoptera Coleoptera Lepidoptera Diptera	39%	Yes	No	Tzaneen, Limpopo Province
Mango (*Mangifera indica)*	Carvalheiro et al.[56]	*Camponotus* spp. *Monomorium* spp. *Apis mellifera scutellata* *Empididae* spp.	18% 12.60% 9% 9%	Coleoptera Diptera Hymenoptera Lepidoptera	51.40%	Yes	No	Mpumalanga Province
Onion hybrid seed production (*Allium cepa*)	Brand[80]	*Apis mellifera capensis*	91.50%	Coccinellidae Diptera Hemiptera Non-*Apis* bees	8.50%	Yes	No	Southern Karoo and Klein Karoo, Western Cape
Rooibos tea seed (*Aspalathus linearis*)	Gess and Gess[57]	Megachilinae Masarinae Xylocopinae	–	–	–	–	–	Citrusdal to Clanwilliam, Western Cape
Sunflowers (*Helianthus annuus*)	Carvalheiro et al.[55]	*Apis mellifera scutellata*	84%	Coleoptera Diptera Heteroptera Hymenoptera Lepidoptera	16%	Yes	0.67–2 km	Settlers, Limpopo Province
Sunflowers (*Helianthus annuus*)	Shenkute[81]	*Apis mellifera scutellata*	90%	Lepidoptera Coleoptera Diptera Heteroptera Hymenoptera	10%	Yes	1 km	Settlers, Limpopo Province

†*We calculated the relative abundance of each species using Eardley and Mansell's[77-79] total counts over 3 years (1994–1996), e.g.* Apis mellifera *30%*

indigenous *Apis*). The available literature indicates that honeybees are important, but because the wild component has not been quantified, the most effective pollination services appear to be derived from a combination of honeybees and other pollinators.

Are there declines in managed honeybees in South Africa?

In South Africa, managed honeybees have not experienced the same dramatic declines as recorded for North America and, to a lesser extent, Europe. They appear to have remained healthy despite the appearance of destructive bee pests such as varroa mite[82] and diseases such as American foulbrood.[83,84] It has been reported that South African honeybees exhibit traits of resilience against these pathogens.[84] However, this tolerance of bee pests and diseases in honeybees is not yet fully understood[84] and it would be premature to assume that honeybees in South Africa will not decline as a result of novel pests or diseases. Despite an absence of significant reports of colony losses, data on the number of honeybee colonies in South Africa are irregular and patchy, with the last census conducted in 1975.[85,86] Added to this, the reduced capacity and limited budget available for the Agricultural Research Council to collect data on honeybees means that data on honeybee colonies are unlikely to improve in the short term. Pirk et al.[87] conducted a beekeeper survey assessing the extent and the potential causes of colony losses in South Africa. Their study found colony losses (reported losses over two consecutive years, 2009–2010 and 2010–2011, of 29.6% and 46.2%, respectively) were higher than those considered acceptable in Europe or North America. Colony losses, specifically for beekeepers using *A. m. scutellata,* have, for the most part, been attributed to the *A. m. capensis* worker social parasite, a problem unique to South Africa. Losses of colonies were shown to be significantly increased by migratory beekeeping practices, in particular when beekeepers moved colonies to provide pollination services.

Global analyses of long-term data have shown that the assessment of hive numbers in the context of demand indicates there has been an increase in pollinator-dependent crops[33] rather than a decline in managed honeybees. Allsopp and Cherry[88], and anecdotal reports a decade later, indicate that colony numbers in South Africa are constrained by access to and availability of floral resources and therefore have a limited capacity to cope with any further demand. The lack of suitable sites forces new entrant commercial beekeepers to buy out established businesses for these highly prized sites. Similar assessments, as done by Aizen et al.[29], are needed in South Africa to determine if the current supply of managed hives meets current and predicted increases in demand for pollinator-dependent crops.

Pollination services to the Western Cape deciduous fruit industry

Given the relative importance of pollination to deciduous fruit production in the Western Cape Province, the region provides an important case study for this review. South Africa is a major volume fruit exporter in global terms and the industry is valued at ZAR9800 million per year.[89,90] There is 77 805 ha under deciduous fruit production in South Africa and a little over half this area is concentrated in the Western Cape.[89] Deciduous fruit growers are largely dependent on managed honeybees for pollination (specifically for apples, plums, pears and apricots).[39] Approximately 87% of the honeybee hives in the Western Cape are used for pollination services[82] and large commercial beekeepers transport their hives hundreds of kilometres to provide pollination services to the industry[82,85].

The Western Cape forms part of the Cape Floristic Region (CFR) – an area of distinctive biological diversity and rich in endemic species.[91-93] It is currently estimated that 30% of the CFR has been transformed through agriculture, invasion by alien vegetation and urbanisation.[91,92] The CFR is globally recognised as a significant centre of diversity for bees, one of the most important pollinator groups.[94] Although agriculture in this region abuts natural vegetation, the contribution of other pollinators from natural vegetation appears limited, but has not been sufficiently quantified (Table 1).

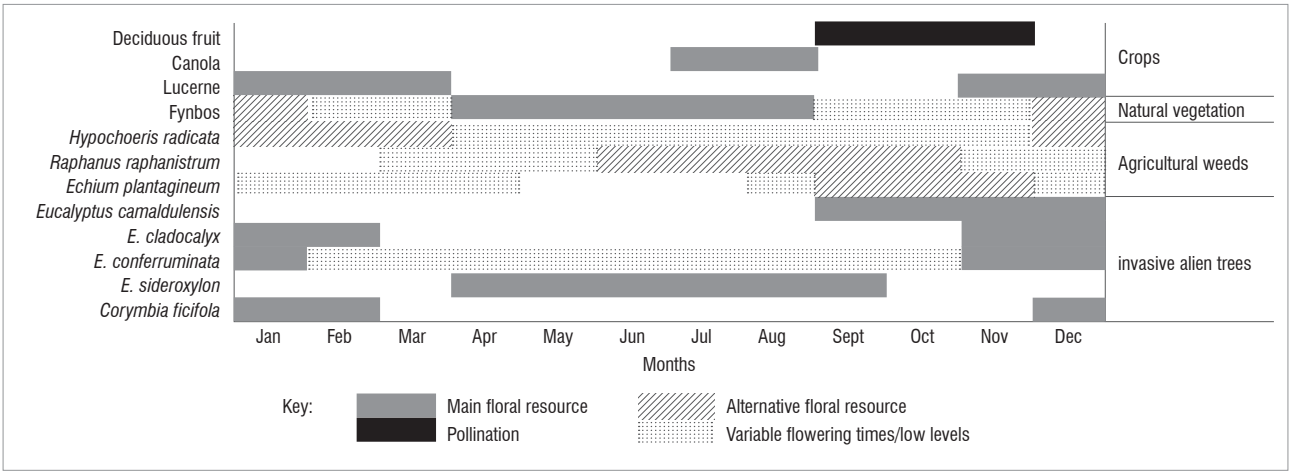
Approximately 30 000 managed hives are required to provide pollination services to the deciduous fruit industry in the Western Cape.[88] On average, each hive can provide 1.7 pollinations (the number of times a hive of suitable strength is used for pollination in crop fields), so that, on average, 51 000 pollinations are supplied each year. Each crop requires different stocking rates of hives to ensure pollination; for example, apples require 2 hives/ha and plums 6 hives/ha.[70,88,95] It has been estimated that deciduous fruit producers in the Western Cape require on average 42 000 pollinations a year.[88] Based on these figures, there is currently approximately a 20% surplus; however, it is unknown if this surplus provides for all possible contingencies, specifically in the light of potential disease outbreaks (e.g. the recent outbreak of the bacterial disease American foulbrood[84] in 2009) or increased demand in pollinator-dependent crops.[29]

Estimates of the economic value of pollination services may be used to prioritise conserving habitat for pollinators in agricultural systems.[96] There is a growing body of scientific literature on methods for valuing ecosystem services, many focusing on the value of managed honeybees as a proxy for wild pollinators, but as yet there is no consensus as to the most appropriate method.[97] Within South Africa, there have been two studies[39,95] valuing pollination services in the Western Cape Province. The direct cost of pollination services to the deciduous fruit industry is estimated as 1% of production costs,[39,89] which is a considerable underestimate of its ecological value. Turpie et al.[95] estimated the value of pollination services from managed honeybees to agricultural crops at ZAR1820 million.[95] Using a different method, Allsopp et al.[39] valued managed pollination services at ZAR46 million and wild insect pollination services at ZAR53 million (based on the 2006 exchange rate used by authors of ZAR6.74388 to USD1).[39] Notwithstanding the need to agree on valuation methods, there may be more important economic questions that have not been addressed. These include the potential increase in crop production costs if there are constraints on managed honeybee numbers (as seen in North America where demand for pollination in almond orchards resulted in significant increases in honeybee rental costs[2]), as well as examining the true cost of pollination services across the supply chain from the provision of forage to crop pollination. Such valuations may better inform land-use planning for the provision of floral resources to ensure sustained managed pollination services.

Landscape and regional level floral resources for managed honeybees

Much like wild bees, honeybees depend on native or alternative floral resources for pollen, nectar and resin when they are not pollinating crops.[3,9,98] Little research has been conducted on the use of floral resources to sustain large numbers of honeybee hives which require a variety of floral resources, depending on the time of year. From September to November, Western Cape beekeepers migrate managed hives from all over the Western Cape to the main fruit-producing areas, e.g. Grabouw, Ceres and Boland. In order to ensure they have strong colonies, beekeepers need to sustain colonies throughout the year. Beekeepers move hives around to take advantage of a range of different floral resources (Figure 1), governed by different flowering times, each fulfilling one or more function(s); for example, honey production, comb build-up, overwintering and swarm trapping (it is common practice in South Africa for beekeepers to trap wild or absconded honeybee populations).[70] Honeybees are successful as managed pollinators because they have a broad diet, forage over long distances and have the ability to locate and utilise discrete patches of resources in the wider landscape.[21] A pressing concern within the South African beekeeping industry is availability and access to suitable floral resources, in particular stands of *Eucalyptus* species for honey production and to maintain hives for pollination services.[88]

The major honeybee plants in the Western Cape, those yielding substantial quantities of pollen and nectar and which are important for colony replenishment, include indigenous vegetation (fynbos), stands of alien



Source: Adapted from Johannsmeier[70,99] and Lange et al.[100]

Figure 1: Seasonal availability of floral resources used by commercial beekeepers to sustain managed hives in the Western Cape Province.

invasive species (*Eucalyptus* spp.) and cultivated crops (canola, citrus and lucerne).[70,88] Interestingly, when looking at this managed system, we see that pollinator floral resources are derived not only from intact natural vegetation but also from human-modified vegetation. These floral resources become available over a temporal and spatial mosaic across the Western Cape. Therefore quantifying the importance of these key floral resources to maintain stable honeybee populations at a landscape or regional level is essential. It is also critically important in light of recent research showing that one of the possible causes of declines in managed hives in North America is a compromised or deficient diet.[36,101] However, it is apparent that in order to understand the complex ecological linkages that exist between the agricultural landscapes and the supporting ecosystem services for managed honeybees, an in-depth analysis is required. Fine-scale data on both the spatial and temporal nature of these resources, their extent, and their seasonal inter-dependence need to be considered when assessing the importance of floral resources.

Not all floral resources are suitable for sustaining hives. Some sites have limited carrying capacities in relation to specific floral resources as a result of nectar flows, pollen availability or seasonality.[102] Furthermore, there are management issues such as access (permission) to certain floral resources (e.g. fynbos in conservation areas[71]), vandalism of hives[70] and high pesticide use[70,88], which result in areas or sites being unsuitable or impossible for keeping honeybees.

In the following sections we discuss the key floral resources used by commercial beekeepers within the Western Cape: crops, alien vegetation, indigenous vegetation and agricultural weeds (Figure 1). Each is discussed in terms of usage, seasonal availability and abundance (area/extent).

Crops (canola, Brassica napus*) – late winter/early spring*

Mass flowering crops, including *Brassica napus* (canola), have been shown to be important for sustaining bumblebee populations in Europe.[65,103] Canola farmers, growing self-compatible varieties, may benefit from insect pollination which has been shown to increase seed set and seed quality.[70,104,105] In the early 1990s, rain-fed canola production was introduced in the winter rainfall region of the Western Cape and grown in rotation with wheat-barley-lucerne.[106] Canola has rapidly become an integral floral resource for beekeepers, particularly for those beekeepers who provide pollination services, as it allows colonies to build-up their strength prior to crop pollination. The high pollen and nectar content of canola stimulates an increase in brood production resulting in an increase foraging for pollen, which is ideal when hives are moved to farms for pollination, as active foragers should equate to better pollination.[67,70,88] Canola is an important attractant for migrating/absconding swarms, enabling beekeepers to trap new swarms (and replenish hive numbers). Currently, 45 000 ha of canola is planted in the Western Cape[107]; and this figure is set to increase.[108,109] However, canola is produced in rotation with other cereal crops on a 1-in-5 or 1-in-10 year cycle,[106] depending on individual farming practices, and not all canola fields are suitable for apiary sites because of heavy pesticide use which increases the risk of colony losses.[88,104] As a result, it is challenging to predict the availability of canola in any particular year or its contribution to apiary sites in maintaining managed honeybees for pollination services.

*Invasive alien trees (*Eucalyptus *spp.) – summer*

Following pollination of deciduous fruit crops, beekeepers move their hives to sites with stands of *Eucalyptus* trees. Beekeepers use eucalypts because they are dependable sources of pollen and nectar, particularly during summer when there is a shortage of alternatives. Eucalypts enable beekeepers to maintain honeybee colonies for pollination for the following season and produce a surplus of honey.[70]

In the Western Cape, commercial beekeepers who provide pollination services depend on three species: *E. cladocalyx, E. camaldulensis* and *E. conferruminata*. Several *Eucalyptus* species have been classified as invasive species under the *Conservation of Agricultural Resources Act (CARA) of 1983*, resulting in programmes aimed at clearing these species.[110] This clearance has raised questions regarding the benefits of these species to beekeepers (and hence agricultural production) relative to the costs associated with invasion; for example, a survey of Western Cape beekeepers found a significant dependency on CARA-listed *Eucalyptus* species.[88] The Department of Environmental Affairs, which coordinates most of the invasive clearing through the Working for Water programme, has been sensitised to these issues and has supported various initiatives to improve the scientific basis for decision-making regarding *Eucalyptus* species, including research on the use of floral resources by honeybees (http://www.sanbi.org/programmes/conservation/pollination-and-honeybees). The evidence gained from these studies is expected to influence the listing of *Eucalyptus* species under the *National Environmental Management Biodiversity Act of 2004*, which will eventually replace the CARA listings. To support the listings, as well as a more evidence-based approach to the management of *Eucalyptus* species, it is essential to have a proper understanding of the dependence of the beekeeping industry on these species. In 2004, it was estimated that the infestation of *Eucalyptus* species for the whole of South Africa (nine provinces) was 62 949 ha, of which 2264 ha was already cleared.[111] These estimates have not been provided on a provincial basis and it is therefore hard to gauge the extent and availability of *Eucalyptus* species to beekeepers in the Western Cape during the summer months. It is also not clear whether beekeepers rely on eucalypt plants that grow in high-risk areas (riparian zones, mountain catchments and high fire-risk zones) or in areas where eucalypts can be retained with a low risk

to the environment. However, based on beekeeper observations, Allsopp and Cherry[88] reported that 60% of eucalypts were found to be on land with a low risk of invasion.

Indigenous vegetation (fynbos) – autumn/winter

There are seasonal patterns in the availability of fynbos plants based on rainfall patterns across the region, with approximately 20% in flower at any time.[67,112] Commercial beekeepers use fynbos in autumn for surplus nectar flow, mainly from *Erica,* although they include Aizoaceae, Fabaceae, Proteaceae, Asteraceae and Ericaceae for pollen. [70,99] Exactly which fynbos plants honeybees use is not yet fully understood.[99] Fynbos provides honeybee colonies with sustenance during winter months, which is essential for attaining optimum strength in preparation for the following spring's pollination season.[70,99]

The broad fynbos types favoured by beekeepers include Mountain Fynbos, Western Sandveld and South Coast Fynbos, all of which fall within the CFR. It appears that a relatively high proportion of the CFR is untransformed, with about 20% formally conserved.[91,92] Approximately 50% of Mountain Fynbos, rich and abundant in *Erica* species,[113] falls within the current conservation system.[91,92] How much of this fynbos is suitable, available or utilised by beekeepers is unknown. However, the demand for accessible and suitable fynbos sites, outside of formal reserve areas, by beekeepers currently far exceeds availability.[88] Reserves currently preclude beekeepers bringing in their hives, based on the possible impact that competition from introduced managed hives would have on other pollinators and plant communities.[114] Evidence to date has shown contrasting results – some studies have found negative competitive interactions while others have found no effect between introduced managed honeybees and native bees (see references in Hudewenz and Klein[115]). In the Western Cape, Brand[116] concluded that the short-term introduction of managed hives in a fynbos reserve did not have a significant impact on increasing the overall abundance of honeybees, nor was there a detectable impact on other insect flower visitors. Despite high densities of honeybees from managed hives, Geerts et al.[117] found no significant depletion in nectar on *Protea repens*. However, high densities of honeybees appeared to interfere with sugarbirds foraging on flowers through disturbance competition.[117] Further studies would be needed to assess the impact of introduced honeybees if beekeepers are permitted access to fynbos reserves. However, providing unambiguous evidence of competition, particularly for mobile organisms, is exceptionally difficult.[66,118] Conclusive results would be further hampered by lack of baseline data on natural populations of *Apis mellifera capensis* occurring in fynbos.[114] Despite restrictions, some beekeepers seem to utilise protected areas by placing their hives on private land abutting reserves.[71]

Agricultural weeds – all year round

Annual weeds such as *Echium plantagineum* (echium), *Raphanus raphanistrum* (wild radish), *Plantago lanceolata* (plantain) and *Hypochoeris radicata* (false dandelion), which typically occur in vineyards, farmlands and road verges, provide a minor nectar flow for honeybees (see Johannsmeier[99] for a complete list of weeds).[70,99,119] Availability of weeds is highly variable[70,119] and therefore considered a minor floral resource[70,99]. However, when available, weeds can offer an important source of pollen and nectar for sustaining hives.[119] Pollen from echium and wild radish is reported to be exceptional in terms of crude protein content.[119] Because none of these plants are cultivated or grown in abundance, it would be difficult to estimate their availability as a floral resource.

Summary and future directions

In summary, our review shows the importance of pollinator richness for some crops and the concomitant need to maintain habitat within the agricultural matrix. Nevertheless, the evidence base linking pollinator richness (including indigenous *Apis*) to crop yield is still relatively weak for most South African systems. The available literature indicates that honeybees are important, but as the wild component has not been quantified, the most effective pollination services appear to be derived from a combination of honeybees and other pollinators.

In addition to the need for accurate census data on managed honeybees, assessments to determine if current supply of managed hives meets current and predicted demand for pollinator-dependent crops are needed. Given the relative importance of pollination to deciduous fruit production in the Western Cape and the current demand for managed honeybees, we highlight potential constraints to increase capacity, such as limited access and availability of suitable floral resources. It is therefore necessary to estimate the potential increase in crop production costs if there are constraints on managed honeybee numbers and to examine the true cost of pollination services across the supply chain from the provision of forage to crop pollination. Such economic evaluations may improve land-use planning for the provision of floral resources to ensure sustained managed pollination services. We conclude that understanding the dynamics of how floral resources are used will help inform how landscapes could be better managed in order to provide long-term sustainable pollination services.

Based on the synthesis presented here, we have identified the following research questions that need to be addressed in order to provide a sustainable pollination service to South African agriculture, particularly in the Western Cape:

- What is the contribution of wild pollinators, including wild honeybees, to particular crops?
- Are managed honeybees constrained by available floral resources and, if so, what does this constraint mean for crop production in South Africa?
- Where are the key floral resources in the landscape and can these be mapped and included in regional plans?
- How can landscapes be managed to optimise the use of different elements to sustain pollination services?

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Authors' contributions

A.M. wrote the first draft of the manuscript with contributions from M.R., J.J.M. and J.S.D.

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Microbial counts of food contact surfaces at schools depending on a feeding scheme

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The prominence of disease transmission between individuals in confined environments is a concern, particularly in the educational environment. With respect to school feeding schemes, food contact surfaces have been shown to be potential vehicles of foodborne pathogens. The aim of this study was to assess the cleanliness of the surfaces that come into contact with food that is provided to children through the National School Nutrition Programme in central South Africa. In each school under study, microbiological samples were collected from the preparation surface and the dominant hand and apron of the food handler. The samples were analysed for total viable counts, coliforms, *Escherichia coli*, *Staphylococcus aureus* and yeasts and moulds. The criteria specified in the British Columbia Guide for Environmental Health Officers were used to evaluate the results. Total viable counts were high for all surfaces, with the majority of colonies being too numerous to count (over 100 colonies per plate). Counts of organisms were relatively low, with 20% of the surfaces producing unsatisfactory enumeration of *S. aureus* and *E. coli* and 30% unsatisfactory for coliforms. Yeast and mould produced 50% and 60% unsatisfactory counts from preparation surfaces and aprons, respectively. Statistically significant differences could not be established amongst microbial counts of the surfaces, which suggests cross-contamination may have occurred. Contamination may be attributed to foodstuffs and animals in the vicinity of the preparation area rather than to the food handlers, because hands had the lowest counts of enumerated organisms amongst the analysed surfaces.

Introduction

The National School Nutrition Programme (NSNP) is a South African school feeding scheme aimed at alleviating poverty and improving learning capacity of children through school feeding.[1,2] The feeding scheme was introduced nationwide in 1994 and is funded through a provisional grant that is transferred to provinces according to the *Division of Revenue Act* as well as directives from the Department of Basic Education (DBE) and the National Treasury (Grant Framework 2010/11).[3,4] The DBE coordinates and oversees the programme, ensuring adherence to policies and relevant legislation through monitoring. The Provincial Education Departments are tasked with the procurement of goods and services for the NSNP while adhering to conditions stipulated by the Grant Framework.[3,4] Ntuli[5] explains that schools are funded according to a national system of ranking and funding of schools referred to as a quintile. The DBE ranks schools within quintiles according to this system, taking into account the socio-economic circumstances (such as inequality and poverty) of learners and schools. For example, schools rated at the lowest quintiles (1 and 2) receive more funding than schools ranked higher based on the Norms and Standards for Funding Schools.[5] The schools targeted for the NSNP are primary and secondary schools ranked in quintiles 1 to 3.[3]

Similarly to other confined environments, the school environment favours direct transmission of diseases among individuals; foodborne illnesses are therefore a concern in the administration of the NSNP in schools. School environments are particularly prone to epidemiological outbreaks as a result of the nature of inter-personal dynamics.[6] The risk is augmented by the introduction of an additional variable that supports microbial proliferation, such as food. Food, water and surfaces may be contaminated with considerable quantities of pathogenic microorganisms during food preparation and consumption, which may result in illnesses.[7] Young children are particularly vulnerable to pathogenic bacteria and are at risk of developing pathological conditions, including haemolytic uremic syndrome and osteomyelitis, when infected with pathogens such as *Escherichia coli*, *Staphylococcus aureus* and some opportunistic pathogens upon consumption of contaminated foods.[6,8] Possible outbreaks amongst school children are of concern as illnesses from pathogenic bacteria may last up to 3–5 days.[8,9]

The main factors that lead to foodborne illnesses are improper time or temperature control, poor personal hygiene of the food preparer and cross-contamination.[10,11] Blackburn[12] describes food contact surfaces and food handlers' hands as significant potential vehicles of pathogens. These surfaces have been found to have a significant contribution to cross-infection and pose a constant risk of microbial transfer.[13] The treatment of such surfaces through cleaning and sanitisation is important in reducing the number and type of potential pathogens.[14] Frequent sanitation (cleaning and disinfection) is the most effective control in ensuring the microbiological safety of foodstuffs.[12] It is also critical to ensure that cleaning is achieved to a degree that substantially reduces cross-contamination and ensures the integrity of the food.[15,16] Failure to effectively clean and disinfect these surfaces is a risk factor in the dispersal of foodborne pathogens.[17]

In addition to cleaning and sanitising, the application and evaluation of monitoring methods is necessary for ensuring the efficiency of sanitation procedures in the food-processing environment.[18] Furthermore, microbiological testing plays an important role in identifying potential threats and their sources as well as in evaluating the effects on the final product. Assessments may further assist in developing and implementing preventative measures[12] and may promote food safety in school feeding schemes such as the NSNP. The NSNP was introduced to serve food to pupils across the country, mainly among poverty-stricken communities. However, because the programme is rolled out at schools that are primarily deficient of proper catering facilities, the maintenance of hygiene may be questionable during the administration of the programme. It was envisaged that the current study would provide information, through the use of microbiological methods, on the general hygiene of surfaces in contact with

foodstuffs during the administration of the NSNP at participating schools in Bloemfontein, South Africa.

Materials and methods

Sampling protocol

Ten schools were randomly selected from amongst beneficiaries of the NSNP in the Bloemfontein area. The sample represented schools in quintiles 1, 2 and 3, and included primary, intermediate, combined and special schools from the rural and urban regions. To maintain confidentiality, each school was assigned an alphabetical code. For each school, representative microbial samples were collected from three previously cleaned surfaces that had come into contact with foodstuffs, namely the preparation surface, and the hand (thumb, forefinger, middle finger and palm of dominant hand) and apron of the food handler. In total, 120 surface samples were collected. All samples were transported on ice to the laboratory where investigations were conducted without delay. All analyses were performed in triplicate.

Sampling procedure and microbial analysis

Microbial samples were collected and quantified using 65-mm Rodac plates (Lasec, Cape Town, South Africa). The media were prepared according to the manufacturers' instructions, followed by preparation of the contact plates according to the method proposed by Ness[19]. The selected agar media were used to investigate total viable counts (TVC), total coliforms, *E. coli*, *S. aureus* and yeasts and moulds on the dominant hand of each food preparer. Four contact plates (containing the respective agar media) were used for each of the three food contact surfaces – the preparation surface and the food handler's hand and apron.

Total viable counts

Plate count agar (Merck, Johannesburg, South Africa) was used for the enumeration and detection of TVC and plates were incubated at 36 °C for 24–48 h.[20]

Total coliforms and *Escherichia coli*

Total coliforms and presumptive *E. coli* were enumerated using Chromocult coliform agar (Merck) and incubated at 36 °C for 24–48 h. Typical coliforms were salmon pink to red in colour, whilst *E. coli* presented as typical dark blue to violet colonies.[21]

Staphylococcus aureus

Baird-Parker agar (Merck) supplemented with egg yolk telluride emulsion was used for the enumeration of presumptive *S. aureus* and plates were incubated at 36 °C for 24–48 h. Grey–black shiny colonies with white margins surrounded by clear zones were identified as *S. aureus* colonies.[22]

Yeasts and moulds

Potato dextrose agar (Merck) plates were incubated at 25 °C for 3–5 days for the enumeration of yeasts and moulds.[23] Typically, yeasts exhibited cream-coloured to white colonies and moulds appeared as filamentous colonies of various colours.

Analysis of data

Upon differentiation of microbial colonies on appearance and colour, the colonies were counted using a Symbiosis aCOLade colony counter (Vacutec, Johannesburg, South Africa) and expressed as colony-forming units (CFU)/cm^2. All results were evaluated using the British Columbia Centre for Disease Control (BCCDC) Guide for Environmental Health Officers and classified according to the following criteria: satisfactory (<5 CFU/cm^2); acceptable (5 CFU/cm^2 to 10 CFU/cm^2); and unsatisfactory (>10 CFU/cm^2).[24] The guideline provided by the BCCDC articulates well with the units and best described assumptions used in this study. In addition, the BCCDC guide was found to cover significantly more categories than the South African R.918 of 1999 which offers only the guideline of 100 CFU/cm^2 for surfaces.[25] For the purposes of this study, counts of over 100 colonies – as determined by the probable number of volumes which produced a matrix of growth rather than individual countable colonies – were labelled as 'too numerous to count' (TNTC). Significance was determined using an unpaired *t*-test and was defined at a *p*-value of 0.05.

Results and discussion

As shown in Table 1, in terms of TVC, 80% of all the surfaces sampled had counts that were TNTC. For total coliforms, 60% of the counts obtained from hands were satisfactory while 20% were acceptable and 20% were not detectable. For preparation surfaces, 40% of coliform counts were satisfactory and 20% were acceptable, whereas 30% were unsatisfactory and 10% were not detectable according to the BCCDC guide. Furthermore, 80% of the apron counts were satisfactory, 10% were acceptable and 10% were not detectable for total coliforms. For hands and aprons, 50% and 90%, respectively, of *E. coli* counts were satisfactory; the remaining counts of both surfaces were not detectable. Additionally, 60% of the *E. coli* counts for the preparation surfaces were satisfactory, 10% were acceptable, 20% were unsatisfactory and 10% were not detectable (Table 1). For hands, 80% of the *S. aureus* counts were satisfactory, 10% were acceptable and 10% were not detectable, whereas for preparation surfaces, 60% were satisfactory, 20% were acceptable and 20% were unsatisfactory, and all detectable counts (90%) were satisfactory for aprons. According to the BCCDC guidelines, for hands, 60% of the counts of yeasts and moulds were satisfactory, 20% were acceptable, 10% were unsatisfactory and 10% were not detectable. For the preparation surfaces, 40% of the counts were satisfactory, 50% were unsatisfactory and 10% were not detectable; and 40% of the counts were satisfactory and 60% were unsatisfactory for aprons (Table 1). Of the three surfaces analysed, preparation surfaces enumerated the highest counts of total coliforms, *E. coli* and *S. aureus*. Aprons yielded the highest counts of yeast and moulds while hands had the lowest counts of these organisms.

The objective of the TVC measure is to provide a general indication of the number of organisms present in the sample, thereby indicating the general hygiene status of the sample[26], whereas the presence of coliforms indicates a risk of occurrence of pathogens and is therefore a measure of the effectiveness of sanitation programmes[27,28]. In addition, coliforms, including *E. coli*, form part of the natural microbiota in the intestinal tracts of warm-blooded humans and other animals. Their presence generally indicates faecal contamination.[20,29,30] Pathogens may be present in faeces in concentrations of between 10^4 and 10^{11} per gram, indicating that even a tenth of a milligram of faeces on the skin may contain up to a million infectious bacterial cells.[8] A higher contamination of food by hands than that by surfaces was observed during a study by Taulo et al.[7] in which they found that the transfer of *S. aureus* was significantly higher than that of *E. coli*. The authors postulated that although the traditional cooking of thick porridge inactivated *S. aureus* and *E. coli*, the porridge could have been contaminated with the bacteria by hands and wooden ladles during serving. During the present study, however, the hands of food handlers yielded lower counts of all enumerated organisms (total coliforms, *E. coli*, *S. aureus* and yeasts and moulds) than did the preparation surfaces. This finding suggests that the sources of contamination are more likely the foodstuffs and animals (particularly rodents in rural areas) in the vicinity of the preparation area rather than the food handlers.

Although some visual differences were observed among the contamination levels of hands, preparation surfaces and aprons, there was no statistically significant difference in microbial counts among these food contact surfaces ($p \geq 0.05$). Thus, it appears that considerable cross-contamination occurred among the surfaces with no evident differences in, for example, cleaning regimes. Additionally, this observation points to the absence of a practice that isolates these surfaces from one another so as to prevent or hinder cross-contamination. Other factors which may lead to the contamination of surfaces include the use of contaminated water and shortcomings in surface sanitation methods, such as an incorrect detergent to water dilution ratio or an inadequate contact time

Table 1: Counts of various organisms from food contact surfaces of schools in Bloemfontein participating in the National School Nutrition Programme

School	Surface	Bacterial counts (CFU/cm²)				
		Total viable counts	Total coliforms	*E. coli*	*S. aureus*	Yeasts and moulds
A	Hands	TNTC	2.50	0.50	0.50	1.33
	Table	TNTC	9.88	4.13	1.47	3.31
	Apron	12.50	3.17	1.00	1.57	2.73
B	Hands	TNTC	0.40	ND	4.00	0.50
	Tray	TNTC	ND	ND	1.00	1.00
	Apron	TNTC	1.44	0.88	0.70	TNTC
C	Hands	TNTC	1.00	0.50	0.40	TNTC
	Sink	TNTC	1.17	1.25	0.60	TNTC
	Apron	TNTC	1.44	0.60	ND	TNTC
D	Hands	TNTC	1.00	0.50	3.67	7.00
	Table	TNTC	TNTC	7.00	12.19	TNTC
	Apron	TNTC	9.19	2.44	2.60	TNTC
E	Hands	TNTC	7.93	2.62	4.80	2.25
	Tray	TNTC	4.75	4.56	5.88	3.94
	Apron	TNTC	1.42	0.29	2.38	TNTC
F	Hands	TNTC	4.00	2.63	1.25	2.33
	Table	TNTC	13.75	11.88	4.31	TNTC
	Apron	TNTC	2.00	1.00	1.33	0.78
G	Hands	TNTC	1.50	ND	2.20	3.71
	Tray	TNTC	TNTC	TNTC	TNTC	TNTC
	Apron	4.06	1.70	1.40	2.77	TNTC
H	Hands	0.83	ND	ND	1.00	0.50
	Table	TNTC	2.75	1.00	1.20	ND
	Apron	TNTC	1.10	1.00	3.57	1.80
I	Hands	0.17	ND	ND	ND	ND
	Table	TNTC	6.13	1.00	1.13	17.19
	Apron	1.00	ND	ND	0.86	0.88
J	Hands	3.80	5.17	ND	5.57	5.75
	Table	TNTC	2.69	1.25	5.14	5.75
	Apron	TNTC	2.00	1.43	4.17	TNTC

TNTC, too numerous to count (>100 colonies); ND, not detectable using the current method.

for disinfectants.[7,31] A study by Mosupye and Von Holy[32], in which they assessed the facilities of street food vendors in Johannesburg, South Africa, indicated high aerobic plate and coliform counts from surface samples collected from a vendor who did not clean the food preparation surface during preparation whereas fewer counts were observed from a vendor who constantly cleaned the surface using a dishcloth. The main source of contamination by yeasts and moulds is the environment, particularly the air.[33] Preparation areas of the majority of the schools

were predisposed to becoming dusty because of a lack of proper kitchen facilities and ventilation which may contribute to contamination of surfaces and foodstuffs.

Illness-causing bacteria may survive on various surfaces around the kitchen, including hands, utensils and cutting boards. The US Centers for Disease Control and Prevention[34] recommend that hands be washed for 20 s with soap and running water, followed by scrubbing at the back, between fingers and under the nails. Furthermore, for utensils and cutting boards to be sufficiently sanitised, hot water with detergent and a sanitising (bleach) solution should be used. Although not sufficient, handwashing alone significantly reduces levels of bacteria load. As a result of a lack of resources and infrastructure limitations, the majority of the schools participating in the NSNP did not have handwashing facilities within the food preparation areas, nor did they have readily available hot water. The water taps, particularly at schools located in rural areas, were located outside and were not in the vicinity of the food preparation areas. Snyder[35] found that rinsing hands in a bucket of acetic acid solution prepared with tap water (at room temperature) and distilled vinegar (5% acetic acid) significantly reduced *E. coli*. The solution proved to maintain effectiveness after several hand rinses (less than 1 CFU/10 mL was observed in the solution after 24 h).

In addition to cleaning practices, the nature of the contact surfaces may have an impact on contamination levels of foods with microorganisms. According to the South African Health Regulations (R.918 of 1999), the surface which comes into direct contact with food should be made of smooth, rust-proof, non-toxic and non-absorbent material that is free of open joints, chips or cracks.[25] Generally, smooth surfaces are easier to clean than irregular surfaces. Surfaces which may crack, splinter, scratch and distort provide harbourage for microorganisms and prevent proper cleaning and sanitising.[14] Additionally, organic material from food residues may reduce the effectiveness of disinfectant by either reacting chemically with the disinfectant or inhibiting the physical access of the disinfectant to the targeted microbiota.[36,37] The high levels of organic material likely to be present on food contact surfaces increase the hydrophilicity of the surfaces; bacteria attach more readily to hydrophilic surfaces, but struggle to remain attached to hydrophobic surfaces.[38-40] The majority (60%) of the schools sampled during the current study prepared food on wooden table tops while the other 40% used plastic surfaces (data not shown). According to Abban et al.[40], stainless steel is the material of choice in the food-processing environment. However, plastic cutting boards may also contribute greatly to cleanliness and minimise cross-contamination.[14] According to Entis[36], the cutting board is the most susceptible of all the kitchen utensils to contamination and the porous nature of wood leads to concerns regarding the potential for cross-contamination. The wooden food preparation surfaces employed by schools in this study were irregular and hydrophilic with distinct flaws, thus creating a favourable habitat for microorganisms to attach and grow. Conversely, it is noteworthy that the preparation surface (which was made of plastic) used by school G had counts that were TNTC for all enumerated organisms (Table1), which indicates that the method of sanitation may have a greater impact on the hygiene of surfaces than the nature of the material from which the surface is made.

Conclusions

Generally, in the present study, we found that preparation surfaces had the highest counts of the detected pathogens, whereas hands had the lowest counts of microorganisms. However, a significant difference in the microbial loads amongst the food contact surfaces could not be established. These findings suggest that although the surfaces may not have been sources of contamination, opportunity for cross-contamination among surfaces may exist because of a lack of surface isolation and shortcomings in cleaning regimes. To prevent cross-contamination, all equipment and working surfaces must be thoroughly washed with hot water and detergent after being used to prepare raw foods. In this regard, sanitation programmes have proved to be cost effective and simple to implement and to significantly reduce microbial contamination.[12,41] According to DeVere and Purchase[17], the traditional two-step detergent and rinse cleaning method has been substituted with various antibacterial products that have been developed to provide fast and effective cleaning to food preparation areas. Household bleach (sodium hypochlorite) is an inexpensive and readily available agent for sanitising preparation surfaces.[36] Individuals may carry thousands of bacteria (such as *S. aureus* and *Salmonella* bacteria) on the surface of their skin and are usually not aware that they may be carriers of food pathogens.[41] The importance of washing hands, particularly after using the toilet, should not be overlooked. With the various opportunities for food to become contaminated during production and preparation, monitoring procedures, which include microbial analyses, may contribute to ensuring the safety of foodstuffs.

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Authors' contributions

W.H.G. was the project leader and made conceptual contributions. R.J.F.L. made conceptual contributions and was responsible for the experimental and project design. N.N. performed all of the experiments and wrote the manuscript.

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Factors affecting graduation and student dropout rates at the University of KwaZulu-Natal

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This paper aims to introduce into the literature a competing risks methodology that can be used to help identify some student-specific and/or institutional factors which may be influencing the type of outcome experienced by a student when they leave the university system. Focusing on the length of time that it takes students to graduate or drop out from their studies, this new methodology was applied to a database comprising all students enrolled for a degree at the University of KwaZulu-Natal between the years 2004 and 2012. Financial aid and residence-based accommodation were found to help students who will eventually graduate to do so quicker in terms of the number of credit points that they have to repeat. These same factors, however, also cause someone who will eventually be excluded on academic grounds to linger longer in the system. By focusing on the number of extra credit points that it takes to reach a particular exit point, this paper introduces into the literature a new measure whose use will help to overcome some of the more obvious problems that can occur when one uses calendar time to measure the length of time that it takes to reach a particular exit point.

Introduction

The effects of race, gender and poverty, among other socio-economic variables, on student dropout or graduation from a higher education institution have been well documented in the literature.[1,2] However, in almost all of these studies, a standard survival analysis based approach was used to analyse the problem. An assumption of stochastic independence amongst the possible outcomes that can occur is made, with these factors then fed into a hazard function which in turn generates a probability distribution for determining the time to dropout or graduation of that particular student. Such an assumption of stochastic independence is often questionable, particularly in our setting, in which a variety of individual and university-specific forces may be interacting with each other and pulling a student towards one or other type of exit point from the university system. The main purpose of this paper is to introduce into the literature a new competing risks based methodology which can then be used to compare the time that it takes to graduate with that of two other types of exit: a voluntary dropout where a student with a good academic record has decided possibly to change universities or an involuntary dropout where the student has been excluded on academic grounds from further study because of poor performance.

There is potentially a large number of factors that may have a causative effect on the length of time that it takes students to graduate or dropout from university-based studies. Some of these factors – such as a student's age, gender, race and financial status – may be more easy to measure than others, such as a student's level of motivation for studying, the level of academic integration and the type of living conditions that exist at the university where they want to study. With suitable proxies for some of these unobservable constructs already developed, most of the research work that appears in the literature attempts to feed these covariates into a predictive model with a statistical procedure then being used to determine the significance (or validity) of any relationship that one observes. Being essentially data-driven, one may argue that each one of the above approaches lacks a foundation that can be fully supported by an underlying socio-economic based theory. In order to bridge this gap, Tinto[3] developed an approach for modelling student dropout behaviour that focuses on the quality of interaction that exists between a student and the higher education institution at which they enrol. More specifically, the individual attributes of each student (such as their underlying ability, race and gender), together with some family background characteristics (such as their parent's level of education) and pre-university schooling experiences (such as the grades that they have achieved), help to form a level of initial motivation that is then forced to interact with a set of institutional experiences within the university. Tinto[3] divided these institutional experiences into two distinct components: (1) an academic component comprising the academic performance of the student and their interaction with faculty or staff members within the university and (2) a social component comprising their extracurricular activities and peer group interactions. The extent to which these forces can successfully integrate with each other helps to determine whether students persist with their studies or leave the university, whether leaving is on a voluntary basis (because they want to enrol at another institution) or an involuntary basis (because their poor results have led to them being permanently excluded on academic grounds from the university). When interpreted in this manner, one deals with a decision-making process that fits more comfortably into a competing risks paradigm in which a variety of socio-economic forces are pulling the student towards one or other mutually exclusive set of possible outcomes.

Why study this problem?

The poor performance of students entering South Africa's higher education system has been well documented in the literature. A 2007 study by Scott et al.[4] found that 25% of all students drop out in their first year of study, with only 21% being able to graduate within the minimum amount of time that has been allocated for the degree. A study by Letseka and Maile[1] placed South Africa's overall graduation rate amongst the lowest in the world (15% across all South African based universities). In particular, their report suggested that a lack of available financing and the existence of a significant articulation gap between secondary education and higher education were the main causes for such a high dropout rate. The report also highlighted another fact that has been well established – that African students are generally under-represented at all universities, with nearly 70% of these students indicating

that they were the first of their generation to be afforded an opportunity to attend university.

In a 2013 report released by the Council for Higher Education[2], it was found that only one in four students was able to graduate from a contact-based institution within the minimum prescribed period set aside for that degree. A total of 58% of students attending a contact-based institution needed an extra 2 years to complete a 3-year degree, with this figure increasing to an alarming 91% for a non-contact based institution. When looking at race, the report stated that the completion rate for white students was on average 50% higher than that for non-white students. It was also found that the performance of students in the Engineering, Commerce and Business Management disciplines had declined sharply when compared with that of a 2000 study. Students enrolling in the Health Sciences, Education and Social Sciences, however, had shown a small improvement when compared with that of the 2000 intake. With this context in mind, it is important that we try and identify an appropriate set of socio-economic and academic factors that may be exacerbating what has become a 'revolving door' for many students who gain access to a higher education institution but then fail to succeed in their studies.[5] However, almost all these studies focused on linking one or more of the above factors to dropout using a standard survival analysis based approach that feeds these factors into a hazard function which in turn generates a probability distribution for predicting the time to dropout of that particular student. No cognisance is taken of the fact that external socio-economic and institutional forces may exert an influence on the type of exit from a university that a student experiences.

The competing risks methodology

The competing risks methodology that has been developed in the statistical literature is ideally suited for modelling a decision-making process where we have a set of underlying but possibly different socio-demographic forces pulling a student towards one or other particular outcome. Given a medical setting, for example, one may be concerned with identifying potential factors that affect the length of time that it takes for someone to die from one of a mutually exclusive set of possible causes; for example, death from a stroke, death from cancer or death from a liver-related disease. The occurrence of one type of death will obviously prevent any one of the other events from occurring. Environmental and genetic factors may, however, be pushing the individual towards one or more possible causes of death. By incorporating this information into one's analysis, one is separating a competing risks problem from that of a more typical survival analysis based problem in which the focus rests solely on a primary cause of death with the other potential causes of death (and their effect on the primary cause) not being explicitly modelled (as potential competitors for the final outcome on an individual) in the model-building process.

Although the language and application of the competing risks idea was originally developed for applications in the health, medical and actuarial sciences, some applications have appeared in the social science literature. These applications include that of De Graaf and Kalmijn[6] who used the idea to study what happens to couples after they have divorced – whether they stay single, remarry or enter into a cohabiting relationship can be viewed as being determined by a set of socio-economic forces that are competing amongst each other for the final outcome of that individual. Diermeier and Stevenson[7] used the theory to determine how long a government tenure will last and whether this end point will result in a reshuffling of ministers in the cabinet or the calling of a new election. Gordon[8] used the theory to determine how long a criminal investigation will last, noting that the end point in this investigation may result in a decision to prosecute or to abandon the case. Researchers in labour markets have used the theory to determine how long people stay in their jobs – noting that one could leave a particular job because of a promotion or demotion within that organisation, a dismissal or even a retirement date being reached. Social scientists studying international conflicts have used the theory to determine how long a conflict will last, particularly for determining whether the conflict will end in a negotiated peace process, a conquest or a stalemate.

Given our education-based setting, let T denote a 'survival time' representing the number of extra credit points that are taken (repeated) by a student before leaving the university. Calendar time has generally been used to measure the length of time that it takes for a student to graduate or drop out from their studies. Attempting to use this measure becomes a difficult bookkeeping exercise when, for example, a student is forced to temporarily suspend their studies because of some family obligation and then returns at a later stage to complete their studies. Let x be a vector containing student-specific covariates, such as their age, gender, race and financial status, which hopefully has an effect on the outcome of T observed. The objectives of this paper can now be summarised as:

1. To compare the time that it takes to graduate from a particular university with that of two other types of exit, namely (1) a voluntary dropout, that is, a student with a good academic record decides, for example, to change universities and (2) an involuntary dropout, that is, a student who is excluded on academic grounds from further study at that university because of poor performance.
2. To ensure that the analysis incorporates the idea that a set of underlying socio-economic and university-based factors are pushing the student towards one or another particular outcome.
3. To determine if any socio-economic, student-specific or university-specific factors can be identified that affect the type of exit that a particular student will experience. In particular, this determination will be done by estimating cumulative incidence functions for each one of the above exit types (eventual graduation, a voluntary dropout or a forced academic exclusion).

A detailed discussion of the competing risks methodology can be found in Beyersmann et al.[9] and Kalbfleisch and Prentice[10] or in introductory articles[11-14]. More formally,

$$CIF_1(t, x) = \mathrm{P}(T \leq t, \text{ student graduates} \mid x)$$

defines a cumulative incidence function (CIF) that one can associate with a student who will eventually graduate from their studies. Setting $t=35$, an outcome of the form

$$\mathrm{P}(T \leq 35, \text{ student graduates} \mid x) = 0.40$$

implies that a student with an associated set of covariate values x has a probability 0.4 of eventually graduating and achieving this outcome without doing more than 35 extra credit points before completing their degree. Plotting $CIF_1(t, x)$ against t will produce a CIF plot for graduation that forms the focus of much of the discussion in the results section of this paper.

A CIF for those students who are forced to drop out of university (on an involuntary basis) because they have a poor academic record is given by

$$CIF_2(t, x) = \mathrm{P}(T \leq t, \text{ student is excluded} \mid x)$$

Similarly, a CIF for those who will eventually drop out on a voluntary basis from their studies can be given by

$$CIF_3(t,x) = \mathrm{P}(T \leq t, \text{ student drops out voluntarily} \mid x)$$

Because each student comes with a very specific set of student-based covariates such as their age, gender and race, which we have coded in the vector x, their effect on each of the above CIFs can now be explicitly modelled by introducing the concept of a jth – a cause-specific sub-distribution hazard function into the model:

$$\overline{h}_j(t,x) = \overline{h}_{0j}(t)e^{x'\beta j} \quad j=1,2,3$$

and allowing this hazard function to be fed into $CIF_j(t,x)$ in the following parametric manner:

$$CIF_j(t,x) \equiv \mathrm{P}(T \leq t, \mathrm{C} = j \mid x) = 1\text{- } exp\ \{-\int_0^t \overline{h}_j(s,x)\, ds\} \qquad \text{Equation 1}$$

Having obtained a suitable set of estimates $\hat{\beta}_j$ for the parameter vector β_j that appears in $\overline{h}_j(t,x)$, whether or not the k'th factor variable in x significantly affects the CIF associated with exit-type j, requires the

computation of what is called a sub-distribution hazard ratio (SHR) for this factor k and exit type j, namely

$$SHR_{jk} = e^{\beta jk},$$

with the following interpretation then given to the result that one observes: if SHR_{jk} is significantly greater than one, then any increase in the value of this kth factor variable will produce a higher CIF value for that exit type j. To illustrate this concept further, assume that the kth factor variable refers to gender, with males coded 1 and females coded 0. If the data set on which this analysis is based produces an estimated SHR value for exit type 1 of 2.34, then, because this value is greater than one, males in this data set have a higher CIF value associated with exit type 1 than females – this result is true regardless of the number of credit points t that they have to repeat. Stating this result in another way, males experience exit type 1 more quickly (on average) than females. If this SHR value is less than 1, then females experience exit type 1 more quickly (on average) than their male counterparts.

A case study

At the University of KwaZulu-Natal (UKZN), each course is assigned a value of 16 credit points, such that on completion of a 3-year degree a total of 384 credits have been awarded. As a response variable T for this paper, the total number of credit points that a student had to repeat before leaving UKZN was recorded together with another response variable for the type of exit. In particular, it was noted whether students had graduated when the data collection period ended in 2012, had been excluded on academic grounds or had dropped out on a voluntary basis (possibly to transfer to another university). Students who were still busy with their studies when the period of observation was completed were treated as being right censored in the analysis that was done.

Dropping out on a voluntary basis may also be associated with a poor academic record (i.e. a student may choose to leave before being excluded on academic grounds). Therefore, to identify only true voluntary dropouts in our data set, any person who had chosen to drop out but who had an academic record reflecting that they had not failed more than 64 credit points was regarded as a voluntary dropout. Students who had dropped out and who had an academic record reflecting that they had failed more than 64 credit points were removed from the data set, primarily because it could not be determined with absolute certainty whether the cause of the dropout was non-academic in nature, such as a funding- or family-related problem, or whether dropping out was a precursor to exclusion for academic reasons. A total of 324 students fell into this category. Ideally one would have liked to ask each student their reason for dropping out from their studies but the logistics behind such a data collection process made such an approach impossible to implement.

Given that different socio-economic and institutional forces may be exerting an influence on those students who drop out on a voluntary basis and those that are excluded on academic grounds, it was important to make a distinction in the analysis between these two types of dropout.

The data collection period

Over the period 2004–2012, the progress of all students entering UKZN was monitored from their date of registration until they had either completed their degree or left the university because of academic exclusion or as a voluntary dropout. A total of 56 079 enrollment records were collected; 17 602 students were still busy with their studies when the period of observation ended in December 2012. The four students who graduated from the 2011 first-time entry cohort would have entered UKZN as second-year students, which would have allowed them enough time to have graduated when the study period ended in December 2012.

The following covariates were also collected: the year in which each student first registered; a 0/1 indicator variable indicating whether (or not) the student was male (male=1); a collection of four 0/1 indicator variables indicating whether the student was African (or not), a student from the Coloured community (or not), an Indian student (or not) or a student from the white community (or not); a 0/1 indicator variable indicating whether the student was in residence during their first year of study; a 0/1 indicator variable indicating whether the student had received some form of financial aid in their first year of study; and a matric point score measuring the quality of pass that a student obtained for all their school-leaving subjects.

A breakdown of the student demographics at UKZN based on race and gender is given in Table 2. The total number of students that received some form of financial aid in their first year of study and/or some form of residence-based accommodation is given in Table 3.

Results

In a competing risks based methodology one needs to look at the CIFs that are generated by each competing event type – in this case, eventual graduation, voluntary dropout and academic exclusion. The SHRs values associated with each factor (and each event type) then help one to determine whether this factor affects the occurrence of the event type that is being considered in a statistically significant way.

Students who eventually graduate

Figure 1 is a plot of the number of credit points repeated by those 23 654 students in our data set who were able to eventually graduate from UKZN. As one would expect, the curve is sharply skewed to the left because these students generally did not need to repeat a large number of credit bearing courses.

Table 1: A breakdown of student outcomes according to their year of first enrolment at the University of KwaZulu-Natal

Year of first enrolment	Graduated (%)	Excluded (%)	Voluntarily dropped out with a good record (%)	Still studying (%)
2004	65.45	27.36	6.75	0.43
2005	71.05	20.90	7.22	0.82
2006	72.15	18.63	7.51	1.64
2007	68.71	20.48	7.26	3.54
2008	64.95	19.02	6.54	9.49
2009	41.92	23.14	5.83	29.12
2010	16.43	20.52	6.49	56.68
2011	0.06	13.42	5.76	80.77
2102	0	10.85	9.72	79.43
Total	42.15	19.45	6.98	31.39

Table 2: A breakdown of student demographics at the University of KwaZulu-Natal, according to race and gender

	Male (%)	Female (%)
African	28.89	22.87
Coloured	0.18	0.79
Indian	21.79	18.60
White	5.40	4.87
Total (*n*)	32 446	23 633

Table 3: A breakdown of student demographics at the University of KwaZulu-Natal, based on financial aid and/or residence-based accommodation

	Residence-based accommodation (%)	No residence-based accommodation (%)
No financial aid	50.37	7.18
Financial aid	23.09	19.34

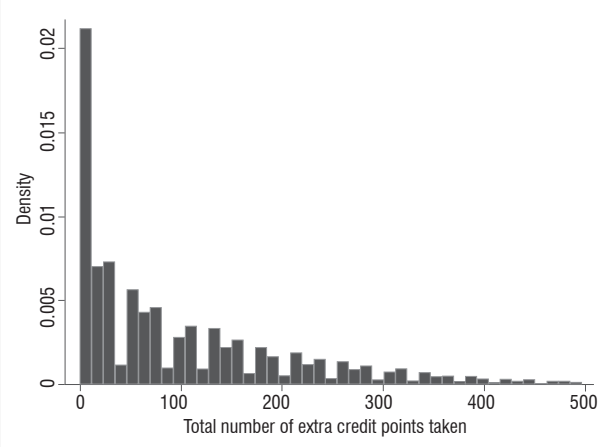

Figure 1: Total number of extra credit points for those who eventually graduated.

Treating academic exclusion and voluntary dropout as competing risks for this event type, the results that appear in the second column of Table 4 were obtained using the Stata version 13 package. The column labelled 'SHR for eventual graduation' contains the estimated sub-distribution based hazard ratios for each covariate-based factor which can be interpreted in the following manner: if the SHR value is significantly greater than one, then any increase in the value of that covariate will produce a higher incidence of eventual graduation for students in that group of students who will eventually graduate. Noting that a student in residence would have been coded a 1 in our data set and those not in residence would have been coded a 0, the statistically significant SHR value of 1.2349 that we have obtained for the residence-based covariate indicates that those who have some form of residence-based accommodation are graduating (on average) more quickly (i.e. repeating fewer credit points) than students who have no form of residence-based accommodation. The stress associated with finding accommodation, or the benefit of being able to associate more easily with one's peers because one has residence-based accommodation, may provide an explanation for this result.

Having some form of financial aid and having a higher matric point score are also helping students in this cohort to graduate on average more quickly in terms of the number of credit points that they are having to repeat. Gender and race also seem to play a significant role – African males take longer on average to graduate than any other race or gender group. Although the above results are well known in the literature, the analysis allows us to study the effects of these factors in a modelling framework in which a set of mutually exclusive events compete for the final outcome.

Students who are excluded on academic grounds

Treating voluntary dropout and eventual graduation as competing risks for this event type, produced the results that appear in the fourth column of Table 4. As one would expect, because students are academically excluded because of a poor academic record, the histogram that appears in Figure 2 has a mean and interquartile range that are much higher than those for graduating students (Figure 1).

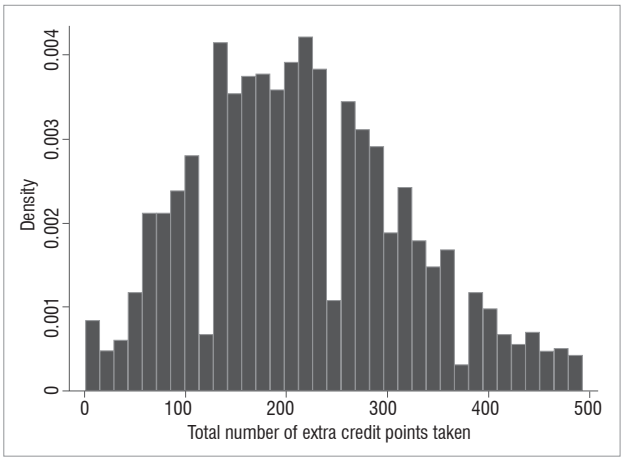

Figure 2: Total number of extra credit points for those who were eventually excluded on academic grounds.

Using a 5% level of significance, being of African origin and/or male seems to shorten the length of time – in terms of extra credit points – that students linger in the system before dropping out as an academic exclusion. Having some form of financial aid and staying in residence increases the length of time that students linger in the system before dropping out as an academic exclusion. An interesting anomaly is therefore observed: financial aid helps a student who will eventually graduate to do so quicker in terms of the number of credit points that they have to repeat, but also helps someone who will eventually be excluded on academic grounds to linger longer in the system. A similar argument could be made for students who receive some form of residence-based accommodation at UKZN.

Students who drop out but with a good academic record

Treating academic exclusion and eventual graduation as competing risks for this event produced the results that appear in the sixth column of Table 4. Using a 5% level of significance, white students seem to drop out more quickly, in terms of the number of credit points that they repeat, than a baseline Indian student. However, access to some form of financial aid and being in a residence helps to prevent these students with a good record from choosing to complete their studies at another university.

Figures 3 contains a CIF that one can associate with a student who will eventually graduate from their studies. In keeping with the national figures recorded in the Council for Higher Education report of 2013 – in which graduation rates within a 5-year period for a 3-year degree ranged between 48% and 58% – Figure 3 indicates that UKZN has an eventual graduation rate that is of a very similar order. Figures 4a and 4b provide an illustration of how easily this methodology can be used to compare one type of student with another. More specifically, the CIF associated with an African male student who will eventually graduate (Figure 4a) is compared with that of a white female student who will also eventually graduate (Figure 4b). From these curves one can see that white female students have a much higher graduation incidence rate, which means that white female students need (on average) fewer extra credit points to graduate than their African male counterparts.

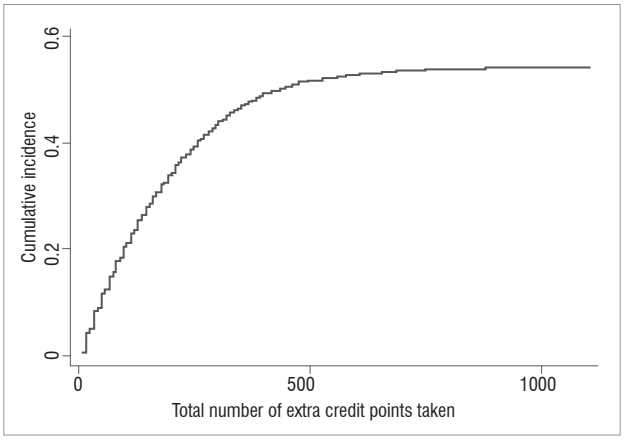

Figure 3: A cumulative incidence function for students who will eventually graduate.

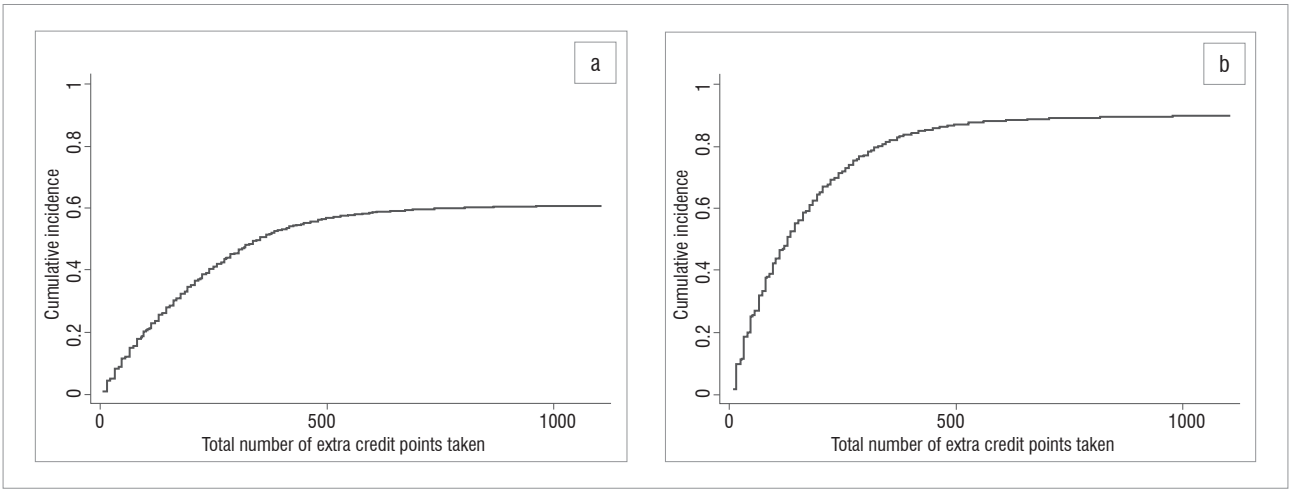

Figure 4: A cumulative incidence function for (a) African male students and (b) white female students staying in a residence who will eventually graduate.

Table 4: Sub-distribution hazard ratio (SHR) based estimates for students who will eventually graduate, be excluded on academic grounds or drop out from their studies on a voluntary basis

Covariate	SHR for an eventual graduation	95% confidence interval	SHR for an academic exclusion	95% confidence interval	SHR for a voluntary dropout	95% confidence interval
Male	0.7549	[0.7331;0.7773]	1.3479	[1.2987;1.3989]	1.0549	[0.9747;1.1415]
African	0.7794	[0.7104;0.8484]	1.3184	[1.1737;1.4631]	0.9261	[0.7415;1.1107]
Coloured	1.1406	[0.8907;1.3905]	1.1229	[0.8917;1.3541]	1.1993	[0.8678;1.5306]
White	1.6099	[1.4546;1.7652]	0.7571	[0.6582;0.8560]	1.8378	[1.7448;1.9308]
Financial aid	1.2176	[1.1772;1.2593]	0.8011	[0.7662; 0.8378]	0.5868	[0.5284;0.6516]
Residence	1.2349	[1.1821;1.2900]	0.7786	[0.7396;0.8198]	0.7307	[0.6429;0.8306]
Matric points	1.0552	[1.0522;1.0583]	0.9505	[0.9472;0.9538]	0.9759	[0.9683;0.9835]

Conclusions

The main purpose of this paper was to introduce into the literature a new methodology for comparing the graduation and dropout rates of students at a university. By changing one's point of focus from a calendar time based survival measure to one that looks at the number of credit points that are repeated before a student can graduate (or drop out), one is able to circumvent the type of problem that can occur when a student has been forced to interrupt their studies, because of a domestic or financial problem, and then returns at a later stage to complete their studies, or when a student is given a lighter load in a given semester to help them cope better with their studies.

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Determining the feasibility of harvesting invasive alien plant species for energy

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Woody invasive alien plants (IAPs) are a threat to South Africa's water resources, biodiversity and land productivity. The impacts of IAPs were the main reason for the South African government to embark on a natural resource management public works programme called Working for Water (WfW), which was aimed at controlling IAPs in a cost-effective yet labour-intensive way. At the same time, the high biomass of these species presents opportunities for synergies between the clearing of IAPs and the generation of biomass-based energy. The purpose of this study was to determine the cost of harvesting and extracting, chipping, and transporting the biomass, and also to determine the financial and economic feasibility of such an exercise from a commercial perspective. Sampling of the biomass was done at 31 representative sites within the Nelson Mandela Metropolitan Municipality, South Africa. The cost of the operation was carefully monitored, documented and reported at each stage, and compared to the cost of replacing the thermal coal currently used by industry within this municipality. The project proved to be financially viable, but only when the energy entrepreneur forms a partnership with the WfW programme, and then only under specific conditions. The project has, however, very high socio-economic returns with respect to a reduction in environmental externalities and job creation.

Introduction

Woody invasive alien plants (IAPs) pose significant direct threats to South Africa's ecosystems and the services they provide, including water, land productivity and biodiversity.[1-5] These threats are being addressed by the Working for Water (WfW) programme which aims to control invasions as well as provide work and training for unskilled people. The biomass produced during control operations could be used to generate energy, potentially fully or partially offsetting the costs of control.

The mining, transportation and combustion of coal for the purposes of generating electricity has negative impacts on the environment and human health. Studies have shown that some of these effects include the impact of air pollution on human health, the impact of climate change and the environmental impact on water quantity and quality and on biodiversity.[6-11] A number of studies have quantified the externality costs of mining coal and transporting it to the Kusile coal-fired power station in eMalahleni, Mpumalanga Province of South Africa[6-9] (see also Letsoalo et al.[12] and O'Farrell et al.[13] for a discussion on the value of natural resources and the difficulties of their quantification). These studies estimated the externalised cost on both the environment and humans of mining and transporting coal to be between ZAR6358 million and ZAR12 690 million per annum. While extremely large in and by themselves, these figures still exclude some externalities like noise pollution, damage to roads and damage caused by ash lagoons on water resources.

The externality costs associated with using coal for electricity generation purposes justify an investigation into the viability of using IAPs for bioenergy production. In particular, the Nelson Mandela Metropolitan area in the Eastern Cape Province of South Africa depends on coal to generate electricity to meet its energy needs. The unit cost of coal has increased noticeably because of increasing transport costs and a decline in the quality of the coal. The combination of the negative externalities and the rising price of coal may make the utilisation of (woody) IAPs for heat and power generation economically viable. While it is generally recognised that the use of biomass for energy generation has many positives, including low ash and low flue gas emissions, there are also recognised risks, particularly uncertainties about the sustainable supply of high-quality biomass and the cost of its delivery.[14]

The use of IAPs for energy purposes has the potential to reduce both the negative externalities caused by coal-fired energy generation and their harmful effects on the environment. In addition, the use of IAPs for bioenergy production will contribute to reducing invasions and restoring the invaded ecosystems. The benefits of clearing IAPs include a reduction in both fire protection costs and damage to infrastructure as a result of wildfires, the conservation of biodiversity and ecosystem resilience, an increase in water quantity and quality, improved river system services, social development and poverty alleviation, job creation, economic empowerment and training, flood control, and the containment of erosion and a decrease in the siltation of dams.[3,15-18] Linking a public works programme like WfW with an industrial sector activity, such as the generation of electricity, has the added benefit of providing sustainability to the job creation process within the so-called 'green economy'. It elevates the WfW project from being a poverty reduction initiative with environmental benefits, to one that is also integrally linked to the mainstream industrial economy.

Although there are these clear synergies between the benefits of control, it is essential to establish the viability of such a venture. In this study, we determined the direct financial cost of harvesting (i.e. felling and extracting),

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chipping and transporting woody IAP biomass in the Nelson Mandela Metropolitan area to a site for energy generation purposes. We also determined the overall financial and economic feasibility of such an exercise.

Materials and methods

Background and rationale

The WfW programme is currently running a number of IAP clearing projects within a 50-km radius of the Coega Industrial Development Zone (Coega IDZ) in the Nelson Mandela Metropolitan area. A biomass processing plant has also been established in the Coega IDZ. This situation presented an opportunity to investigate the synergies between the clearing of IAPs and the bioenergy plant within the Nelson Mandela Metropolitan area. A joint venture between the bioenergy power (pelletising) plant and WfW was formed to conduct a trial project. This trial project entailed WFW clearing IAPs in four WfW project areas and the bioenergy power plant chipping and transporting the material to a weigh bridge, and carefully monitoring and documenting all costs, moisture levels, species composition and densities of the IAPs harvested. Biomass-based electricity generation requires a constant supply of biomass. Yet, the biomass source is finite. This necessitates that (1) the method of harvesting and transporting the biomass must be as efficient as possible and (2) both the area of supply and the period within which the material can be harvested are constrained. Therefore the study area was limited to a 50-km radius and a project period of 60 months was assumed. No regrowth was factored in, as that would negate the benefits of harvesting IAPs. This source, however, provides the project developer with a window of opportunity to develop other, sustainable, sources of biomass supply without having to wait.

Selection of harvesting sites

A desktop analysis was conducted using ArcView geographic information system (GIS) software to characterise the woody alien vegetation biomass within the boundaries of the study area. Polygons of alien vegetation were digitised from recent (late-2009) aerial photography and the species composition and density were classified and mapped. The biomass models developed by Le Maitre et al.[19] were then used to estimate the available biomass based on this classification.

This desktop analysis was then filtered using an area-based IAP clearing suitability index. The index was based on five factors: slope, distance from the pelletising plant, distance from an access road, biomass volume and influence of riparian area. Windrows were included but treated separately. Maps ranking the suitability of the study area based on the above-mentioned parameters were produced.[20] The 15 364 polygons were ranked in terms of their suitability and the ones that scored poorly were eliminated as there was a general consensus among stakeholders that it would be unlikely to be economically viable in the long term to extract biomass from these polygons. This exclusion resulted in a reduction in the number of polygons to approximately 650.

Field verification was done on 286 of these pre-selected polygons noting the type of species, age of trees, tree density, the slope, distance from the road and also distance from the riparian zone for each polygon. This observed information was then compared to the information contained in the original GIS data set to ascertain the correctness of the GIS database through a process of 'ground truthing'. Field verification is essential because it is very difficult to accurately identify actual species in a given polygon based solely on aerial photography, particularly for acacias, and to refine the estimates of density and tree size. The field verification thus increased confidence in the biomass determination.

The IAPs were then harvested on 5%, or 31, of the 622 contiguous polygons. Of the 622 polygons, 81 were randomly selected for field trials using a GIS random selection function to determine which sites should be harvested. This number was more than is required but the extras were included to make provision for farmers or landowners who did not want portions of their land to be cleared.

Harvesting, chipping and transporting methods

The harvesting was done using two methods. Method 1 involved felling and stacking the branches on the roadside and then chipping them. Method 2 entailed felling and hand-feeding the branches into the chipper directly, avoiding the stacking. Felling was done using chainsaws and/or brush cutters depending on the size of the trees. Felling and extraction was done by three teams, each comprising 22 people. The chipper that was used for both methods is a Bandit 250XP (Port Elizabeth, South Africa).

A truck brought two empty 28-m^3 bins to the site, one on the truck and another on a trailer. The bins usually were placed close to the stacked branches or where the branches would be stacked. The chipper would then chip the biomass directly into the bins. The chipping team consisted of one supervisor, two chipper operators and eight general workers. The team was responsible for hand-feeding the chipper and managing the chipping process. Once the bins were full, the truck would collect them and take them to the weigh bridge. The weight of each bin and the transportation costs were then passed on to the data collection team. Samples were taken from each bin and sent to a laboratory to determine the moisture content and calculate the dry mass.

Data collection methods

The data collection team (with the help from the chipping team, felling and extraction team, and project manager) developed data logging forms for felling and extraction and chipping. These were completed by the respective supervisors in charge of felling and extraction, and chipping. Information recorded on the forms included the number of workers, amount of fuel used, number of days worked per site, and chipping hours. The records were checked daily to establish whether they were completed correctly.

Calibrating the GIS data

Non-destructive mensuration was also to supplement the remote sensing and field harvesting, and refine the estimates of the available biomass in the study area. As in similar studies[21-23] on invasive Acacia species, 'non-standard, non-plantation and non-commercial forestry concepts' were required.[21] We noted, however, that the size (age), density and species distribution of the stands had changed and thus the biomass composition had changed from that found in previous studies. It was critical to have accurate estimates of the available biomass in the study area because the trial demonstrated that the cost of harvesting, chipping and transporting biomass is very sensitive to the volume of biomass. Furthermore, if the amount of biomass available in the study area is not well known or if there is insufficient biomass it may not be worthwhile to undertake such a project.

The objective of the mensuration for this trial was to estimate the standing biomass of the complete tree, inclusive of all tree components, as well as the biomass of whole stands. Allometric measurements were taken on a total of 103 different polygons, including all the field harvesting sites. A representative transect of 50 m x 4 m was selected within each polygon based on its species composition, density, tree age and growth form. The site was briefly described and photographs were taken for reference purposes. Necromass (standing dead wood) was not measured. Diameter measurements were taken according to the tree type: medium trees had their diameter measured at knee height (0.5 m above ground level) and large trees had their diameter measured at breast height (1.3 m above ground level). Tall (large) trees included *Eucalyptus* spp., *Acacia mearnsii* and *Pinus* species, with height also measured for pines. Medium trees included *Acacia cyclops*, *Acacia saligna* and *Acacia longifolia*. The mass of each tree was determined and used to calculate species-specific allometric equations based on the corresponding stem diameters. These equations were then used with the sample of diameters to estimate the standing biomass in each polygon. As a result of the limited contribution of *Pinus* spp. to the biomass of the area, standard plantation volume equations with conversion factors were applied to calculate oven-dry mass for the whole tree.

Results and discussion

Harvesting and extraction, and chipping and transport costs

There is a wide range in the cost of harvesting and extraction, and chipping and transportation of biomass per species class (Table 1). The *Acacia longifolia* class has the highest harvesting and extraction costs, while the *Acacia* spp. class has the lowest harvesting and extraction costs. The variance in the cost of harvesting and extraction can be attributed mainly to differences in stand densities, tree sizes and the slope in the study area. The *Eucalyptus-Acacia-Pine* class had the highest chipping costs, while the *Acacia saligna* class had the lowest chipping costs. The *Eucalyptus-Acacia* class showed the greatest variance in terms of transport costs. The cost of transport is based on the actual realised (invoiced) cost of transporting the biomass from the harvesting site, and the distances varied between 30 km and 50 km. The unit costs varied between ZAR1.09/km/t and ZAR4.63/km/t with a weighted average of approximately ZAR2.50/km/t. This cost is much higher than the industry average of approximately ZAR1.1/km/t (Road Freight Association 2013, verbal communication, September 16) because of the method used, namely outsourcing the transport to a contractor who uses non-customised bins.

The harvesting and extraction cost generally constitutes most of the overall cost, followed by chipping and then transport (Figure 1). The chipping cost is particularly high for the *Eucalyptus-Acacia-Pine* and *Acacia-Pine* classes. These high chipping costs were a result largely of operational issues – including road conditions and related challenges with respect to access and transport – that is, conditions that were site specific and not determined by the species class.

Allometry biomass data verification

The findings from the in-field verification, detailed in-field mensuration, destructive allometry and the actual harvested biomass tonnages were used to confirm the availability of the biomass and calibrate the available biomass GIS data values. The net result was that each of the mapped invasion classes was allocated a relevant biomass value (Table 2). The allometry species class biomass values show a variance of between -22% and +16% from the allocated class biomass values. The relatively high variances within species classes for allometry biomass tonnage results reflect the in-field realities of varying densities, ages and previous selective harvesting by wood cutters. The variances observed justified the in-field harvesting of the biomass to improve the credibility of the estimated volume of biomass availability. Based on the biomass distribution and densities in the GIS database, after being calibrated with the information from the harvested sites, there is approximately 551 550 tonnes of readily accessible woody IAPs scattered across 8900 ha within a 50-km radius of the Coega IDZ.

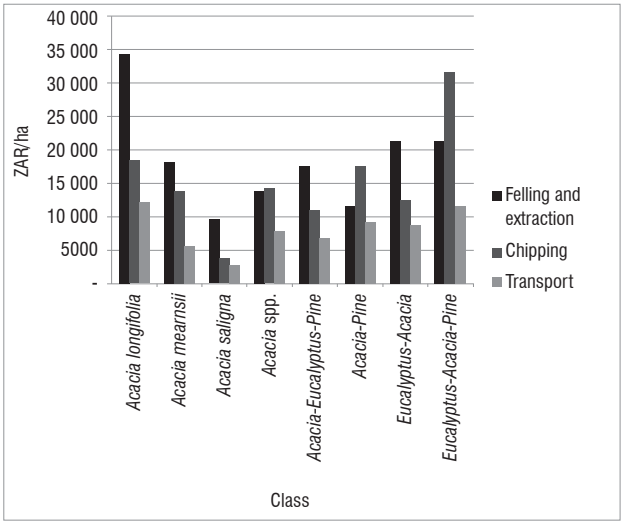

Figure 1: A comparison of the felling and extraction, chipping and transport costs per species class.

Feasibility assessment

Eight scenarios were developed to assess the feasibility of harvesting IAPs for energy purposes under different conditions. Each scenario had three different pricing options (the main inputs and assumptions of the model are presented in the Appendix). The eight scenarios are:

1. All activities are outsourced to third parties, and all costs are paid for by energy entrepreneur.
2. All activities are outsourced to third parties, but harvesting and extraction cost is carried by the Natural Resource Management (NRM) programmes (i.e. WfW).
3. As in Scenario 2, but biomass is allowed to dry in-field for 60 days.
4. Transporting is done in-house, all other activities are outsourced to third parties, but harvesting and extraction cost is carried by the NRM programmes.
5. Transporting and chipping are done in-house, but harvesting and extraction cost is carried by the NRM programmes.

Table 1: The costs of harvesting, chipping and transporting biomass

	Cost (ZAR/ha)					
Class	**Harvesting and extraction**		**Chipping**		**Transport**	
	Minimum	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Acacia longifolia	25 403	43 487	13 678	23 340	9513	14 853
Acacia mearnsii	15 431	21 097	5831	22 045	2433	8834
Acacia saligna	50 46	14 274	2545	5081	2579	3089
Acacia spp.	7726	20 093	8696	20 009	4176	11 773
Acacia-Eucalyptus-Pine	13 812	21 523	10 976	11 285	6597	6951
Acacia-Pine	8135	15 084	8567	27 027	4874	13 819
Eucalyptus-Acacia	8644	34 502	3863	21 245	1468	16 522
Eucalyptus-Acacia-Pine	19 719	23 083	19 957	43 312	10 784	12 721

Note: The species are in order of descending dominance.

6. As in Scenario 5, but biomass is allowed to dry in-field for 60 days.

7a. As in Scenario 6, but the biomass cost payable by the pelletising plant to NRM is increased from ZAR100/tonne (Scenarios 1–6), to ZAR150/tonne.

7b. As in Scenario 7a, but limiting the operation to 100 000 tonnes.

The costs of all the scenarios were based on the actual data that was collected throughout the course of the project, except for the transport costs of Scenarios 4–6 which were based on the Road Freight Association's information. The chipping costs for Scenarios 5 and 6 were based on the default costs of the manufacturer of the chippers (Bandit). The price for coal was set at 4.7c/MJ, which is 95% of the value of thermal coal landed in the municipal area.

Feasibility assessment results

Scenario 1, the scenario under which the energy entrepreneur has to carry all the cost, is not financially viable (Table 3). Scenario 6 offers the highest net present value for the net income to the energy entrepreneur. Under this scenario the energy entrepreneur would be responsible for all chipping and transport activities in-house, allow the biomass to dry for 60 days in-field, and compensate the WfW ZAR100/t (wet) biomass harvested (felled and extracted to road side). Scenario 6, however, implies an increase in clearing cost to the WfW from a norm of about ZAR6000/ha to ZAR11 200/ha which does not meet the WfW mandate of cost-effective clearing of IAPs. This is despite the large externality benefits as a result of the biomass replacing coal as energy feedstock. The introduction of Scenario 7a, which is the same as Scenario 6 except for an increase in the cost of the biomass to ZAR150/tonne, reduces the cost of clearing for the WfW to ZAR8200/ha. The estimates with respect to the externality costs only refer to the use of coal for electricity generation purposes in the Highveld of South Africa as point of reference. This approach excludes the externality cost associated with the transport of the coal to the Nelson Mandela Metropolitan area. It also excludes, as an addition, the externality benefits associated with clearing IAPs. It was decided to exclude these benefits as they are very site specific and because a harvesting plan and method had not been developed; it would be erroneous to include them.

Scenarios 7a and 7b indicate the economic feasibility of the operation without comparing it with the cost of coal. Using a calorific value of 11.5 MJ/kg for biomass with a moisture content of 35% (i.e. freshly cut) and 13.6 MJ/kg for biomass with a moisture content of 25% (i.e. after an in-field drying period of 60 days), the energy unit costs for all the scenarios were estimated (Figure 2). While the unit costs of Scenarios 7a (ZAR28.7/GJ) and 7b (ZAR31/GJ) exceed that of Scenario 6 (ZAR24.8/GJ), they are still much lower than that of coal (ZAR49/GJ), making them potentially economically feasible.

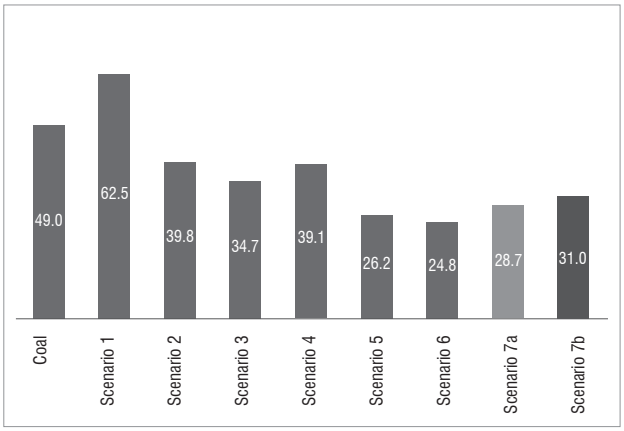

Figure 2: Unit cost (ZAR/GJ) of harvesting and transporting (woody) invasive alien plants within a radius of 50 km to a central plant for energy purposes.

Conclusion

Invasive alien plants are widespread in South Africa and pose a major threat to the country's water sources and biodiversity as well as threatening lives and infrastructure by being fire prone. At the same time, South Africa is highly dependent on coal for its energy needs. We investigated the economic feasibility of using woody IAPs as a source of bioenergy in the Nelson Mandela Metropolitan Municipality. The total cost of the operation could be as high as ZAR62/GJ, which compares unfavourably to that of coal at ZAR49/GJ. If the WfW programme bears a portion of the cost, the direct cost to the energy entrepreneur declines to between ZAR25/GJ and ZAR31/GJ depending on the scenario. Under such conditions, the harvesting of IAPs for bioenergy purposes is both financially and economically viable given the large, positive externalities associated with such an operation, namely replacing fossil fuels, clearing IAPs and generating employment.

In sum, the project is financially viable when done in conjunction with the WfW programme and has high socio-economic returns with respect to a reduction in environmental externalities and the creation of job opportunities.

Table 2: Comparison of allometry biomass estimation and allocated species class biomass

Mapped species class	Biomass (tonnes/ha) at 100% cover: Mean values: Allometry	Biomass (tonnes/ha) at 100% cover: Mean values: Harvested	Percentage difference (%)
Acacia-Eucalyptus-Pine	63.80	56.58	13%
Acacia-Pine	82.31	71.97	14%
Acacia longifolia	51.30	58.48	-12%
Acacia mearnsii	35.77	31.73	13%
Acacia saligna	18.10	23.20	-22%
Acacia spp.	96.34	83.14	16%
Eucalyptus-Acacia-Pine	75.96	86.51	-12%
Eucalyptus-Acacia	79.71	84.94	-6%

Note: The species are in order of descending dominance.

Table 3: Summary of results of the feasibility model

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7a	Scenario 7b
Total tonnes	524 467	524 467	454 538	524 467	524 467	454 538	454 538	86 667
NPV of entrepreneur's OpEx (ZAR)	298 663 916	168 807 285	142 238 448	135 912 623	43 187 901	37 290 171	37 290 171	8 132 039
NPV of biomass cost (ZAR)	47 040 810	47 040 810	48 213 421	47 040 810	47 040 810	48 213 421	72 320 132	14 511 895
NPV of total CapEx (ZAR)	19 256 768	12 087 949	12 087 949	41 252 728	67 605 633	67 605 633	67 605 633	13 941 272
NPV of gross income (ZAR)	252 201 897	252 201 897	258 488 669	252 201 897	252 201 897	258 488 669	258 488 669	51 868 828
Net income (NPV) (excl. externalities) (ZAR)	-112 759 596	24 265 854	55 948 851	27 995 736	94 367 554	105 379 443	81 272 733	15 283 621
IRR (excl. externalities)	NA	5.7%	9.9%	2.2%	3.7%	4.0%	3.3%	6.2%
NPV of externality (average ZAR)	678 240 873	678 240 873	695 147 747	678 240 873	678 240 873	695 147 747	695 147 747	139 489 669
Net income (NPV) (incl. externalities) (ZAR)	565 481 277	702 506 727	751 096 598	706 236 609	772 608 427	800 527 191	776 420 480	154 773 291
IRR (incl. externalities)	129.1%	511.8%	811.6%	33.0%	20.6%	21.4%	20.7%	63.9%
NPV of biomass cost/tonne (ZAR)	90	90	106	90	90	106	82	94
Discounted OpEx/tonne (ZAR)	569	322	313	259	82	82	159	167
Total initial CapEx requirement (ZAR)	14 063 500	11 540 000	11 540 000	40 440 000	66 745 000	66 745 000	66 745 000	13 490 000

NPV, net present value; OpEx: operating expenditure; CapEx: capital expenditure; IRR, internal rate of return

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Authors' contributions

W.M. was responsible for all data collection, data analysis and the compilation of the text. J.B. was responsible for the project management, data analysis and the compilation of the text. M.J. was responsible for the site management, client and landowner liaison and technical analysis. J.d.W was responsible for the verification of the data in relation to forestry benchmark statistics. A.K. was responsible for managing the WfW harvesting and extraction teams. S.J. was co-responsible for the allometry estimates. B.C. was responsible for the GIS analysis. J.J. was responsible for landowner liaison from a WfW perspective. D.L.M. was responsible for the GIS and allometry calibration. M.v.d.V. was co-responsible for the allometry estimates.

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Appendix: Summary of key inputs and assumptions into the feasibility model

Key assumptions kept constant for Scenarios 1–6, with the biomass cost raised to ZAR150 for Scenarios 7a & 7b and the size of the operation reduced to 100 000t for Scenario 7b								
Term:	60 months							
Discount rate:	4% p.a.							
Cost scenario:	Low, i.e. 85% of experimental cost to allow for improvements in efficiency and economies of scale							
Cost of biomass:	ZAR100/wet tonne and ZAR118/dry tonne							
Price scenario:				ZAR/MJ	MJ/kg (~35% moisture)	MJ/kg (~25% moisture)	ZAR/wet tonne	ZAR/dry tonne
	Pessimistic (85% of realistic)			0.040	11.5	13.6	455.7	538.9
	Realistic (95% of coal equiv. (27 MJ/kg))			0.047	11.5	13.6	536.1	634.0
	Optimistic (115% of realistic)			0.054	11.5	13.6	616.6	729.1
Biomass:	Cluster	Distance (km)	Hectares	Total tonnes	Tonnes/month	Months to clear	Number of teams	Hectare/month
	Area 1	40	2206	138 370	6490	22	25	100
	Area 2	40	3583	223 574	10 354	22	40	163
	Area 3	40	240	15 176	18 242	1	70	240
	Area 4	65	451	30 784	19 025	2	70	225
	Area 5	65	1539	88 183	12 360	8	50	192
	Area 6	65	410	28 380	8215	4	30	102

Please note that harvesting and extraction is defined as up to roadside. Cost of biomass refers to the amount per tonne paid to the Natural Resource Management programmes (i.e. WfW) for the biomass extracted to roadside.

Nelson Mandela's defence: A psychological capital documentary analysis

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This qualitative documentary analysis examines Nelson Mandela's defence statement at the Rivonia Trial, Pretoria Supreme Court, on 20 April 1964. The defence document is analysed through the psychological capital lens, depicting themes that support the constructs of hope, efficacy, resilience and optimism. Psychological capital characteristics played a major role in the initial non-violent policies of negotiation. The inevitable establishment of Umkhonto we Sizwe followed, as a result of the increased restrictions and unwillingness of government to negotiate and collaborate. Mandela showed a determined spirit to unite the country. The discussion gives insight into Mandela's authentic psychological capital leadership under difficult political and personal circumstances. Some implications are indicated in adopting Mandela's psychological characteristics for personal reform.

> *When I walked out of prison, that was my mission, to liberate the oppressed and the oppressor both.*
>
> *Nelson Mandela*

Introduction

The African National Congress (ANC) was banned in 1952 and unbanned on 11 February 1990. With the banning of the ANC, the South African public was deprived of the views of the ANC and its leaders. During the 38-year ban, the publication of Nelson Mandela's photo was prohibited, and the South African public was given one-sided, apartheid-supporting propaganda.[1] With the bar on information on the ANC, the South African public was deprived of the detail of Mandela's defence statement during the Rivonia Trial in 1964. Because of the restriction and censoring of Mandela's correspondence during his imprisonment, knowledge of his personal views were restricted to the outside world.[2] However, the world and South Africans soon became more informed after his release from prison. Millions of people globally protested against his imprisonment and applauded his release, signalling the end of apartheid and the transition to democracy.[3] Mandela is probably one of the most distinguished modern-day leaders.[4] He captured the imagination of the world, resisted the moral decline of South Africa[5] and made a global historical impact[2,6].

Mandela's imprisonment did not jeopardise his cause and will to unite the country[6], nor did the apartheid government manage to break his spirit[7]. His prime years were spent in prison, and he gave up 5 years of his law practice to defend himself and others accused in the Treason Trials.[4] Without bitterness[8], embracing forgiveness[5], he purposefully engaged in peaceful resolutions to unify opposing parties, and, in this way, embarrassed his enemies[5]. He aspired to create a democratic, race-free South Africa, by operating through a policy of forgiveness[5,9] and providing peace and stability to the new democracy[7]. Mandela chose to walk the road of forgiveness despite his 27 years of imprisonment and harassment of his family.[8] Mandela's vision of reconciliation, notwithstanding hostility from opposing factions,[10] emphasised his positive behaviour. His ethical behaviour is regarded as functioning at the highest level, as he demonstrated extraordinary proactive leadership.[11] His actions were co-evolutionary, based on values that strengthened the effectiveness of the South African society as a whole.[11]

It is argued that Mandela's extraordinary psychological capital (PsyCap) leadership and dignity led to the positive reforms that took place at Robben Island.[12] The purpose of this study was to explore the PsyCap displayed by Mandela as a person before his imprisonment, as depicted in his defence statement.[13] Mandela's strategic leadership – based on reconciliation – contributed to the peaceful transition in South Africa.[14,15] He became a symbol of endurance in the face of oppression.[9] Notwithstanding worldwide accolades and joint receipt of the Nobel Peace Prize with FW de Klerk in 1993[16], Mandela did not regard himself as a messiah, but rather as an ordinary leader exposed to extraordinary circumstances[17].

Cascio and Luthans[12] argue that the nurturing of positive resources in the form of PsyCap contributed to the metamorphosis of both prisoners and warders on Robben Island. The prisoners prevailed by creating transformation through positive psychological self-governance, which changed the attitude of warders towards them. Mandela took part in an effort of collective forgiveness on Robben Island and was central in developing political education for prisoners.[4] Different forms of authentic leadership empowered the political prisoners to convert the 'hell hole' to a freedom symbol.[12] In the current study, authentic PsyCap leadership themes were investigated by examining the defence statement of Mandela at the Rivonia Trial[13], as he dedicated and sacrificed his life to the struggle[17].

Problem statement and objective of the study

Although Nelson Mandela is one of the most admired historical leaders, not much research has been done on his leadership style.[2] There is also a lack of research on positive behaviour in the functioning of governments.[18] As far as could be established, no positive behaviour studies have been done on the ANC leadership, with the exception of the metamorphosis of Robben Island.[12] Although the ANC was not governing the country at the time of the Rivonia Trial, they had their own governance infrastructure. Most studies on PsyCap are quantitative, using Luthans et al.'s[19] PCQ24 measure; however, qualitative investigations would improve our understanding of the

phenomenon.[20] The current study is the first qualitative investigation into the phenomenon of the strategic PsyCap leadership of Mandela before his imprisonment on Robben Island.

The objective of this study was to qualitatively examine Mandela's[13] statement against the PsyCap concepts of hope, efficacy, resilience and optimism (HERO). This paper adds to the investigation of Cascio and Luthans[12] regarding evidence of the positive role that PsyCap played in the alleviation of the oppressive environment at Robben Island. The oppressive environment existed long before Mandela was imprisoned. The defence argument of Mandela on 20 April 1964[13] was examined to uncover Mandela's positive psychological attempts to amicably resolve the oppression of Africans. This analysis should give more insight into the authentic leadership and PsyCap HERO actions of Nelson Mandela, despite the impossible political circumstances at the time.

PsyCap theory

While PsyCap has not been linked to leadership behaviour, with the exception of the Cascio and Luthans[12] study, many positive associations with psychological well-being have been found in organisations; these associations are evident in employee well-being[21], overall well-being[22], greater work engagement[23], enhanced academic performance[24], work satisfaction[25], organisational commitment[26,27], maintenance of a safety climate[28], job performance[25], organisational citizenship[29], low counterproductive behaviour and cynicism[29], fewer symptoms of depression[30], life satisfaction[31] and authentic leadership[12,32].

PsyCap is regarded as the cognitive component and positive psychological state encompassing hope, efficacy, resilience and optimism.[19,25] It has been indicated that the individual and collective PsyCap of the political prisoners at Robben Island contributed to the effective metamorphosis of prison life.[12] This PsyCap behaviour of hope, efficacy, resilience and optimism, depicted by the acronym HERO, was demonstrated through the different coping strategies of the prisoners who disrupted the oppressive situation. The individual HERO concepts are explained below.

Hope

Hope consists of two forms of goal-directed behaviour: agency (willpower) and pathways (waypower) in fulfilling objectives[33] within a specific historical context[34]. Dispositional optimistic hope increases a person's expectancy of achieving desired goals.[33] An individual maintains hopeful behaviour through interaction of agency (the will) and pathways (the way). Hope is the positive attribute of developing pathways and goal-directed behaviour through perseverance.[19,22] Hope is regarded as a motivational construct[35] that is generally related to positive well-being, effective performance[36], psychological strength and optimal health[37].

Efficacy

Self-efficacy is defined as personal agency and confidence in performing directed behaviour[38] as well as an optimistic appraisal of the ability to execute desired behaviour.[39] It is the confidence in being able to invest the necessary input to succeed in difficult tasks[19,22] and achieve goals.[40] Self-efficacy probably plays a mediating role in the belief in one's abilities, the motivation to produce outcomes[41] and psychological well-being[42]. A person with high efficacy is likely to effectively challenge problematic external factors.[43]

Resilience

Resilience is the ability to sustain and recover, despite problematic circumstances.[19] It is the propensity to pull through, despite demanding obstacles.[44] Resilience promotes an adaptive response that supports positive functioning, self-repair and promptness in dealing with challenges.[45] Resilience adds to an individual's successful control of a situation[46], dynamic sense-making during a crisis[47] and adaptation to and recovery from an adverse event[48].

Optimism

Optimism manifests in positive attributes towards future success[19] and in a disposition to expect positive outcomes[49]. It is an inclination to attribute success to internal positive traits and a refusal to relent during temporary external hardship.[49] Optimists presuppose that events will turn out positively.[50] Pessimists regard negative events as permanent internal attributes.[51] Optimism is associated with mental and physical health[52,53] as well as longevity[54] and proactive healthy behaviour[52].

Research questions

Two questions were asked: (1) Were there PsyCap factors involved in Mandela's[13] defence statement in the form of hope, efficacy, resilience and optimism? (2) What are the underlying themes that support the presence of PsyCap factors in Mandela's defence?

Method

Procedure

A qualitative content analysis – referred to as a documentary analysis – was performed of the historical document, the Nelson Mandela Rivonia Trial defence statement.[55] The content analysis was done using PsyCap theory as a benchmark. The primary method of inquiry was qualitative, chosen for its interpretive and inductive nature in an attempt to elicit meaning from the particular event.[56] The investigation was done from a positivist objective paradigm as the researcher and the participant did not interact.[56,57] This approach implies a realist's ontology regarding relationships in the world and an objective epistemology of getting to know phenomena.[58] Such a paradigm requires the researcher to be objective and free from cultural values.[59]

Documentary analysis was chosen because: (1) the defence statement is publically available on the ANC's website,[13] (2) it was the only way to gain information concerning the event, (3) it lessens ethical issues as the document is in the public domain and (4) the process of data collection could not be influenced.[55] The defence statement of Nelson Mandela[13] was used in a single documentary analysis, which complied with the principles of authenticity, credibility, representativeness and transparency of meaning, as it is the original comprehensive statement.[60]

A data extraction sheet was used to systematically capture the different PsyCap HERO themes by means of content analysis.[55] The content of the argument was categorised according to the themes[61] depicted in the PsyCap theoretical model. The framing of data into a theoretical model prevents under-emphasis of key concepts.[55] The analysis and interpretation took place through the identification of reappearing themes and categorisation of topics, and by demonstrating incidences that brought about change. These incidences were compared with the PsyCap theory.[62]

Data analysis

A content analysis of the transcript of the Rivonia Trial was done. Content analysis of the defence text was done systematically by coding and quantifying information.[63] The content analysis was of an interpretive nature, and focused on the implicit meaning in the transcript.[59] Codes in the transcript of the defence statement were categorised, analysing the meaning within the context of the PsyCap HERO constructs. Coding was done by identifying constant phrases, which were classified into themes[56] that were categorised under four main PsyCap constructs. Categories were judged by means of internal homogeneity – reflecting the same implicit meaning – as well as by external homogeneity.[56] The internal and external differentiation indicated the distinctness of categories. Certain reappearing themes were identified and categorised according to the PsyCap constructs of hope, efficacy, resilience and optimism. The number of incidents of each theme is shown in brackets in the following sections.

Hope

In hope there is a deep conviction to contribute to the freedom of people. Although there were many attempts at peaceful negotiation and discussions with government, no settlement was reached. Instead more legislation that restricted the rights of Africans was brought to bear (3). Thirty years of failed peaceful negotiations inevitably led to overt action with a policy of no bloodshed (6). Military and administrative training was organised outside the country to prepare for future governance of the country (6). Siding with communists was by no means an acceptance of their ideology – it was a welcoming of their support for freedom from apartheid (5). The objective was to correct the economic imbalance between white supremacy coupled with high economic living standards and African poverty and misery (3). The further aim was to improve the health conditions and living standards of Africans, preventing malnutrition and disease (3). Figure 1 depicts the themes that support hope.

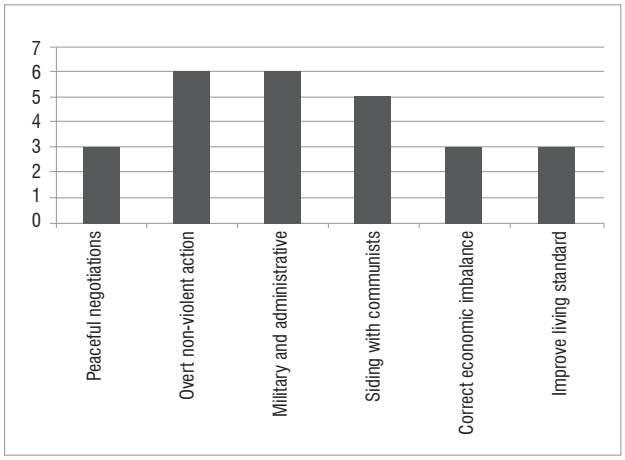

Figure 1: Number of occurrences of themes supporting hope.

Efficacy

In the defence document, consistent efficacy principles were contrasted with the false impressions created by the state. The ANC was founded to defend the rights of African people. The policy was consistently one of non-violence and non-communism (9). The establishment of Umkhonto we Sizwe was an answer to government's constant mobilisation of armed forces and violent actions. The ANC was obliged to depart from their non-violence policy of 50 years to controlled violence of economic sabotage without bloodshed, as a result of unsuccessful negotiations and increasingly restrictive laws (10). The ANC's ideology did not imply the acceptance of Marxism; it was one of African nationalism, liberation, freedom and harmonisation of all people (10). In Mandela's ideology, he saw himself as an African patriot. While influenced by Eastern Marxist thoughts of advancing the poor, Mandela was also an admirer of the democratic parliamentary system of the West. Mandela's political formula was objective and impartial in forming a non-racial state (7). Figure 2 depicts the efficacy themes.

Resilience

The 30 years of non-violent passive resistance led to increased harsh reactions from government. Thousands were imprisoned, there were many deaths of followers (such as in the Sharpeville incident) as well as proclamations of states of emergency. The ANC inevitably reacted by going underground after being banned, and operated by means of controlled violence, i.e. stay-aways and sabotage (14). Mandela explained that the unavoidable adoption of sabotage was not reckless, it was rather a sober assessment of the political situation of oppression and exploitation (7). The ANC stood for the promotion of equal education (7), removal of the industrial colour bar that reserved better jobs for whites only (5), the restoration of human dignity and family life, and the enhancement of moral standards of Africans (8). The resilience themes are depicted in Figure 3.

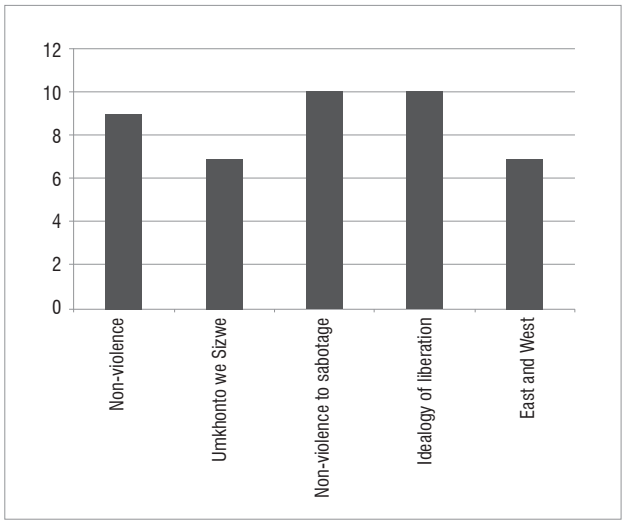

Figure 2: Number of occurrences of themes supporting efficacy.

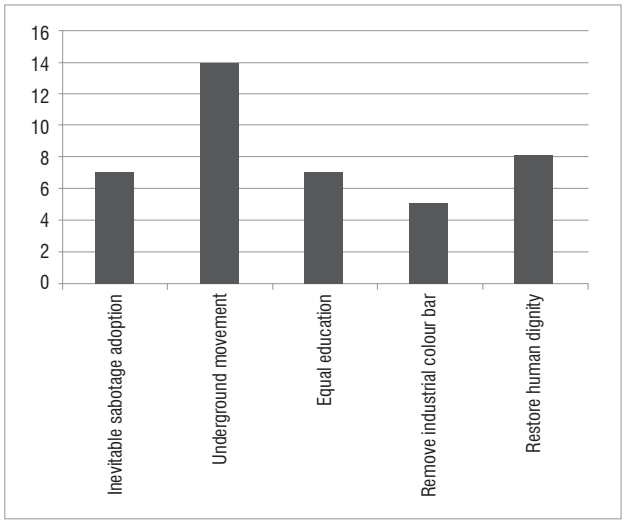

Figure 3: Number of occurrences of themes supporting resilience.

Optimism

Notwithstanding circumstances at the time, the policy of the ANC had an optimistic theme. The aim was to establish a non-dominant political dispensation to preserve a South Africa for all its people (8). Mandela took personal accountability for passive and active reaction with the underlying aim of the prevention of loss of life (4). The inevitable adoption of violence as part of ANC policy was to avoid civil war (10). Financial sources supporting the ANC, the struggle and Umkhonto we Sizwe were initially internal; from 1962, funding was sourced externally in Africa and internationally (5). The ANC's vision was to create equal political rights and dignity for all South Africans (9). Figure 4 illustrates the optimistic themes.

The individual PsyCap HERO themes are summarised in Figure 5.

Figure 6 indicates the aims of the negotiation strategies that progressed from non-violent negotiation to inevitable overt action and economic sabotage. The purpose was to acquire equal political, economic and educational rights, restore human dignity of Africans and create a non-racial democratic South Africa.

Discussion

An explanation of how PsyCap HERO themes played a role in the perseverance of Mandela and the ANC has been given. Neither Mandela's imprisonment nor the banning of the ANC could undermine his spirit and drive to unite the country.[6,7] PsyCap also played a large

role in the positive reforms and metamorphosis at Robben Island.[12] The apparent PsyCap characteristics and strategic leadership of Mandela[14,15] seemed to also have played a major role in the peaceful transition in post-apartheid South Africa.

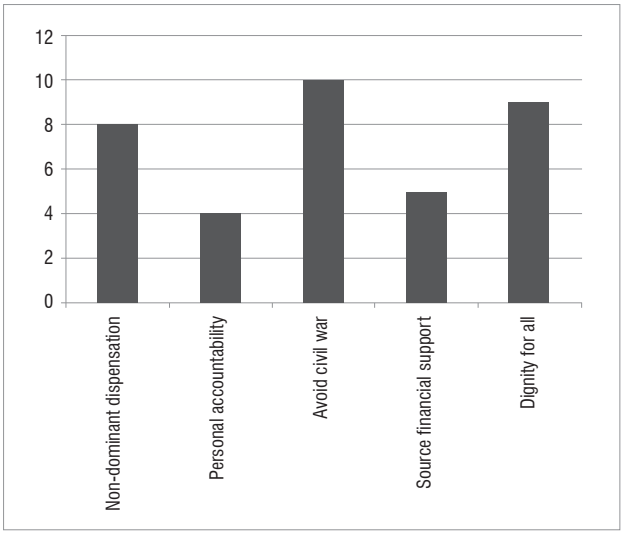

Figure 4: Number of occurrences of themes supporting optimism.

Different themes were identified in each of the PsyCap HERO fields. Hope, depicting the expectancy of achieving desired goals,[33] was pursued by trying to improve the economic imbalance and living standards. This pursuit was initially non-violent, but, when met by government's stricter legislation, the ANC sided with the communists (not their ideology), and were supported by military and administrative training.

Efficacy, seen as the personal agency of desired behaviour,[38,39] was evident in the aim to form a non-racial state. This ideal was mainly supported by the belief in maintaining non-violent action, which developed into non-violent protest and sabotage. This ideal was disillusioned by the government's retaliation by violent mobilisation of armed forces, which inevitably led to the development of an ideology of liberation and establishment of Umkhonto we Sizwe.

Resilience epitomises being adaptive and an ability to recover despite difficult circumstances.[19,44] After constantly being met by violent government reaction and strict legislations, new strategies were formed, by mobilising an underground movement. Political oppression and exploitation was met with sabotage, organised stay-aways, insisting on equal education, removal of the industrial colour bar and ultimately restoring human dignity.

Optimism refers to an ability to optimise future success.[19] Optimism was apparent in striving to create a political system that acknowledges the dignity of all people, establishing a non-dominant dispensation. The aim was always to avoid civil war. Because of the lack of resources and the high ideals, financial support for the ANC and Umkhonto we Sizwe was sourced nationally and, from 1962, internationally. Through all endeavours, Mandela was always prepared to take personal accountability for decisions made.

A summary of a combination of the main themes identified in the four PsyCap HERO fields is depicted in Figure 7.

Figure 7 emphasises Mandela's strife for a non-racial South Africa, to acknowledge the human dignity of Africans, as well as to establish equal political and economic rights through peaceful negotiation.

Implications and future research

The advantage of using documentary evidence lies in its unbiased, non-reactive nature.[64,65] An ethical advantage is the current public availability[55] of the complete historical document of Mandela's personal defence, available on the ANC website. The defence statement of Nelson Mandela is regarded as an aspirational document of the ANC at that point in time. It is considered to be an aspirational document because it deliberately states strategies, policies, objectives and values.[55] Credibility and transferability were confirmed as suggested by Mayan[56]. The credibility of the classification of arguments that support the four PsyCap constructs of hope, efficacy, resilience and optimism is founded in the transferability of the findings to the Robben Island situation described by Cascio and Luthans[12].

A limitation of the documentary analysis is that the researcher could be biased and subjective in the interpretation of the document.[55,64] The analysis was also not followed up with interviews or case studies, as suggested by Abbott et al.[55], because of its historical nature. Although

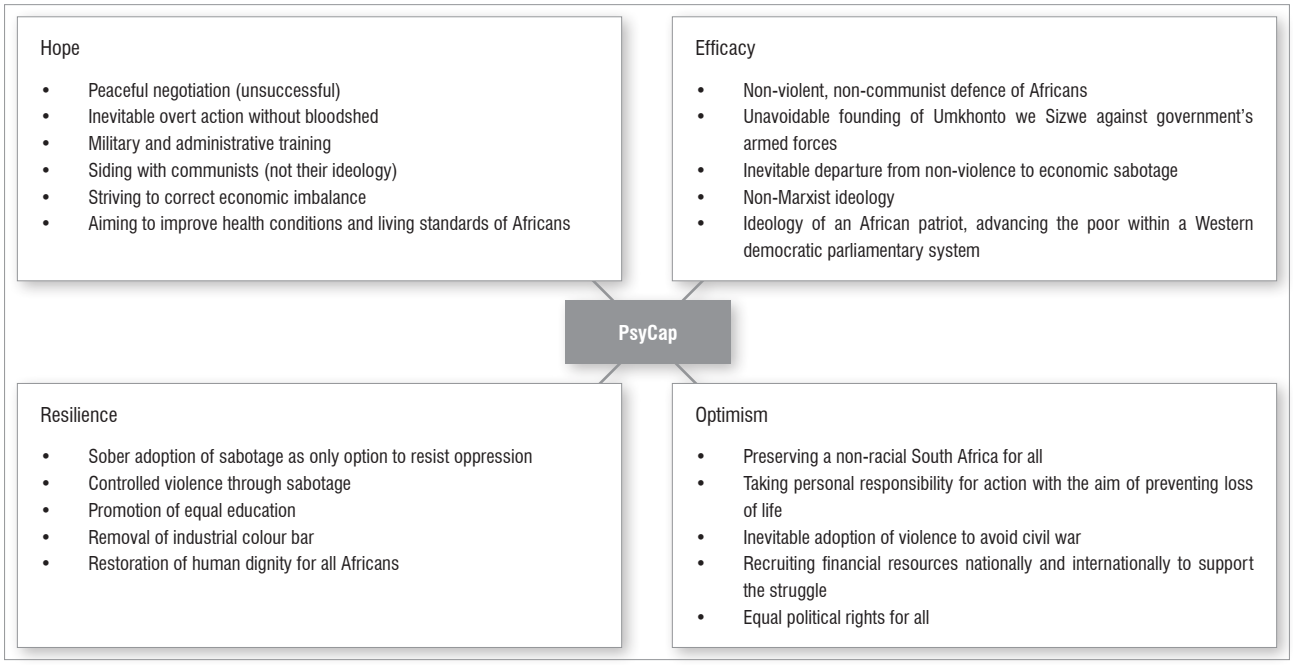

Figure 5: Psychological capital (PsyCap) HERO (hope, efficacy, resilience, optimism) themes in Nelson Mandela's Rivonia Trial defence statement.

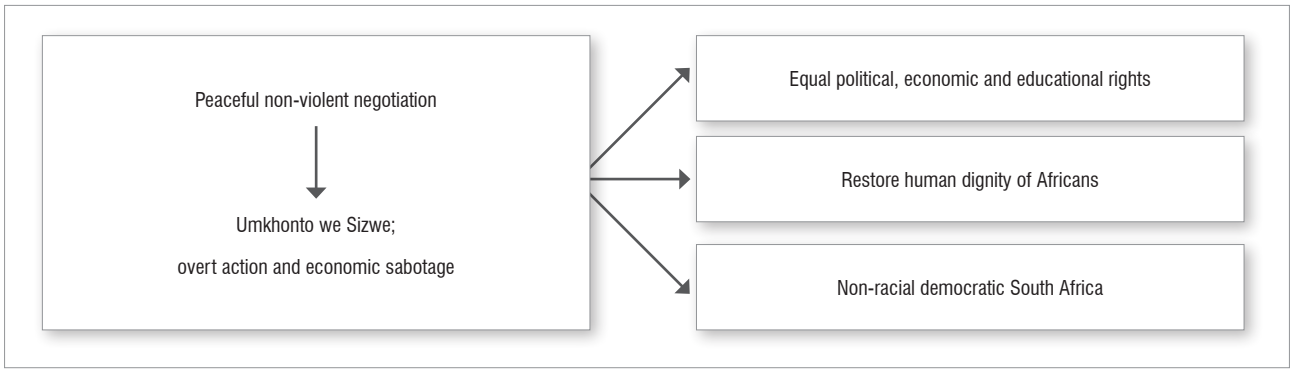

Figure 6: Aims of negotiation strategies.

the Mandela[13] defence document gives a good overview of his perspectives at the time, more documents on his views at that point may have delivered more insight. However, as far as could be established, such documents before his 27 years of imprisonment are not available. A future cross-sectional study, comparing speeches before and after his release, could shed more light on similarities or differences regarding PsyCap features. Future research should compare the concepts of the main arguments by Mandela concerning the aims of the ANC and the envisioned future of South Africa. Further studies could also investigate the role of PsyCap in Mandela's positive reform actions after his release.

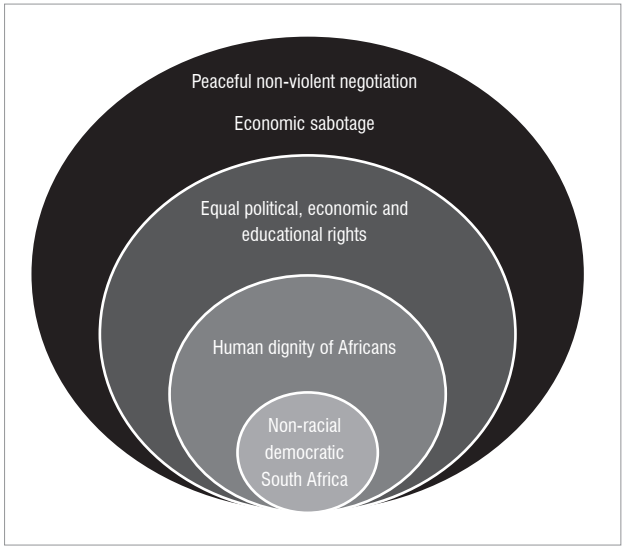

Figure 7: Main themes of the negotiation strategies.

Implications for leadership add to the argument of Cascio and Luthans[12] that positive resources should be cultivated in oppressive circumstances. The PsyCap displayed at the Rivonia Trial that contributed to transformation at Robben Island should be embraced and ploughed back into building the future of South Africa. Management should strive to incorporate the PsyCap features displayed by Mandela in business. Leaders would gain by nurturing in themselves and others the HERO behaviour displayed by Mandela. Mac Maharaj, who was imprisoned with Mandela, referred to Mandela as a leader who all of us could aspire to become.[66] These findings give insight and direction in developing PsyCap characteristics.

Conclusion

This analysis assists in gaining insight into the PsyCap HERO values that may have driven historical decisions that led to the first democratic general election in South Africa, in 1994. This analysis helps us to understand the reasoning of Mandela through a theoretical lens of PsyCap despite adverse circumstances. Inherent PsyCap HERO behaviour made it possible for Mandela to conclude both his Rivonia Trial[13] and his first public speech after his release from prison[67] with a statement reflecting goodwill for all South Africans:

> *I have fought against white domination, and I have fought against black domination. I have cherished the ideal of a democratic and free society in which all persons live together in harmony and with equal opportunity. It is an ideal which I hope to live for and to achieve. But, if need be, it is an ideal for which I am prepared to die.*

The main findings depict an ideal to form a non-racial South Africa, in which the dignity as well as equal political and economic rights of all Africans is protected through peaceful negotiation. Leadership should take cognisance of the PsyCap HERO characteristics employed by Mandela to overcome challenging political obstacles.

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Antibacterial, antioxidant activities and cytotoxicity of plants against *Propionibacterium acnes*

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The use of plants to treat skin ailments has strong support in the current trend of drug discovery. *Propionibacterium acnes*, an anaerobic pathogen, plays an important role in the occurrence of acne. The present study was conducted to evaluate the antimicrobial and antioxidant activities against *P. acnes* and cytotoxic effects of 48 medicinal plants grown in South Africa. The broth dilution and DPPH radical scavenging methods were used to determine antibacterial and antioxidant activities, respectively. Cytotoxicity was determined on mouse melanocytes (B16-F10). The ethanolic bark extract of *Acacia galpinii* Burtt Davy. (Leguminosae) exhibited the lowest minimum inhibitory concentration of 62.5 μg/mL. Excellent antioxidant activity was shown by *Aspalathus linearis* (Burm.f.) R.Dahlgren (Leguminosae), *Combretum apiculatum* Sond. (Combretaceae), *Harpephyllum caffrum* Bernh. ex Krauss (Anacardiaceae) and *Sclerocarya birrea* Hochst. (Anacardiaceae), with 50% radical scavenging activity (EC_{50}) at concentrations ranging from 1.6 μg/mL to 3.5 μg/mL. *Greyia sutherlandii* Hook. & Harv. (Greyiaceae) also exhibited good antioxidant activity with an EC_{50} value of 7.9$\pm$0.23 μg/mL. *A. linearis, G. sutherlandii* and *S. birrea* showed low toxicity with 50% viability of cells (EC_{50}) at concentrations of 125.09$\pm$0.71 μg/mL, 107.85$\pm$1.53 μg/mL and 92.07$\pm$0.09 μg/mL, respectively. The extracts of *A. linearis, G. sutherlandii* and *S. birrea* showed good antibacterial and antioxidant activities and low toxicity. Therefore, these plants can be considered as possible anti-acne agents and warrant further investigation.

Introduction

Acne, one of the most common disorders of the skin, is a polymorphic disease with non-inflammatory (blackhead or whitehead) and inflammatory (papules, pustules, or nodules) aspects and a wide spectrum of severity. Acne can have a significant impact on the psychosocial and physical aspects of life. It affects up to 85% of adolescents to some extent but is less common among infants. Its prevalence has been estimated to be 95–100% in male adolescents and 83–85% in female adolescents.[1-4]

Propionibacterium acnes, a Gram-positive anaerobic bacterium, is a normal component of the microbiota of human skin. *P. acnes* causes an increase in the secretion of sebum from sebaceous glands, which is accompanied by the thickening of the epidermis at the outlet to the pilosebaceous follicles. As a result, there is an obstruction to the flow of sebum outwards, and a comedone develops. Colonisation of the follicles with *P. acnes* and the host's inflammatory response play a pivotal role in the development of typical inflammatory papulopustular lesions.[5] In an anaerobic environment, the bacteria secretes nucleases, nuraminidases, hyaluronidases, acid phosphatises, lecithinases and other lipases. As a result of the action of these enzymes, the sebum content changes and reactive oxygen species may be released from the damaged follicular walls. Reactive oxygen species may also be the reason for the progression of inflammation in the pathogenesis of disease.[6]

Conventional drugs commonly used in acne treatment – such as tetracycline, erythromycin, mynocycline and metronidazole – act as antioxidants and antibacterials. Benzoyl peroxide, a topical agent for the treatment of acne, shows the ability to induce an inflammatory reaction mediated by reactive oxygen species in addition to its antibacterial activity.[6] These drugs also have various known side effects. The topical antibiotics can lead to dryness, redness and irritation of the skin, as well as hypopigmentation while oral antibiotics have age restrictions, can cause gastrointestinal disorders and increase the risk of venous thromboembolism.[5]

Herbal medicines are an important part of African tradition and also have very deep roots in the treatment of dermatological ailments. Ethnobotanical studies have documented the use of plants by traditional healers for the treatment of various skin ailments.[7] Different plant parts commonly used as cosmetics or face masks, known as *umemezis*, are widely used in southern Africa for skin problems like inflammation, wounds, burns, eczema and puberty acne.[8]

Because many skin disorders like atopic dermatitis and acne are associated with inflammation and the release of free radicals, which lead to oxidative and cellular damage and bacterial infections such as *P. acnes*, the presence of antioxidant and antimicrobial agents can explain the effectiveness of plants in the treatment of skin infections. In order to develop the therapeutic and drug potential of these plants, it is important to know whether they have any cytotoxic effects. Therefore, ethanol extracts of selected plants were evaluated for their antibacterial and antioxidant activities and cytotoxicity.

Limitations in the usage of some drugs and the prevailing side effects of the various chemically derived compounds have led to the search for alternative herbal agents to treat acne. The aim of this study was to test the effect of selected plant extracts on the pathogenic bacteria *P. acnes*, and to identify which plant extracts could be considered as possible anti-acne agents.

Methods

Materials

Tetracycline, vitamin C, *p*-iodonitrotetrazolium salt and 2,2-diphenyl-1-picrylhydrazyl (DPPH) were obtained from Sigma-Aldrich (Johannesburg, South Africa). Nutrient agar and nutrient broth were obtained from Merck

SA (Pty) Ltd (Johannesburg, South Africa). *P. acnes* (ATCC 11827) was purchased from Anatech Company South Africa (Johannesburg, South Africa). The cell culture reagents and the equipment were purchased from Highveld Biological (Johannesburg, South Africa), Labotech (Johannesburg, South Africa) and The Scientific Group (Johannesburg, South Africa). The B16-F10 mouse melanocyte cell line was obtained from Highveld Biological.

Preparation of plant extracts

Different plant parts (leaves, roots, bark and twigs) were collected from the Botanical Garden of the University of Pretoria (Pretoria, South Africa). The plants were identified by a taxonomist, Professor A.E. (Braam) van Wyk, at the H.G.W.J. Schweickerdt Herbarium of the University of Pretoria. The shade-dried plant material (80 g) was ground with a mechanical grinder, then soaked in 300 mL of ethanol and left on a shaker for 3 days. The plant material was then filtered and the solvent was evaporated under vacuum (Buchi Rotavapor, Labotech, Switzerland) to yield dry extracts. The plants were selected based on their medicinal usage as summarised in Table 1.

Antibacterial bioassay

The minimal inhibitory concentration (MIC) of the ethanolic extracts of the 48 selected plants was determined by a microdilution assay. This assay was done using the method described by Mapunya et al.[36], with slight modifications. For this purpose, *P. acnes* (ATCC 11827) was cultured from a Kwik-Stick on nutrient agar and incubated at 37 °C for 72 h under anaerobic conditions. The ethanolic extracts were dissolved in 10% dimethyl sulphoxide (DMSO) to obtain a stock solution of 2 mg/mL. The positive control (tetracycline) was dissolved in sterile distilled water to obtain a stock solution of 0.2 mg/mL. The 96-well plates were prepared by dispensing 100 μL of the nutrient broth into each well; 100 μL of the plant stock samples and positive control were added to the first row of wells in triplicate. Twofold serial dilutions were made in broth over a range to give concentrations of 3.9–500 μg/mL and 0.3–50 μg/mL for the plant extracts and positive control, respectively. The 72-h culture of bacteria was dissolved in nutrient broth and the suspensions were adjusted to 0.5 McFarland standard turbidity at 550 nm. Then 100 μL of this bacterial inoculum with 10^5–10^6 CFU/mL was added to all the wells. The wells with 2.5% DMSO and bacterial suspension without samples served as the solvent and negative controls, respectively. The plates were then incubated at 37 °C for 72 h under anaerobic conditions. The MIC (defined as the lowest concentration that showed no bacterial growth) was determined by observing the colour change in the wells after the addition of *p*-iodonitrotetrazolium salt.

Antioxidant assay

The antioxidant activity of selected plant extracts was investigated using the DPPH radical scavenging method as previously described by Du Toit et al.[37], with slight modifications. DPPH is a free radical, which is stable at room temperature and produces a violet solution in ethanol. When reduced in the presence of an antioxidant molecule, it gives rise to a colourless solution. DPPH was dissolved in ethanol to obtain a solution of 0.04% w/v.

The selected plant samples and the positive control (vitamin C) stock solutions (2 mg/mL) were serially diluted to final concentrations ranging from 0.78 μg/mL to 100 μg/mL. Ethanol and DPPH without any plant material were used as blanks while plant samples diluted in distilled water were used as controls. DPPH solution (90 μg/mL) was then added to all the wells except for the controls and allowed to react at room temperature. After 30 min, the absorbance values were measured at 515 nm using a Biotek Power-wave XS multiwell reader (A.D.P., Johannesburg, South Africa). The values were converted into the percentage antioxidant activity (AA) using the formula given below. The 50% inhibitory concentration (EC_{50}) values were then calculated by linear regression of the plots using GraphPad Prism version 4.

$$AA\% = \{Abs_{blank}(Abs_{sample} - Abs_{control}) / Abs_{blank}\}*100$$

Mouse melanocyte cytotoxicity assay

The cytotoxicity of selected plant extracts was determined following a previously described method.[36] Briefly, mouse melanocyte (B16-F10) cells were plated in complete Roswell Park Memorial Institute medium (10% foetal bovine serum and 1% gentamycin) directly in the wells of a 96-well plate (10^5 cells per well). After an overnight incubation at 37 °C in 5% CO_2 and a humidified atmosphere, extract samples and the positive control (actinomycin D) were added to the cells to give the final concentrations of plant extract and positive control of 3.13–400 μg/mL and $0.03x10^{-2}$–0.05 μg/mL, respectively. Plates were incubated at 37 °C in 5% CO_2 in a humidified atmosphere for 3 days. The toxicity effects of the extracts on the B16-F10 cells were assayed using the sodium 3'-[1-(phenyl amino-carbonyl)-3,4-tetrazolium]-bis-[4-methoxy-6-nitrobenzene sulphonic acid hydrate (XTT) cytotoxicity assay. Thereafter, 50 μL of XTT reagent (1 mg/mL XTT with 0.383 mg/mL penazine methosulphate) was added to the wells and incubated for 1 h. The optical densities of the wells were measured at 450 nm with background subtraction at 690 nm. Cell survival was assessed by comparison with the controls (medium with DMSO). The EC_{50} value, which represents the concentration of plant extract that causes death in 50% of the cells, was analysed using GraphPad Prism version 4.

Statistical analysis

All the assays were performed in triplicate with three independent studies for each assay. EC_{50} values for antioxidant and cytotoxicity tests were derived from a non-linear regression model (curve fit) based on a sigmoidal dose response curve (variable) and computed using GraphPad Prism version 4 (GraphPad, San Diego, CA, USA).

Results

Antibacterial activity of ethanolic extracts

The antibacterial activity of the selected plants against *P. acnes* is summarised in Table 2. After the addition of *p*-iodonitrotetrazolium salt, the MIC value of the positive drug control (tetracycline) was determined to be 3.1 μg/mL. Most of the plants exhibited antibacterial activity at MIC values ranging from 62.5 μg/mL to 500 μg/mL. The ethanolic bark extract of *Acacia galpinii* Burtt Davy. (Leguminosae) exhibited the lowest MIC value of 62.5 μg/mL. Some of the plant extracts – *Aspalathus linearis* (Burm.f.) R.Dahlgren (Leguminosae), *Combretum apiculatum* Sond. (Combretaceae), *Combretum molle* Engl. & Diels (Combretaceae), *Galenia africana* L. (Aizoaceae), *Greyia sutherlandii* Hook. & Harv. (Greyiacece), *Harpephyllum caffrum* Bernh. ex Krauss (Anacardiaceae), *Ranunculus repens* L. (Ranunculaceae), *Sclerocarya birrea* Hochst. (Anacardiaceae) and *Warburgia salutaris* (G. Bertol.) Chiov. (Cancellaceae) – exhibited MIC values of 125 μg/mL. Another 28 extracts inhibited the growth of bacteria at MIC values ranging from 250 μg/mL to 500 μg/mL, whereas the remaining 10 extracts did not show any antibacterial activity, even at the highest concentration (500 μg/mL) tested. A threshold MIC value of ~100 μg/mL is suggested for rating plant extracts as having significant antimicrobial activity.[38] Therefore, the plant extracts exhibiting MIC values ranging from 62.5 μg/mL to 125 μg/mL were selected for the evaluation of antioxidant activity.

Antioxidant activity of selected extracts

Vitamin C, a widely used antioxidant compound, was used as the positive control (EC_{50} = 1.98 ± 0.005 μg/mL). The plant extracts which demonstrated excellent radical scavenging activity, comparable to vitamin C, were *A. linearis* (EC_{50} of 3.5 ± 0.5 μg/mL), *C. apiculatum* (EC_{50} of 1.6 ± 0.02 μg/mL), *H. caffrum* (EC_{50} of 2.6 ± 0.21 μg/mL) and *S. birrea* (EC_{50} of 2.06 ± 0.03 μg/mL) (Figure 1). The plant extracts of *C. molle* and *G. sutherlandii* also showed good antioxidant activity with EC_{50} values of 9.83 ± 0.8 μg/mL and 7.9 ± 0.23 μg/mL, respectively (Figure 1). *A. galpinii* and *R. repens* exhibited comparatively higher antioxidant activity with EC_{50} values of 16.05 ± 2.25 μg/mL and 24.7 ± 2.05 μg/mL, respectively. The extracts of *G. africana* and *W. salutaris* exhibited the lowest radical scavenging activity with the highest EC_{50} values of 90.92 ± 1.2 μg/mL and 111 ± 2.5 μg/mL, respectively.

Table 1: Medicinal use of plants selected for present study

Plant Name	Medicinal use
Acacia caffra Willd.	Treatment of blood disorders, infantile abdominal disorders[7]
Acacia galpinii Burtt Davy.	As a demulcent[8]
Acacia mellifera Benth.	Treatment of coughs, gastrointestinal ailments, malaria, pneumonia, stomach aches, sterility, skin diseases[9]
Aloe arborescens Mill.	Used in cosmetics; treatment of X-ray burns, stomach aches[7]
Aloe barbadensis Mill.	As an antioxidant; used in cosmetic application, wound healing[7,10,11]
Aloe ferox Mill.	Treatment of ophthalmia, venereal sores[7]
Aloe sessiliflora Pole-Evans.	Believed to promote menstruation; as enemas[7,12]
Anchusa capensis Thunb.	Used as a mutagenic and neurotoxin, and in traditional phytomedicine[13]
Annona senegalensis Pers.	Treatment of dermatological diseases and ophthalmic disorders[14]
Arbutus unedo L.	As anti-diarrhoeal, astringent, antioxidant, urinary antiseptic, depurative; treatment of diabetes and hypertension[15-18]
Aspalathus linearis (Burm.f.) R.Dahlgren	Used for alleviation of infantile colic, allergies, asthma, dermatological problems[12]
Barleria albostellata C. B. Clarke	As antibacterial, antifungal, anti-inflammatory, antioxidant and for acne inhibition[19]
Barleria repens Nees	As antibacterial, antifungal[19]
Broussonetia papyrifera (L.) Vent.	Treatment of stomach pains, ill-defined abdominal pains[20]
Buxus macowanii Oliv.	Treatment of gout, malaria, rheumatism, skin disorders[13]
Carpobrotus edulis (L.) Bolus	Treatment of infections of the mouth and throat, eczema, wounds and burns[12]
Ceratonia siliqua L.	As anti-diarrhoeal, antitussive, diuretic; treatment of warts[21]
Combretum apiculatum Sond.	Treatment of conjunctivitis, stomach disorders[7]
Combretum molle Engl. & Diels	As a anthelmintic; treatment of coughs, fever, stomach ailments, wounds[7]
Cotyledon orbiculata L.	Treatment of earache, toothache, epilepsy, boils and inflammation[7,12]
Cryptocarya woodii Engl.	Treatment of diarrhoea[22]
Dahlia imperialis Roezl	Treatment of skin ailments like rashes, grazes, infected scratches[23]
Datura stramonium L.	Treatment of abscesses and wounds; relieves asthma and reduces pain; remedy for boils[7,12]
Dichrostachys cinerea (L.) Wight & Arn.	Treatment of body pains, elephantiasis, sores and skin ailments, toothache[7,12]
Diospyros lycioides Desf.	Chewed and used as a toothbrush, and to ease body pains[7]
Dodonaea viscosa Jacq.	As antipruritic in skin rashes and fungal skin diseases[12]
Erythrophleum lasianthum Corbishley.	Treatment of fever, general body pains, headaches, intestinal spasms, migraines[7,12]
Euclea divinorum Hiern.	As chewing sticks for toothache, headaches; as a purgative; bark infusion is used to enhance appetite[7]
Euclea natalensis A.DC.	Treatment of bronchitis, chronic asthmas, pleurisy, toothache, urinary tract infections[7]
Galenia africana L.	Treatment of asthma, coughs, skin diseases, eye inflammation, venereal sores, wounds[24]
Gomphocarpus fruticosus R.Br.	Treatment of headache and tuberculosis and to relieve stomach pain and general aches in the body[7,12]
Greyia flanaganii Bolus.	To ward off sickness[25]
Greyia sutherlandii Hook. & Harv.	As emetics for biliousness[7]
Harpephyllum caffrum Bernh. ex Krauss	As blood purifiers, for facial saunas, skin washes; to treat acne and eczema[7,12]
Heteropyxis natalensis Harv.	Treatment of colds, bleeding gums, nosebleeds; as a vermifuge[7,12]
Hyaenanche globosa Lamb.	Treatment against vermins[13]
Knowltonia vesicatoria Sims.	Treatment of headaches, toothaches, skin blisters[12]
Magnolia grandiflora L.	Treatment of abdominal discomfort, blood pressure, dyspnoea, epilepsy, heart disturbances, infertility, muscle spasm[26,27]
Myrsine africana L.	As anthelmintics, blood purifier[28]
Parinari curatellifolia Planch. ex Benth.	Treatment of ailments of the eye or ear, pneumonia[29,30]
Ranunculus repens L.	Treatment of muscular aches, rheumatic pains, sores[31]
Rhus lancea L.f.	As antibacterial and antifungal[32]
Sclerocarya birrea Hochst.	Treatment of diarrhoea, inflammation, skin ailments, stomach ailments, malaria, ulcers[7,12]
Sideroxylon inerme L.	As skin lightener; to treat fevers; to treat gall sickness in stock[7,12,33]
Symphytum officinale L.	Treatment of arthritis, bruises, insect bites, inflamed bunions, wounds, skin conditions, nosebleeds, sunburn, rheumatism[34]
Warburgia salutaris (G. Bertol.) Chiov.	Treatment of influenza, rheumatism, malaria, venereal diseases, headaches, toothaches, dermatological disorders, gastric ulcers[7,12]
Zanthoxylum capense Harv.	Treatment of colic, stomach aches, toothaches, fever, epilepsy[7,12,35]

Table 2: Minimum inhibitory concentrations (MICs) for antibacterial activity of extracts against *Propionibacterium acnes* determined by microdilution assay

Plant name	Common name	Family	Voucher no.	Part used	MIC μg/mL
Acacia caffra	Cat thorn	Leguminosae	PRU 90700	Leaves	250
Acacia galpinii	Monkey thorn	Leguminosae	PRU 16209	Bark	62.5
Acacia mellifera	Blackthorn	Leguminosae	PRU 078373	Leaves	250
Aloe arborescens	Krantz aloe	Aloaceae	MN 5	Leaves	500
Aloe barbadensis	Aloe vera	Aloaceae	PRU 118947	Leaves	Na†
Aloe ferox	Red aloe	Aloaceae	PRU 110308	Leaves	Na†
Aloe sessiliflora	Lebombo aloe	Aloaceae	PRU 118948	Leaves	Na†
Anchusa capensis	Cape forget-me-not	Boraginaceae	Not available	Leaves	Na†
Annona senegalensis	White custard apple	Annonaceae	PRU 074974	Bark	250
Arbutus unedo	Strawberry tree	Ericaceae	PRU 6211000	Leaves	500
Aspalathus linearis	Rooibos	Leguminosae	PRU 110523	Leaves	125
Barleria albostellata	Grey barleria	Acanthaceae	PRU 096399	Leaves	500
Barleria repens	Small bush violet	Acanthaceae	PRU 081712	Leaves	250
Broussonetia papyrifera	Paper mulberry	Moraceae	PRU 51221	Leaves	500
Buxus macowanii	Cape box	Buxaceae	PRU 110526	Leaves	Na†
Carpobrotus edulis	Sour fig	Azioaceae	PRU 096398	Leaves	Na†
Ceratonia siliqua	Carob tree	Leguminosae	SM 95502	Leaves	Na†
Combretum apiculatum	Red bushwillow	Combretaceae	PRU 110531	Leaves	125
Combretum molle	Velvet bushwillow	Combretaceae	EP 81	Leaves	125
Cotyledon orbiculata	Pig's ear	Crassulaceae	PRU 096402	Leaves	Na†
Cryptocarya woodii	Cape laurel	Lauraceae	PRU 064439	Leaves	250
Dahlia imperialis	Dahlia	Asteraceae	PRU 3311010	Leaves	500
Datura stramonium	Thorn apple	Solanaceae	MN 8	Leaves	500
Dichrostachys cinerea	Sickle brush	Leguminosae	PRU 096403	Leaves	500
Diospyros lycioides	Blue brush	Ebenaceae	PRU 118949	Twigs	Na†
Dodonaea viscosa	Hopbrush	Sapindaceae	PRU 096404	Leaves	500
Erythrophleum lasianthum	Swazi ordeal tree	Leguminosae	PRU 110525	Leaves	250
Euclea divinorum	Magin gwarra	Ebenaceae	AJ 64	Leaves	250
Euclea natalensis	Natal guarri	Ebenaceae	PRU 95059	Leaves	250
Euclea natalensis	Natal guarri	Ebenaceae	NL 22	Roots	250
Galenia africana	Kraalbos	Aizoaceae	SM 93723	Leaves	125
Gomphocarpus fruticosus	Milkweed	Asclepiadaceae	MN 1	Leaves	250
Greyia flanaganii	Kei bottlebrush	Greyiaceae	P. Van Wyk 2274	Leaves	250
Greyia sutherlandii	Natal bottlebrush	Greyiaceae	PRU 118946	Leaves	125
Harpephyllum caffrum	Wild plum	Anacardiaceae	PRU 118950	Leaves	125
Heteropyxis natalensis	Lavender tree	Myrtaceae	PRU 096405	Leaves	250
Hyaenanche globosa	Hyaena poison	Euphorbiaceae	SM 95499	Leaves	250
Knowltonia vesicatoria	Blister-leaf	Ranunculaceae	PRU 096499	Roots	250
Magnolia grandiflora	Magnolia	Magnoliaceae	PRU 2651000	Leaves	250
Myrsine africana	African boxwood	Myrsinaceae	SM 95503	Stalks	500
Parinari curatellifolia	Mobola plum	Chrysobalanaceae	PRU 096215	Bark	250
Ranunculus repens	Creeping buttercup	Ranunculaceae	PRU 096416	Leaves	125
Rhus lancea	Karee	Anacardiaceae	PRU 110530	Leaves	250
Sclerocarya birrea	Marula	Anacardiaceae	NH 1910	Bark	125
Sideroxylon inerme	White milkwood	Sapotaceae	PRU 96216	Bark	250
Symphytum officinale	Comfrey	Boraginaceae	PRU 096414	Leaves	250
Warburgia salutaris	Pepper-bark tree	Cancellaceae	PRU 110529	Leaves	125
Zanthoxylum capense	Small knob wood	Rutaceae	PRU 096406	Leaves	Na†

†*Na, not active at the highest concentration (500 μg/mL) tested.*

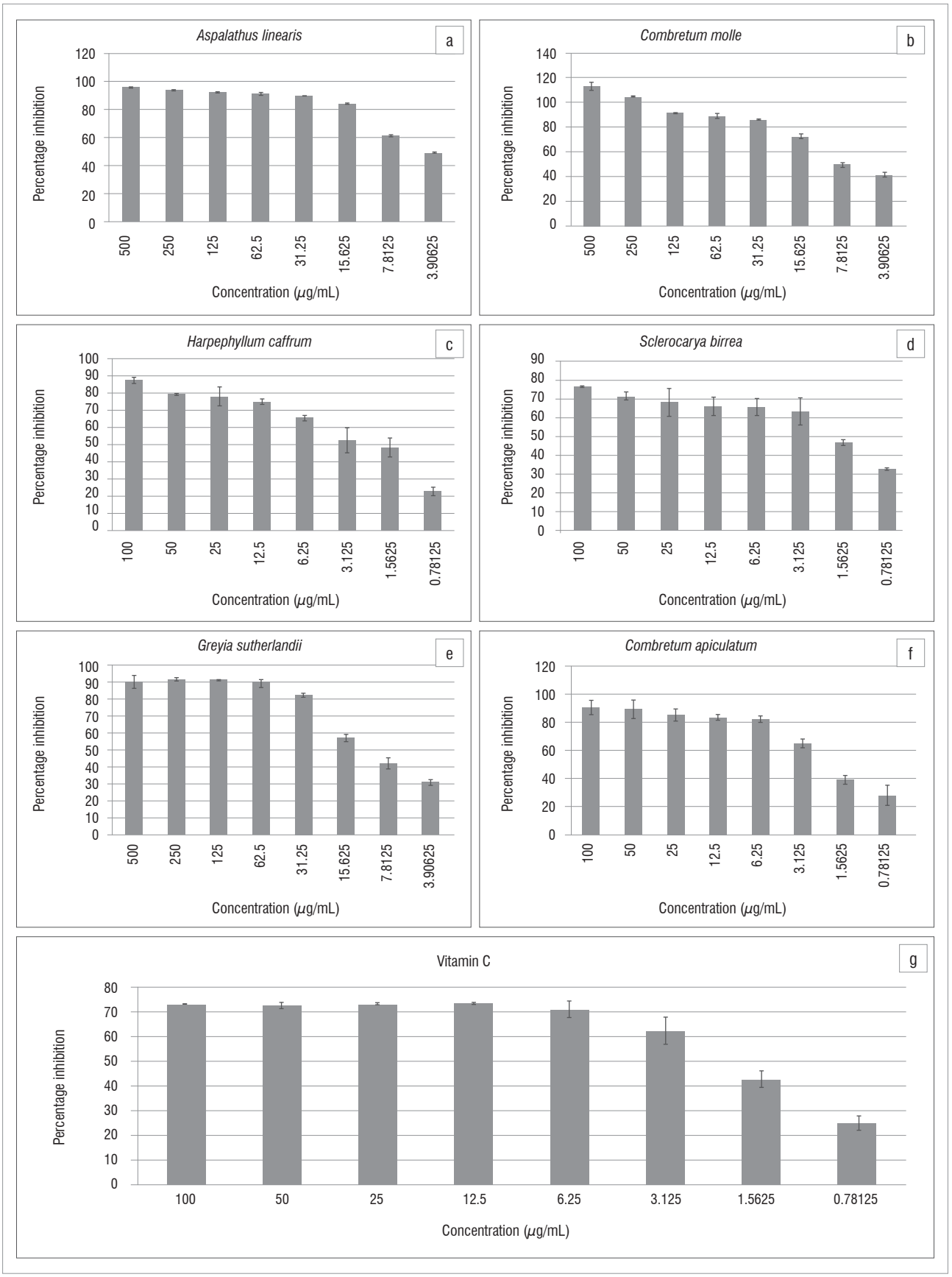

Figure 1: The DPPH radical scavenging activity of the potential extracts and the positive control (vitamin C): (a) *Aspalathus linearis* (EC_{50} = 3.5 ± 0.5 μg/mL), (b) *Combretum molle* (EC_{50} = 9.83 ± 0.8 μg/mL), (c) *Harpephyllum caffrum* (EC_{50} = 2.6 ± 0.21 μg/mL), (d) *Sclerocarya birrea* (EC_{50} = 2.06 ± 0.03 μg/mL), (e) *Greyia sutherlandii* (EC_{50} = 7.9 ± 0.23 μg/mL), (f) *Combretum apiculatum* (EC_{50} = 1.6 ± 0.02 μg/mL) and (g) vitamin C (EC_{50} = 1.98 ± 0.005 μg/mL).

Cytotoxicity of selected extracts

Cytotoxicity was assessed on the plant extracts which demonstrated EC_{50} values of ≤10 μg/mL for radical scavenging activity. The plant extracts of *A. linearis*, *G. sutherlandii* and *S. birrea* showed low toxicity with 50% viability of cells (EC_{50}) at concentrations of 125.09±0.71 μg/mL, 107.85±1.53 μg/mL and 92.07±0.09 μg/mL, respectively (Figure 2). During a previous study by our research group, the leaf extract of *H. caffrum* showed toxicity to B16-F10 cells at a concentration of 100 μg/mL.[39] The plant extract of *C. molle* showed moderate toxicity with an EC_{50} value of 48.83±0.21 μg/mL, whereas *C. apiculatum* was found to be the most toxic with an EC_{50} value of 12.15±0.03 μg/mL and was found to be lethal to almost all cells at the highest concentration of 400 μg/mL. Actinomycin D, the positive control, showed an EC_{50} value of $4.5x10^{-3} \pm 0.5x10^{-3}$ μg/mL (Figure 2).

Discussions

Plant extracts were explored for antibacterial activity against *P. acnes*. Similar to our findings, the ethanolic extract of *Coscinium fenestratum* (Gaertn.) Colebr. (Menispermaceae) inhibited the growth of *P. acnes* at an MIC value of 46 μg/mL.[40] According to Tsai et al.[41], methanolic extracts of *Rosa damascena* Mill (Rosaceae), *Eucommia ulmoides* Oliv. (Eucommiaceae) and *Ilex paraguariensis* A. St.-Hil. (Aquifoliaceae) inhibited the growth of *P. acnes* at MIC values of 2000 μg/mL, 500 μg/mL and 1000 μg/mL, respectively. To the best of our knowledge, the present study is the first scientific report of the antibacterial activity of all the selected plants against *P. acnes*. However, some of the plants used in this study have been previously reported to be active against other pathogens. In another study, leaf extracts of *A. linearis* showed zones of inhibition against *Bacillus cereus*, *Micrococcus luteus* and *Candida albicans* of 7.0 mm, 6.4 mm and 8.5 mm, respectively.[42] The antibacterial activity of *C. apiculatum* against *Staphylococcus aureus, Pseudomonas aeruginosa* and *Escherichia coli* was reported by Serage[43]. The acetone extract of the stem bark of *C. molle* showed antimicrobial activity against *E. coli* and *Shigella* spp. at an MIC of 50 000 μg/mL. The extract also showed inhibitory effects on the fungus *C. albicans* with complete inhibition at a concentration of 400 μg/mL.[44] In a study done by Lining et al.[45], the crude methanolic extract of *Diospyros lycioides* Desf. (Ebenaceae) showed activity against *Streptococcus mutans* and *Prevotella intermedia* at an MIC of 1250 μg/mL. In contrast, our results showed no activity of the ethanolic extract of *D. lycioides* against *P. acnes*. In another study conducted by Mativandlela et al.[46], the ethanolic extract of *G. africana* showed antimycobacterial activity against *Mycobacterium tuberculosis* and *Mycobacterium smegmatis* at MIC values of 780 μg/mL and 1200 μg/mL, respectively. The ethanolic extract of *H. caffrum* was reported to be active against four bacterial species, namely *Bacillus subtilis*, *E. coli*, *Klebsiella pneumoniae* and *S. aureus,* while an aqueous extract showed activity against *C. albicans*.[47] The acetone extracts of the bark and leaves of *S. birrea* were reported to be active against *S. aureus*, *P. aeruginosa*, *E. coli* and *Enterococcus faecalis* at MIC values ranging from 150 μg/mL to 3000 μg/mL.[48] In a study done by Motsei et al.[49], the leaf extracts of *W. salutaris* inhibited growth of *C. albicans* at MIC values ranging from 12 500 μg/mL to 25 000 μg/mL and the bark extracts showed growth of inhibition against *S. aureus*, *Staphylococcus epidermis*, *B. subtilis* and *E. coli*.[50] No reports regarding the antimicrobial activity of *G. sutherlandii* and *R. repens* were found in the literature. However, in the present study, both of these plants showed growth inhibitory activity against *P. acnes* at an MIC of 125 μg/mL. In a study conducted by Eloff and Katerere[51], the acetone and chloroform leaf extracts of *A. galpinii* inhibited the growth of *S. aureus* and *E. coli*. Similar to our findings, the ethanol bark extract of

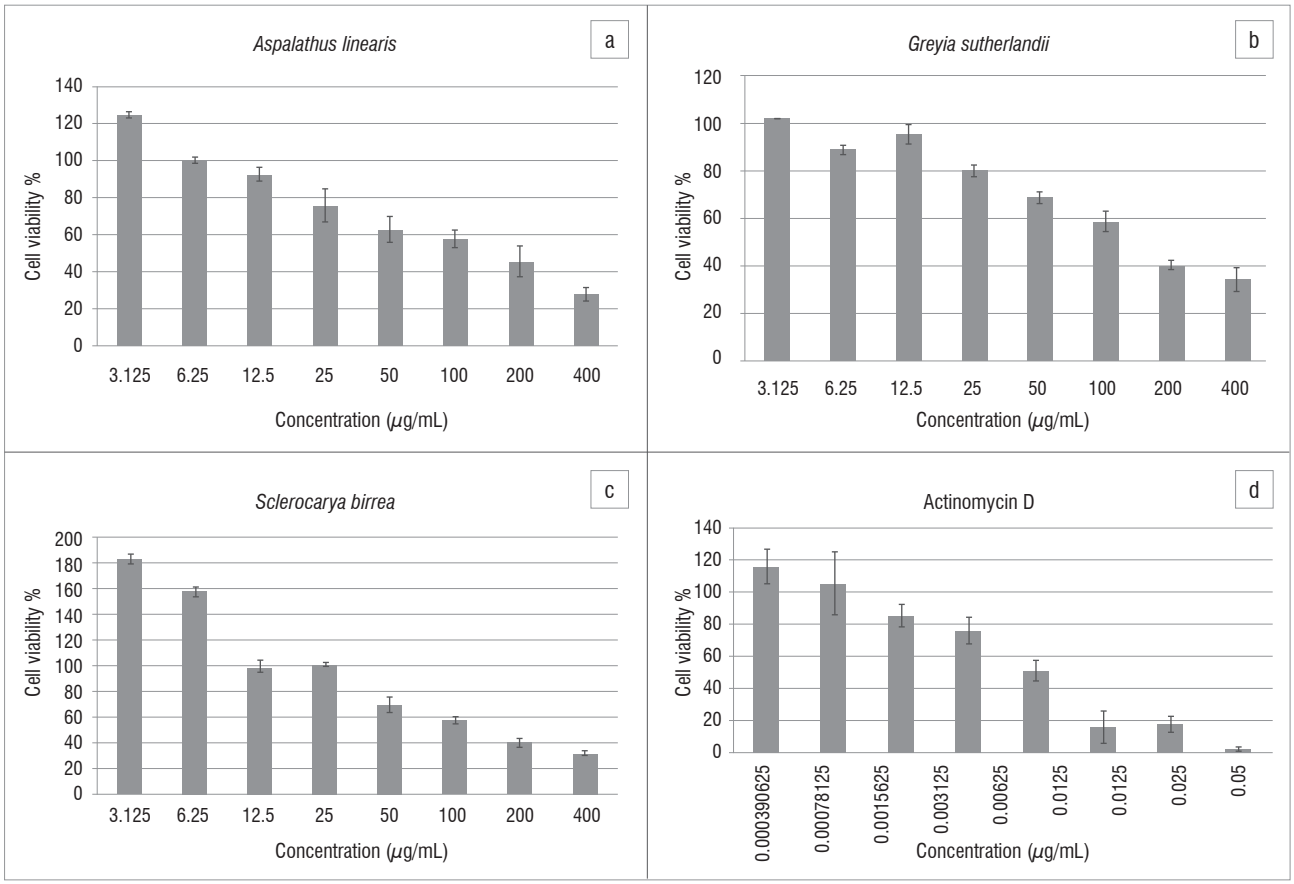

Figure 2: The cytotoxic effects of the plant extracts and the positive control (actinomycin D) on mouse melanocytes B16-F10: (a) *Aspalathus linearis* (EC_{50} =125.09±0.71 μg/mL), (b) *Greyia sutherlandii* (EC_{50} =107.85±1.53 μg/mL), (c) *Sclerocarya birrea* (EC_{50} =92.07±0.09 μg/mL) and (d) actinomycin D (EC_{50} =$4.5x10^{-3} \pm 0.5x10^{-3}$ μg/mL).

A. galpinii exhibited good inhibitory effect on *P. acnes* (MIC 62.5 μg/mL). However, no reports on the antimicrobial activity of bark extracts of *A. galpinii* were found in the literature.

Acne is associated with the production of free radicals along with the infection of *P. acnes*. Reactive oxygen species are produced as a result of the action of hydrolytic enzymes released from bacteria on the follicular walls of pilosebaceous units. Therefore, the plant extracts were evaluated for antioxidant activity along with antibacterial activity. In our study, the ethanol extracts of *A. linearis, C. apiculatum*, *H. caffrum*, *S. birrea, C. molle* and *G. sutherlandii* exhibited significant antioxidant activity with EC_{50} values of $\leq$10 μg/mL. Our results are in agreement with other researchers. During a previous study by Joubert et al.[52], the DPPH radical scavenging activity of *A. linearis* and its constituents were confirmed. The polar fractions of *C. apiculatum* showed antioxidant activity with an EC_{50} value of 3.91 μg/mL.[53] The DPPH radical scavenging activity of *H. caffrum* and *S. birrea* was confirmed by Moyo et al.[54] with EC_{50} values of 6.8 μg/mL and 5.02 μg/mL, respectively. In another study, acetone and dichloromethane extracts of *C. molle* displayed antioxidant activity after spraying with DPPH.[55] It has been reported that DPPH free radicals abstract the phenolic hydrogen of the electron-donating molecule, which could be the general mechanism for the scavenging action of flavonoids.[56] Based on the mechanism of reduction of the DPPH molecule that is correlated with the presence of hydroxyl groups on the antioxidant molecule, the antioxidant activity of the polar plant extracts in the present study can be explained as a result of the presence of their phytoconstituents (phenolics or flavonoids) which are radical scavengers with an available hydroxyl group and are known to occur abundantly in plant species.

In order to evaluate the therapeutic potential of the plants, the cytotoxicity of selected samples was tested on B16-F10 cells. To the best of our knowledge, the cytotoxicity of the extracts described in the present study is reported for the first time. However, previous researchers have documented similar cytotoxic effects on different cell lines. In a study by McGaw et al.[57], *A. linearis* showed low toxicity on vero cells and brine shrimp larvae with LD_{50} values of >1000 μg/mL. *S. birrea* showed low cytotoxicity on vero cells with an IC_{50} value of 361.24 μg/mL.[58] According to previous studies by Fyhrquist et al.[59] on the cytotoxicity of *C. molle*, the extract showed IC_{50} values of 27.7 μg/mL, 72.6 μg/mL and 42.6 μg/mL on T24 (bladder carcinoma), HeLa (cervical carcinoma) and MCF-7 (breast carcinoma) cells, respectively, while the *C. apiculatum* extract showed IC_{50} values of 65.0 μg/mL and 40.1 μg/mL for T24 and MCF-7 cells, respectively. No records of cell cytotoxicity for *G. sutherlandii* were found in the literature.

The results shown in this study prove the capability of medicinal plants as anti-acne agents, although the mode of action and in vivo studies are required to give conclusive results.

Conclusions

Based on the results obtained, it can be concluded that the ethanol bark extract of *A. galpinii* demonstrated the best activity against *P. acnes* with acceptable antioxidant activity. This plant might have other attributes that were not investigated in the present study which could be useful in the treatment of *P. acnes*. Although the plant extracts of *H. caffrum, C. apiculatum* and *C. molle* showed good antibacterial and excellent antioxidant activity, these samples also showed moderate toxicity to mouse melanocyte cells. The plant extracts of *A. linearis, S. birrea* and *G. sutherlandii* also exhibited good antibacterial and antioxidant activity but had low toxicity to the mouse melanocytes; these extracts therefore have potential as anti-acne agents, either alone or in combination.

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Authors' contributions

R.S. conducted the experiments and drafted the manuscript; N.L. supervised the work and edited the manuscript.

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Enterprise richness as an important characteristic of South African towns

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Towards the end of the 20th century there were almost 500 small towns of fewer than 50 000 persons in South Africa, accommodating about one tenth of the country's population. Little was known or said in national debates about the future of these places. A decade later this situation had changed and many studies have been or are being undertaken on small towns. For instance, the South African Government recognised that to stem the continued migration from rural to urban areas, a different approach was needed to economic development in rural municipalities and a 'Small Towns Regeneration Project' was initiated. Concerns about a perceived decline of rural towns also stimulated a quest to develop or find methods and/or measures to monitor the well-being of towns. Elsewhere in the world, small and medium enterprise 'observatories' were established to study and report on all aspects of small and medium enterprises, an approach recently followed in South Africa. New ways are needed to improve our understanding of the enterprise dynamics of South African towns. In this contribution, we examine the potential utility of the enterprise richness (i.e. the number of enterprise types) of South African towns and show that enterprise richness has a strong and fully quantifiable relationship with the total number of enterprises in the towns. This contribution adds a new dimension to the capability to make predictions about the enterprise structures of South African towns.

Introduction

The role of lower-order urban centres in regional development constitutes an important subject of debate[1] both internationally and in South Africa, which has seen a dramatic rise in scholarship on small town geographies since 2000.[2] A large number of empirical case studies form part of this scholarship. Two broad strands of enquiry related to small towns in South Africa have dominated recent writings.[3] The first focused on small town growth and development potential, particularly local economic development, and the second strand focused on various new rural and small town activities relative to debates on post-productivist landscapes.[3]

A third strand of investigation originated from ideas about the similarities between economic wealth and biological wealth. Beinhocker[4] is adamant that economic wealth and biological wealth are thermodynamically the same sort of phenomena. He stated that both are systems of low entropy and patterns of order that have evolved over time under constraint of fitness functions. Like each living organism, each individual enterprise is also in constant competition for survival and only the fittest survive. The similarities between living organisms and enterprises offer the opportunity to transfer lessons learnt from natural ecology to enterprise development in towns. The third-strand studies built on these possibilities.

The latter studies followed two broad themes. Firstly, they explored the interface between natural ecology and regional geography. It was concluded on the basis of norms set for natural ecosystems that towns are 'enterprise ecosystems'.[5] Based on the similarities between biological species and enterprises and consideration of the well-known species equilibrium model[6] of natural ecology, it was concluded that towns in the Karoo can conceptually be viewed as islands in a sea of farms, and the extent to which entrepreneurs successfully crossed the sea and established enterprises in available entrepreneurial spaces in the towns, determined the enterprise architectures of the latter.[7]

Secondly, a large number of business sector proportionalities (i.e. statistically significant correlations between the enterprise numbers in specific business sectors and total enterprise numbers of towns) were reported for a large group of South African towns[8] as well as for Karoo towns[9]. Such proportionalities also occurred in the tourism sector of towns in arid and semi-arid South Africa.[10] These studies revealed additional ways in which the enterprise dynamics of South African towns could be understood and predicted.

A logical conclusion of Beinhocker's[4] views is that the organisms that survive the competitive forces in natural ecosystems determine their biological diversity. Likewise, surviving enterprises determine the enterprise diversity, and hence the enterprise architecture, of towns. Examination of the utility of diversity concepts used in natural ecology could, therefore, be useful in developing an understanding of the enterprise diversity of South African towns.

The biological diversity of the earth has, ever since Wallace and Darwin, been a source of amazement and curiosity, and an area of formal inquiry. Tilman[11] remarked:

> *We still do not know, for example, how hundreds of plant species and thousands of insect species coexist on a hectare of rainforest or prairie, or how millions of species coexist on earth.*

This lack of understanding is also broadly true for the coexistence of enterprises in towns.

There are basically three reasons for natural ecologists' interest in ecological diversity and its measurement: (1) it is a central theme in ecology, (2) measures of diversity are often used as indicators of the well-being of ecological systems and (3) considerable debate surrounds the measurement of diversity.[12] Magurran[12] stated that biological diversity is like an optical illusion: the more it is looked at, the less clearly defined it appears to be.

There is, however, a simple explanation for why biological diversity is so hard to define, which consists of two components: (1) the variety of and (2) the relative abundance of species.[12] Biological diversity is, therefore, measured by recording the number of species, by describing their relative abundances or by using a measure that combines the two components.[13] The term 'species richness' should be used to refer to the number of natural species in a given area or in a given sample.[14] The equivalent term in economic geography is 'enterprise richness', which is used in this contribution.

In the context of enterprise dynamics, questions can be raised about how enterprises coexist in towns. In pursuing this issue we can build on the knowledge and experience of natural ecology. A number of natural ecological diversity indices have been derived using some combination of the number of biological species recorded in natural ecosystems (= species richness) and the total number of individuals summed over all species.[12] A widely used diversity index is the Margalef (D_{Mg}) Index[13]:

$$DMg = (S - 1)/ln\ N \qquad \text{Equation 1}$$

where S is the number of different species observed and N is the total number of individuals recorded.

The Margalef Index simply states that in natural ecosystems the species richness is a function of the natural log of the total number of individuals present. An ecosystem that is able to carry more individuals will have a greater species richness than ecosystems that can carry fewer individuals and the differences are totally quantifiable. If the same is true for the enterprise richness of South African towns and the relationship can be quantified, a powerful predictor of the link between the total number of enterprises of South African towns and their enterprise richness could be gained.

It is important to note that functional diversity in natural ecosystems differs from species diversity.[15] Functional diversity reflects the extent of functional differences among the species in a natural community. An enterprise diversity index, a functional index based on the relative presence of 19 different business sectors in South African towns, was inter alia used to examine functional differences between towns in water abundant and water poor areas of South Africa.[16] However, mathematical modelling of the enterprise richness (i.e. enterprise types) of South African towns has not been studied before – a situation which is addressed in this contribution.

The primary purpose of this study was to examine if there is a statistically significant relationship between the number of enterprise types (i.e. enterprise richness and not just functional types) and the total number of formal enterprises present in South African towns.

Over the past three decades, one of the more controversial issues in natural ecology has been the hypothesis that greater diversity and trophic complexity in natural ecosystems increase population and ecosystem stability.[17] This concept has been repeatedly challenged[18,19] but still remains a possibility.[11]

Are towns with a greater enterprise richness more stable than towns that are less enterprise rich? A possible answer could be derived from comparing different types of towns. Groups of South African towns have been identified based on their enterprise structures.[8] A secondary purpose of the study was, therefore, to examine the enterprise richness–enterprise number relationships of different groups of South African towns in order to determine whether such relationships, if they exist, could be used as indicators of town (i.e. enterprise ecosystem) stability.

Methods and results

Enterprise architectures and enterprise richness of towns

In total, 134 towns (Table 1) were examined in this study. There was no logic to the choice of the towns apart from the fact that they were, at the time of writing, part of a database of the enterprise architecture of South African towns. The selected towns were from eight South African provinces (Table 1) and represented a large subset of South African towns.

Town data was obtained as follows. A list of all enterprises in a specific town was prepared from telephone directories as described by Toerien and Seaman[5]. Each enterprise was allocated to one of 19 business sectors[5] (Table 2) by examining and/or 'Googling' its name. If it was impossible to determine the sector in which the enterprise functioned it was ignored in further analyses.[5] The enterprise type was then identified. For example, an enterprise with a name such as Union Wholesale Traders would be allocated to the trade services sector and the enterprise type would be recorded as a wholesaler. Salon Isabel would be allocated to the personal services sector and be identified as a beauty parlour. We previously identified more than 500 different enterprise types in our database of South African towns and these were used to allocate the enterprise types. For each town, we recorded: (1) a business profile consisting of the number of enterprises in each of 19 business sectors and the enterprises expressed as percentages of the total number of enterprises per town and (2) the number of different enterprise types (Table 1).

Statistical distribution of enterprise numbers

The selection of 134 towns contained many more small than large towns (Table 1). Statistica 12® software was used to examine the statistical distribution of the enterprise numbers of the selected towns. The median number (73 enterprises per town) was appreciably lower than the average number (138 enterprises per town) and the enterprise numbers were clearly not normally distributed. Further analysis showed that the enterprise numbers of the 134 towns had a log-normal distribution. This distribution suggested that, in order to test a hypothesis that enterprise richness is statistically related to enterprise numbers, an approach similar to that of Margalef could be followed.

Enterprise richness of a large group of South African towns

We related the number of enterprise types observed (as the dependent variable) to the $\log_{10}$ values of the total number of enterprises observed in towns (the independent variable) and then tested the statistical significance of the resulting equation(s). Enterprise richness increased as the enterprise numbers of towns increased (Figure 1); the best-fit relationship was statistically highly significant ($p < 0.01$ and $n = 134$) and 97% of the variance was explained:

$$\text{Enterprise types in town}_A = 1.8086\ (\text{number of enterprises in town}_A{}^{0.7164}) \qquad \text{Equation 2}$$

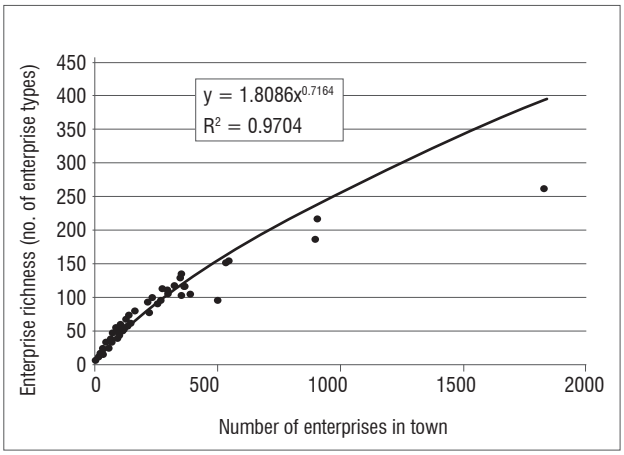

Figure 1: Enterprise richness as a function of the total enterprise numbers of 134 South African towns.

Bigger towns not only have more enterprises than smaller towns but also more enterprise types. The increase in enterprise richness is, however, not linear but moderates at higher enterprise numbers (Equation 2), similar to the Margalef Index in natural ecology. As towns grow, their 'entrepreneurial spaces'[9] increase in a predictable fashion (or vice versa).

Table 1: South African towns used in this study

Town	Province	Source†	No. of enterprises	No. of types	Town	Province	Source†	No. of enterprises	No. of types	Town	Province	Source†	No. of enterprises	No. of types
Aberdeen	EC	g	39	31	Hartswater	NC	g	295	107	Prieska	NC	g	108	56
Albertinia	WC	d	93	49	Heidelberg	WC	d	115	51	Prince Albert	WC	h	82	42
Alexander Bay	NC	g	55	34	Hobhouse	FS	h	10	10	Richmond	NC	b	30	17
Aliwal-North	EC	e	266	95	Hofmeyr	EC	g	17	13	Riversdal	WC	d	232	99
Allanridge	FS	f	22	16	Hopetown	NC	g	70	49	Riviersonderend	WC	c	67	40
Ashton	WC	c	73	41	Jacobsdal	FS	g	42	33	Robertson	WC	c	323	116
Augrabies	NC	g	41	22	Jagersfontein	FS	g	28	21	Rosendal	FS	g	11	9
Barkly-West	NC	g	77	43	Jan Kempdorp	NC	g	121	61	Rouxville	FS	g	32	19
Barrydale	WC	d	56	26	Jansenville	EC	g	47	28	Sannieshof	NW	a	84	57
Beaufort-West	WC	g	353	104	Kakamas	NC	g	138	69	Schweizer-Reneke	NW	a	224	92
Bethulie	FS	g	43	30	Kathu	NC	g	135	71	Senekal	FS	g	132	63
Bloemhof	NW	g	120	64	Keimoes	NC	g	101	53	Smithfield	FS	g	35	23
Bonnievale	WC	c	122	53	Keimouth	EC	g	35	16	Springfontein	FS	g	23	19
Boshof	FS	h	39	27	Kenhardt	NC	h	29	23	Steynsburg	EC	g	39	28
Bothaville	FS	f	241	94	Kleinmond	WC	c	210	93	Steytlerville	EC	g	30	23
Botshabelo	FS	f	223	78	Klipplaat	EC	g	15	11	Stilbaai	WC	g	199	93
Brandfort	FS	h	91	50	Koffiefontein	FS	g	43	34	Struisbaai	WC	d	103	45
Brandvlei	NC	h	22	16	Komga	EC	e	52	31	Strydenburg	NC	h	17	14
Bredasdorp	WC	d	274	113	Ladismith	WC	d	88	42	Stutterheim	EC	e	152	79
Britstown	NC	g	27	17	Ladybrand	FS	h	252	91	Sutherland	WC	f	35	21
Bultfontein	FS	g	102	47	Laingsburg	WC	g	56	30	Swellendam	WC	h	342	120
Burgersdorp	EC	g	115	66	Lime Acres	NC	g	42	31	Tarkastad	EC	g	42	32
Caledon	WC	c	245	94	Loeriesfontein	NC	h	29	22	Taung	NC	g	91	45
Calitzdorp	WC	d	54	27	Loxton	NC	h	7	7	Thabazimbi	LIM	f	323	118
Calvinia	NC	g	110	56	Luckhoff	FS	h	16	14	Thohoyandou	LIM	f	499	95
Carnarvon	NC	g	58	37	Lutzville	WC	c	72	48	Trompsburg	FS	g	38	23
Christiana	NW	g	137	59	McGregor	WC	g	38	23	Tulbagh	WC	c	158	72
Clarens	FS	g	126	51	Middelburg (EC)	EC	f	161	79	Uniondale	WC	f	42	28
Clocolan	FS	g	90	50	Montagu	WC	d	224	93	Upington	NC	g	906	216
Colesberg	EC	g	144	58	Mookgophong	LIM	f	227	87	Vanderkloof	NC	g	18	15
Cradock	EC	g	296	111	Mtubatuba	KZN	g	362	116	Vanwyksvlei	NC	h	8	7
De Aar	NC	g	223	89	Murraysburg	WC	e	21	16	Venterstad	EC	e	18	14
Douglas	NC	g	127	70	Napier	WC	f	63	36	Victoria West	WC	a	74	43
Dullstroom	MP	d	101	44	Nieu-Bethesda	EC	e	21	9	Viljoenskroon	FS	f	131	72
Fauresmith	FS	g	22	15	Nieuwoudtville	NC	h	30	19	Vosburg	NC	a	16	14
Ficksburg	FS	g	299	105	Norvalspont	FS	e	8	6	Vredendal	WC	c	351	134
Fraserburg	NC	g	33	22	Orania	NC	g	28	23	Wakkerstroom	MP	d	30	20
Gansbaai	WC	c	254	91	Oudtshoorn	WC	f	897	186	Warrenton	NC	g	90	52
Gariepdam	FS	g	21	14	Parys	FS	h	532	152	Welkom	FS	f	1830	262
Garies	NC	g	26	16	Petrusville	NC	f	17	14	Williston	NC	a	26	21
Graaff-Reinet	EC	e	329	130	Phalaborwa	LIM	f	543	154	Willowmore	EC	e	49	25
Great Brak River	WC	f	148	71	Philippolis	FS	f	24	15	Winburg	FS	f	73	35
Greyton	WC	c	59	36	Philipstown	NC	f	15	13	Winterton	KZN	h	117	63
Griekwastad	NC	g	31	23	Phuthaditjhaba	FS	f	387	105	Yzerfontein	WC	c	52	29
Hanover	NC	g	22	13	Porterville	WC	c	93	52					

EC, Eastern Cape; FS, Free State; LIM, Limpopo; MP, Mpumalanga; NC, Northern Cape; NW, Northwest; WC, Western Cape.

†Year of telephone directory: a = 2000/2001; b = 2002/2003; c = 2004/2005; d = 2005/2006; e = 2006/2007; f = 2007/2008; g = 2008/2009; h = 2009/2010

For example, should (for whatever reason) the total number of enterprises of a town increase from 100 to 200, Equation 2 predicts that the enterprise richness will increase from 49 to 81, an increase of 32 types. Similarly, if a town degenerates and its total enterprises reduce from 200 to 100, the enterprise types present will decrease from 81 to 49 types. However, if a town's total enterprises rose from 200 to 300, the change in enterprise types would be from 81 to 108, a mere increase of 27 types (or vice versa). As towns get bigger, the enterprise richness grows at a slower rate than the total enterprises. In other words, the 'entrepreneurial space' for similar enterprise types increases, increasing the likelihood of heightened competition between peer group enterprises. The contrary is also true – if a town degenerates, it sheds entrepreneurial space and enterprises in a predictable fashion.

Close examination of Figure 1 indicates that at higher enterprise numbers the best-fit line does not fit the data very closely. Because smaller towns dominate the group of selected towns (Table 1), it is possible that their influence might have introduced a degree of spuriousness in the enterprise number–enterprise richness response of Figure 1. To test this possibility we divided the selected towns into two groups: Group 1 – small towns (88 towns with fewer than 115 enterprises per town) and, Group 2 – large towns (46 towns with 115 or more enterprises). The relationship between enterprise richness and the enterprise numbers of each of these groups was determined as described earlier and the results are presented in Figures 2 and 3.

Table 2: The business sectors used for determining the enterprise architectures of the selected towns

No.	Economic drivers
1	Agricultural Products & Services
2	Processors
3	Factories
4	Construction Services
5	Mining
6	Tourism & Hospitality Services
	Service sectors
7	Engineering & Technical Services
8	Financial Services
9	Legal Services
10	Telecommunications Services
11	News & Advertising Services
12	Trade Services
13	Vehicle Services
14	General Services
15	Professional Services
16	Personal Services
17	Health Services
18	Transport & Earthworks Services
19	Real Estate Services

The statistical relationships of the two groups, i.e.:

$$\text{Enterprise types in small town}_{ST} = 1.44\ (\text{number of enterprises in town}_{ST}^{0.7789}) \quad \text{Equation 3}$$

and

$$\text{Enterprise types in large town}_{LT} = 4.1293\ (\text{number of enterprises in town}_{LT}^{0.5661}) \quad \text{Equation 4}$$

were statistically highly significant ($p<0.01$) and in excess of 90% of the variance of both groups was explained.

To understand the differences among Equations 2, 3 and 4, we used the equations to predict the enterprise richness of towns of different sizes (Table 3). For lower enterprise numbers, the predictions of the 'all town' (Equation 2) and 'small town' (Equation 3) models were very similar. From 100 to 200 enterprises, the 'all town' model lagged behind the other two models but at higher values it exceeded the 'large town' model considerably. From about 200 enterprises, the 'small town' model started exceeding the 'large town' (Equation 4) model. Below 100 enterprises, the predictions of the 'large town' model exceeded those of the two other models. Taken together, it is clear that town size has some effect and it is advisable to use the small town model for predictions of the enterprise richness of towns with up to 150 enterprises. For predictions for towns with more than 150 enterprises, the 'large town' model should be used.

Table 3: Predictions of enterprise richness for towns with different enterprise numbers

	Derived from model		
Number of enterprises	All towns†	Small towns††	Large towns†††
10	9	**9**	15
50	30	**30**	38
100	49	**52**	56
150	66	**71**	**70**
200	81	89	**83**
300	108	122	**104**
1200	291	360	**229**
1800	389	494	**288**
2500	492	638	**346**

†From Equation 2; ††from Equation 3; †††from Equation 4

Numbers in bold indicate the recommended models for town size and number of enterprises.

Clusters of towns and enterprise richness

Although the small town data in Figure 2 clearly shows a strong relationship between enterprise numbers and enterprise types, it is also evident that there is quite a bit of data variation around the best-fit line. The earlier detection of so-called 'proportionality-in-proportionality' phenomena in the enterprise architectures of towns in arid and semi-arid South Africa[10] raised the question of whether the above variability could be a result of differences in the enterprise architectures of different groups of towns. The proportionality-in-proportionality term refers to a phenomenon in which a selection of South African towns exhibited an overall statistically significant correlation between town size (measured by the number of enterprises) and the number of enterprises in specific business sectors.[10] In these cases, specific regression coefficients defined the proportion of the total number of enterprises that sector enterprises constitute. Yet if the larger group was separated into sub-groups of towns with similar enterprise architectures, the above relationships were more clearly defined and distinct differences between the regression coefficients were observed. There was not only proportionality at an overhead level but also proportionality at lower levels; thus proportionality-in-proportionality.

To detect the possible presence of a proportionality-in-proportionality phenomenon in the overall enterprise numbers–enterprise richness relationship established here (Equation 2), the 134 towns were clustered on the basis of their enterprise architectures as described elsewhere.[5] Use was made of PRIMER v.6 software[20] and a complete linkage clustering strategy was used. Eight clusters (groups) with at least three member towns were identified at a correlation level of 0.55 (Figure 4 and Table 4). To identify differences between the clusters, the enterprise architecture of each cluster was calculated from the total enterprises for

Table 4: Towns in each of the clusters

Cluster 1	Cluster 2	Cluster 3			Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Brandvlei	Kenhardt	Aberdeen	Jan Kempdorp	Robertson	Ashton	Aliwal North	Albertinia	Augrabies	Barrydale
Britstown	Klipplaat	Allanridge	Kakamas	Sannieshof	Bethulie	Beaufort West	Gansbaai	Sutherland	Calitzdorp
Colesberg	Loxton	Barkly West	Kathu	Schweizer-Reneke	Bothaville	Bonnievale	Great Brak River	Vanwyksvlei	Clarens
Hanover	Vosburg	Bloemhof	Koffiefontein	Senekal	Brandfort	Calvinia	Kleinmond	Winterton	Dullstroom
Laingsburg		Boshof	Ladismith	Steynsburg	Bultfontein	Carnarvon	McGregor		Gariepdam
Richmond		Botshabelo	Ladybrand	Stutterheim	Christiana	Graaff-Reinet	Napier		Greyton
Vanderkloof		Bredasdorp	Lime Acres	Tarkastad	Clocolan	Griekwastad	Orania		Keimouth
		Burgersdorp	Loeriesfontein	Taung	Fauresmith	Komga	Stilbaai		Nieu-Bethesda
		Caledon	Lutzville	Thabazimbi	Fraserburg	Montagu	Struisbaai		Nieuwoudtville
		Cradock	Middelburg (EC)	Thohoyandou	Heidelberg	Mookgophong			Norvalspont
		De Aar	Mtubatuba	Upington	Hopetown	Oudtshoorn			Philippolis
		Douglas	Parys	Vredendal	Jansenville	Philipstown			Prince Albert
		Ficksburg	Phalaborwa	Warrenton	Keimoes	Rosendal			Wakkerstroom
		Garies	Phuthaditjhaba	Welkom	Luckhoff	Smithfield			Yzerfontein
		Hartswater	Porterville	Williston	Murraysburg	Springfontein			
		Jacobsdal	Prieska	Willowmore	Petrusville	Steytlerville			
		Jagersfontein	Riversdal	Winburg	Riviersonderend	Swellendam			
					Rouxville	Tulbagh			
					Trompsburg	Uniondale			
					Viljoenskroon	Venterstad			
						Victoria West			

each of the 19 business sectors expressed as a percentage of the total enterprises of each cluster (Table 5).

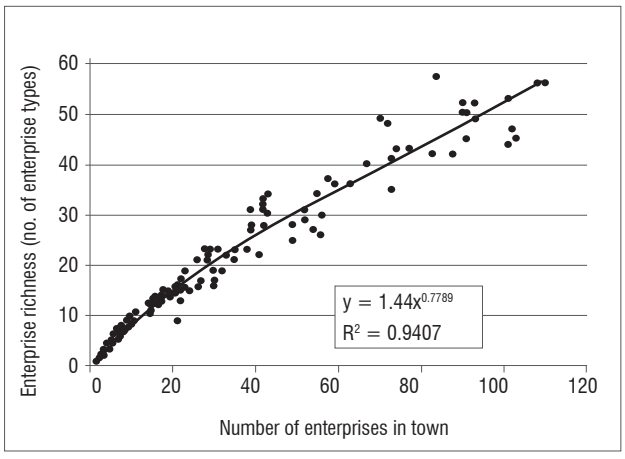

Figure 2: Enterprise richness as a function of the total enterprise numbers of 88 smaller (<115 enterprises per town) South African towns.

Each cluster received a designation based on the identity of towns clustered in it. 'Highway' towns (Cluster 1) are located on major routes and have strength in the tourism and hospitality, trade and vehicle services sectors. They differ from 'Tourism' towns (Cluster 5) mainly by way of a weaker construction sector but stronger tourism and hospitality and trade sectors. Three clusters have strength in the agricultural products and services sector. 'Small Agri' towns (Cluster 2) differ from 'Large Agri' towns (Cluster 4) and 'Agri Tourism' towns (Cluster 6) in terms of greater strength in the agricultural products and services and vehicle sectors. Large Agri towns are weaker in the agricultural products and services sector and in the tourism and hospitality sector, but have strength in the financial services, trade and vehicle sectors. Agri Tourism towns (Cluster 7) are strong in agricultural products and services and the tourism and hospitality sectors, but weaker in the trade, financial services and vehicle services sectors. Cluster 3 contains a large group of towns that are weak in the agricultural products and services sector, strong in the trade sector and have mostly well-balanced enterprise architectures – they are called 'Trade' towns. Cluster 8 towns are exceptionally strong in the tourism and hospitality sector as well as the real estate services sector but weaker in the trade sector; they are called 'Gentry' towns because gentrification is a significant factor in these towns (e.g. Clarens[21] and Prince Albert[22]).

The clusters differed greatly in their enterprise architectures (Table 5). As a consequence, the clusters met the requirement that different groups of towns could be used to test for proportionality-in-proportionality phenomena in enterprise number–enterprise richness relationships. These relationships and other characteristics were determined for each cluster through the use of Microsoft Excel (Table 6).

Table 5: The enterprise architecture (percentage composition) of Clusters 1 to 8. The top three sectors for each cluster (four in the case of Cluster 4) are shown in bold.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Agricultural Products & Services	6.9	**25.4**	4.9	**16.6**	4.9	1.5	**17.9**	4.6
Processing Plants	1.3	0.0	1.5	2.8	2.8	2.5	5.0	3.6
Factories	0.0	0.0	0.8	0.6	0.5	1.7	1.0	0.4
Construction	0.9	0.0	5.5	2.5	6.3	**12.2**	4.0	2.9
Mining	0.3	3.0	1.4	0.2	0.2	0.2	0.0	0.6
Tourism & Hospitality	**26.0**	9.0	**7.7**	6.0	**15.8**	**17.5**	**25.9**	**36.6**
Engineering & Technical Services	2.2	1.5	3.4	1.9	1.9	1.3	1.0	0.1
Financial Services	7.2	6.0	7.6	**9.2**	7.3	3.9	4.0	3.6
Legal Services	1.6	1.5	2.0	2.3	2.0	2.1	1.5	1.3
Telecommunications	0.6	4.5	1.1	0.3	0.7	0.6	0.0	0.3
News & Advertising	0.0	0.0	0.2	0.1	0.2	0.5	0.0	0.4
Trade	**20.7**	**17.9**	**27.2**	**26.2**	**25.0**	**23.1**	**18.9**	**20.1**
Vehicle industry	**12.9**	**10.4**	**9.2**	**9.2**	**7.7**	4.1	3.0	2.1
General Services	3.8	3.0	6.0	3.7	5.2	5.1	4.0	3.1
Professional Services	1.3	1.5	3.5	1.7	2.6	1.8	3.0	4.0
Personal Services	7.2	6.0	6.6	7.0	6.4	7.7	2.5	3.7
Health Services	4.7	7.5	7.1	5.6	5.9	4.5	2.0	4.9
Transport & Earthworks	1.3	1.5	2.4	2.4	2.1	2.1	2.0	1.7
Real Estate	1.3	1.5	1.8	1.7	2.6	7.6	4.5	**6.0**
Total	100	100	100	100	100	100	100	100
Designation	Highway	Small Agri	Trade	Large Agri	Tourism	Second Home	Agri Tourism	Gentry

Table 6: Cluster relationships between enterprise richness and enterprise numbers and other characteristics

Characteristic	Cluster							
	1	2	3	4	5	6	7	8
Model: y =	$1.667x^{.7105}$	$1.317x^{0.8353}$	$2.681x^{0.6436}$	$1.631x^{0.7486}$	$2.063x^{0.6891}$	$1.94x^{0.7077}$	$1.227x^{0.8084}$	$1.068x^{0.8178}$
Correlation	0.98	0.98	0.98	0.99	1.00	0.99	1.00	0.98
Variance explained (%)	96.7	96.5	96.1	97.4	99.0	97.7	98.9	95.2
No. in cluster	7	4	51	20	21	9	4	14
Enterprises in smallest town	18	7	22	16	11	28	8	8
Enterprises in largest town	144	29	1830	241	897	254	117	126
Median no. of enterprises	27	15.5	127	68.5	74	103	38	41

With the exception of Cluster 2, which has only small towns, all clusters contained a range of different-sized towns (Table 6). The composition of the enterprise architectures (Table 5) rather than the magnitude of enterprise development in towns defined specific clusters of towns. The statistical significance of the relationships between enterprise numbers and enterprise richness of the different clusters was highly significant in all cases and in no case was less than 95% of the variance explained. Figure 5 shows the enterprise number–enterprise richness relationship of Cluster 4 as a visual example of the goodness of fit obtained when cluster-level analyses were done. There is clearly some proportionality-in-proportionality within the enterprise number–enterprise richness relationship of the 134 towns (Equation 2), which could be discerned by examination at cluster level.

To test if the proportionality-in-proportionality phenomenon would introduce distortions that would have to be considered, the predictive powers of the cluster equations were examined by comparing predictions for a range of town sizes (expressed as the total number of enterprises in towns) and what was limited to the range of town sizes included in each cluster (Table 7). This exercise showed that the predictions stemming from the different cluster equations did not differ by much, particularly for larger towns (see Clusters 3 and 5 in Table 7). The relationship between enterprise richness and total enterprise number seems to hold for whatever group of towns is considered and seems to represent a general property of the enterprise dynamics of South African towns. Although there are subtle differences between clusters, at this time, Equations 3 and 4 should rather be used for predictive purposes.

Discussion and conclusions

There clearly is a quantitative link among the factors that control the growth or decline of towns, the total number of enterprises and enterprise richness. On the basis of the results presented, the hypothesis that the relative abundance of enterprises (= enterprise richness) in South African towns offers no or little potential to serve as a potential indicator of business well-being of towns can be rejected. Enterprise richness is

Table 7: Predictions of enterprise richness of the different town clusters at different enterprise numbers (predictions are limited to being close to the minimum and maximum enterprise numbers recorded in any town of a cluster)

No. of enterprises	Enterprise richness (no. of enterprise types)							
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
10		9		9	10		8	7
40	23	29	29	26	26	26	24	22
80	38		45	43	42	43	42	38
120	50		58	59	56	57	59	54
200			81	86	79	82		
300			105		105			
900			214		224			
1500			297					
2000			357					

one of the tools that may be useful in assessing the economic health of towns.

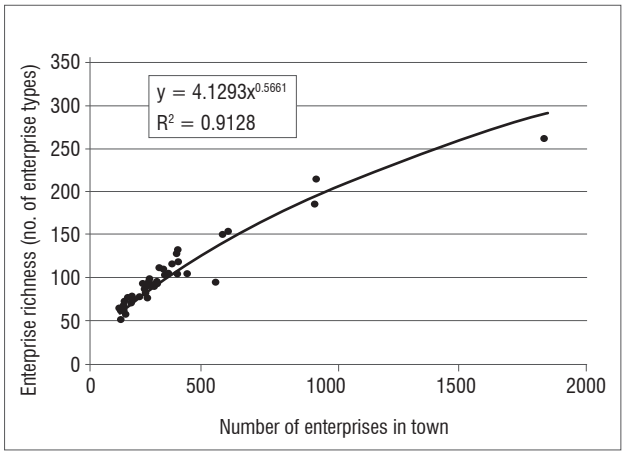

Figure 3: Enterprise richness as a function of the total enterprise numbers of 46 larger (>115 enterprises per town) South African towns.

The fact that the enterprise richness of South African towns increases with increased town size is not unexpected and could be inferred from earlier studies of South African towns.[23,24] In the 1960s and 1970s, the fashion (largely driven by a belief in central place theory[23]) was to construct town classification hierarchies based on the levels of services provided. For instance, Davies and Cook[24] identified eight different orders among 601 settlements in South Africa. However, Figures 1 to 3 and Figure 5 indicate that the increase in enterprise richness, and hence the level of business services provided in South African towns, is a continuous rather than a stepwise phenomenon (which the hierarchy approach of Davies and Cook seemed to infer). Our results caution against simply categorising towns on the basis of service levels.

Toerien and Seaman[25] applied systems thinking to enterprise dynamics in South African towns. They provided proof that the gross domestic products (GDPs) of towns drive the available money, which drives the number of people in the towns, which drives the total number of enterprises in the towns. Toerien and Seaman[8] showed that there are strong proportionalities between the total number of enterprises and the enterprise numbers of a wide range of business sectors in South African towns. This study now adds the fact that the enterprise richness of towns is distinctly and quantitatively linked to the total number of enterprises, which increases our predictive capabilities. The underlying reasons for the observed regularities in the numbers of enterprise types in South African towns are still obscure and deserve further research.

To illustrate the potential value of our results we turn to the burning issue of the potential use of hydraulic fracturing ('fracking') of shales in the Karoo for the exploitation of shale gas.[26] The potential benefits or detriments of such exploitation are being strongly debated,[27] but without any indication of what Karoo towns may gain or lose in terms of enterprise development. Toerien and Seaman[25] quantified some of the expected impacts and Table 3 provides further guidance. For instance, should fracking activities in the vicinity of a Karoo town with 100 existing enterprises result in an increase of 50 new enterprises, the enterprise richness would increase by 19 additional enterprise types. In other words, 31 of the new enterprises would enter business sectors that are already served by one or more existing enterprises. In addition to expanding the business services in the town there would be increased business competition in some business sectors. However, should pollution of groundwater as a result of fracking activities result in a loss of economic activities and 50 enterprises from a town of 150 enterprises, the contrary picture would emerge. Apart from 50 enterprises, 19 enterprise types would disappear, probably to the detriment of the residents. This predictive capability should be factored into considerations of the application of fracking in South Africa.

What views have guided the thinking about the developmental roles of small towns? In 1950 to 1970, small towns were seen as centres for innovation and modernisation in rural areas.[28] The concept of 'urban functions in rural development' suggested that a rational rural spatial strategy is to develop a well-articulated, integrated and balanced urban hierarchy.[29] Rural development would be promoted by locating more service supply points for a variety of services, agricultural inputs and consumer goods to the rural areas.[29] However, this approach was criticised on the grounds that low rural consumption is caused by social inequality and low incomes rather than by access difficulties.[30] Southall[31] suggested that small towns contribute to rural impoverishment in Africa because they are 'vanguards of exploitation' of the rural poor by external forces which, depending on the case, may be colonial powers, multinational enterprises, central national government, local administrators and élites and, in some cases, international donors. However, Hardoy and Satterthwaite[30] cautioned against universal generalisations and prescriptions and suggested that attention should be given to the social dimensions of small towns including the complexity of social networks, kinship and family ties. Later Hinderink and Titus[1] also challenged optimistic assumptions about the developmental role of small towns. They suggested that the divergent character of different contexts and differential impacts of regional conditions made generalisations about the role of small towns difficult.

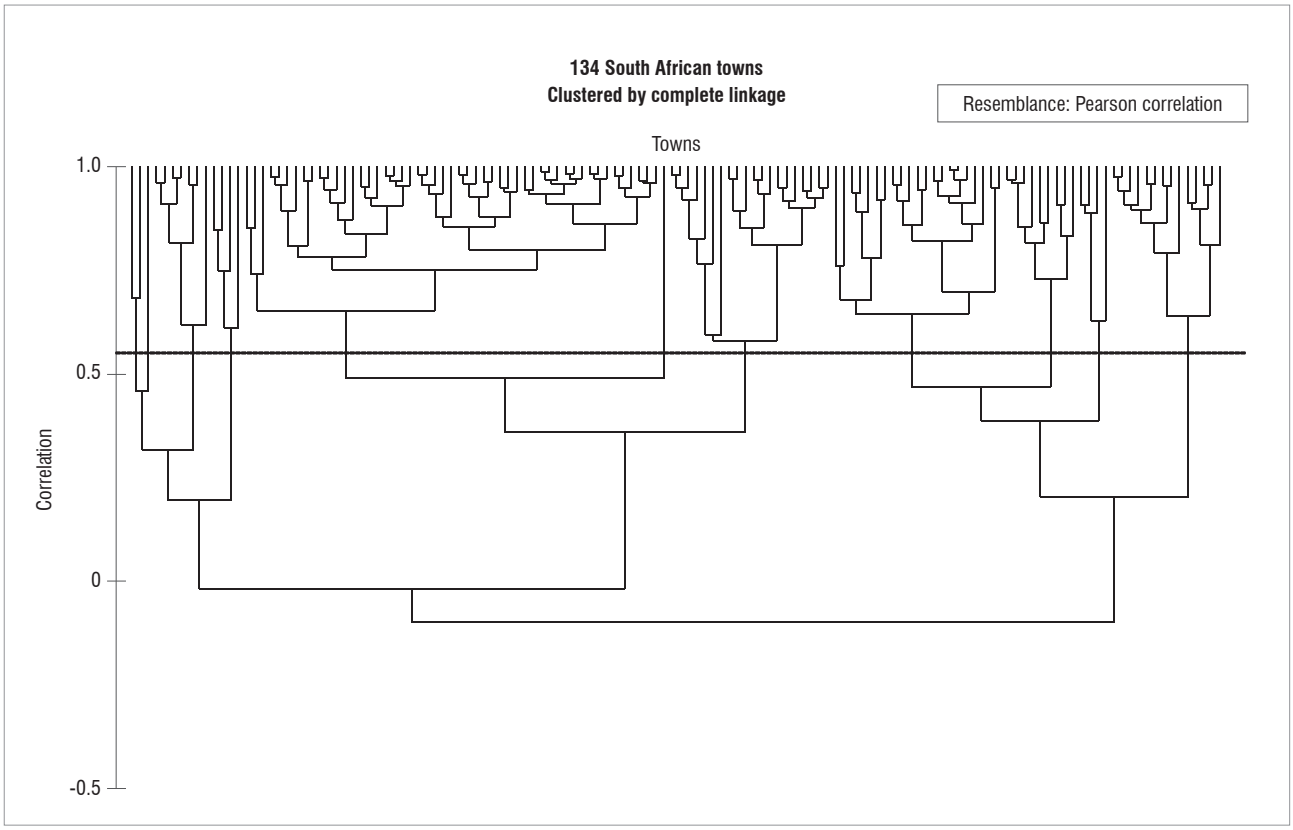

Figure 4: The enterprise architecture similarity dendrogram of 134 South African towns. Clusters 1 to 8 with four or more towns per cluster are identified at a correlation coefficient level of 0.55.

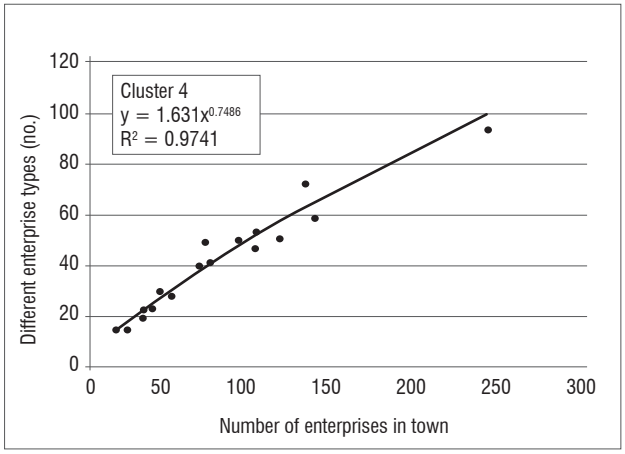

Figure 5: Enterprise richness as a function of the total enterprise numbers of Cluster 4 towns, illustrating the closeness of fit of cluster data.

Two core themes in modern literature are relevant in small town development dynamics in South Africa: locality-based development and post-productivism.[3] The former has its roots in locality theory and endogenous development theory and indicates that local resources, human assets and partnerships are important. This theme contributed to an emphasis on local economic development strategies.[3] This study raises questions about certain assumptions that seem to permeate thinking about local economic development, namely that training of entrepreneurs and promotion of entrepreneurship could solve many developmental problems. Our results emphasise the systemic nature of business development. The degree to which economic value is added through products and services that have a distinct external market is the foremost limiting factor. Entrepreneurial spaces have limits, and unless these limits are expanded, little success will be achieved. To paraphrase a comment made[25]: you cannot expect champagne outcomes from beer systems. The right leverage points must be sought to achieve success and the quantified insights developed here might be helpful tools in this regard.

The declining role of agriculture in South Africa as shown by a decline in the number of farmers and agricultural workers has contributed to an erosion of traditional livelihoods and the displacement of thousands of people.[3] A rise in post-productivist activities in rural South Africa such as the development of farm tourism, game farming and production of products for niche markets (e.g. olive products) have helped to bridge the decline of traditional agriculture[3] – a conclusion which is supported by the results presented in Table 5. Nevertheless, the dynamics of enterprise richness of South African towns remain overall the same irrespective of whether towns are productivist or post-productivist (Table 7). The usefulness of the application of the post-productivist label to South African towns needs further elucidation.

A question was posed about enterprise richness in and the stability of South African towns. The fact that enterprise richness is a function of all town clusters identified and that small and large towns clustered together (Table 7), suggests that fewer enterprise types do not necessarily indicate the potential for greater instability. The stability question needs further investigation, perhaps by a greater focus on the functional diversity of enterprises in South African towns.

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Authors' contributions

D.F.T. was responsible for the conceptualisation of the study, the analyses of the enterprise diversity, the interpretation of the results and the write-up. M.T.S. refined some concepts and provided advice on ecological aspects of diversity.

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Early planting and hand sorting effectively controls seed-borne fungi in farm-retained bean seed

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Home-saved bean (*Phaseolus vulgaris* L.) seed can be hand-sorted to remove discoloured seed, thereby reducing the level of contamination by certain seed-borne fungi and improving seed germination. In this study, the effect of planting date on the infection and discolouration of bean seed by seed-borne fungi was investigated in order to improve the quality of hand-sorted, farm-retained bean seeds used by resource poor smallholder farmers. The germination quality and level of seed-borne fungi in hand-sorted first-generation bean seed harvested from an early-, mid- and late-summer season planted crop was therefore assessed. The highest percentage of discoloured seed (68%) was obtained from the mid-summer season planting. Non-discoloured seed from early- and late-season plantings had significantly ($p<0.001$) higher normal germination (82% and 77%, respectively) than that from the mid-season planting date (58%). Irrespective of planting date, unsorted seed and discoloured seed had higher levels of infection by *Fusarium* spp. and *Phaeoisariopsis* spp. than the non-discoloured seed. Removal of discoloured seed by hand sorting eliminated *Rhizoctonia* spp. from all seed lots. Farmers can eliminate this pathogen by simply removing discoloured seed. Non-discoloured seed from the early-planted crop had the lowest level of infection by *Fusarium* spp. and *Phaeoisariopsis* spp. The results indicate that planting date is an important consideration in improving the quality of hand-sorted farm-retained bean seed.

Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume for direct human consumption and it provides a cheap source of dietary proteins for poor people in several countries.[1,2] It is commonly consumed for its delicacy, high protein content and as a source of certain antioxidants, minerals and polyphenols.[3] In addition to the superior quality of the protein, common bean is an excellent source of starch, dietary fibre, vitamins and minerals.[4] The superior nutritional attributes of common bean make it a potential crop for improving the nutritional security of resource poor communities. However, insect pests and diseases, especially those caused by fungal pathogens, constitute the major constraint to bean production.[5,6] Diseases may cause 80–100% yield loss for common beans on resource poor farms.[7] Of all transmittable seed-borne diseases of beans, fungi cause the most damage.[8] This damage includes shrunken seeds, seed rot, seed discolouration and, above all, diseases in emerging seedlings that may kill a certain proportion of the seedlings.[8,9] These effects on seedlings lead to poor stands and reduced yield.

The use of certified bean seed minimises yield reduction from fungal seed-borne diseases. In order to reduce production costs, smallholder farmers prefer to retain their own bean seed,[10,11] which inevitably harbours more infected seed than certified treated seed. Seed-borne diseases are always more prevalent in farm-retained bean seed than in certified and treated seed.[11,12]

Seed-borne fungi may survive for 5 years in seeds that are air dried and stored at 4 °C.[13] Several fungicides may be used to treat seed; however, these chemicals are expensive and they may pose a health hazard to smallholder farmers who lack technical expertise on their use. Chemical treatment of seed gives variable results because deep-seated infections may survive treatment. Avoidance of conditions favourable for seed infection during the growing period and prevention of the dissemination of the pathogen spores may be used as a management strategy for minimising seed-borne diseases. Consequently, it has often been recommended that farmers should select suitable planting dates and appropriate field sites in order to avoid infection.[14]

There are three types of seed discolouration caused by seed-borne fungi: (1) superficial necrotic lesions, (2) fungal coatings and (3) pigmentation.[8] These characteristic symptoms are the basis of visual sorting of bean seed to reduce or exclude seed-borne disease from the seed.[9,15,16] The formal seed sector has invested large amounts of money into seed cleaning machinery and sophisticated electronic colour sorters to remove disease-stained seeds. Although these machines are efficient, they may not give a better result than hand sorting. However, non-discoloured seeds may also harbour latent infections. The extent of seed discolouration caused by seed-borne fungi depends on the seed micro-flora, environmental conditions, host cultivar, physiology and genetics.[17]

The identification of seed-borne pathogens of importance to the quality of common bean seeds is mostly based on practical experience of crop damage. Some important seed-borne fungal pathogens that have been shown to cause significant bean yield reductions in smallholder farmer fields in the tropics include: *Colletotrichum lindemuthianum* (Saccardo and Magnus) Scribner*, Phaeoisariopsis griseola* (Sacc.) Ferr.*, Fusarium solani* (Mart.) Sacc.*, Fusarium oxysporum* (Schltdl.)*, Macrophomina phaseolina* (Tassi) Goid. (charcoal rot fungus) and *Rhizoctonia solani* (A.B. Frank) Donk.[11,14] *Phaeoisariopsis griseola* (Sacc.) Ferr. is the causal agent of angular leaf spot on beans. It is also a necrotic fungus which causes reddish spots with typical angular shapes on the bean seed coat. These spots have been reported to be central to the hilum.[18] *Colletotrichum lindemuthianum* is the causal agent of bean anthracnose and infected seeds often have oily brown droplets that coalesce to cover the whole seed as the fungi grow old. *Rhizoctonia solani, F. solani* and *F. oxysporum* are responsible for damping off, collar rots and wilt diseases in bean seedlings.

It was hypothesised in this study that planting time has an effect on the infection and extent of discolouration of common beans caused by these problematic seed-borne fungi. Planting time would thus affect the quality of hand-sorted farm-retained bean seed that is used by resource poor smallholder farmers. The objectives of the study were to determine the extent of seed-borne fungal infections and the germination quality of non-discoloured and discoloured farm retained seed harvested from crops planted in the early-, mid- and late-summer season.

Materials and methods

Field experiments were replicated on two sites in Harare, Zimbabwe. The sites were at the University of Zimbabwe Crop Science fields (17° 51′ S and 31°10′ E) and on the University of Zimbabwe farm (17° 48′ S and 31° 00′ E). The sites are approximately 20 km apart and have similar soil and climatic conditions. The Harare region has moderate annual rainfall averaging 750–1000 mm and mean annual temperatures of 21–27 °C. The average temperature, rainfall and humidity are presented in Figure 1. These conditions are conducive for high disease prevalence during summer. The soils are deep and red, belonging to the fersiallitic group.

Certified common bean seed (cultivar PAN 116, Pannar Seed [Pvt] Ltd, Zimbabwe) was planted. The cultivar has a determinate, bushy type growth habit and is commonly referred to as red speckled or 'sugar beans'. The three planting dates used were early summer (planting date: 01 October), mid-summer (planting date: 01 December) and late summer (planting date: 01 February). The experimental design of the field trials was a randomised complete block design with three replicates. Seeds were planted at a seed density of 30 seeds/m^2 and a depth of approximately 30 mm using hand hoes. Seedlings were later thinned to 22 plants/m^2 to give a population of 220 000 plants/ha. Plots were 6 m long and had 10 rows that were spaced 300 mm apart. To prevent spore movement from one plot to another, each bean plot was surrounded by one row of maize (*Zea mays* L.). Compound D fertiliser (8% N, 14% P, 7% K) was applied as basal dressing to all plots at a rate of 300 kg/ha. Bait pesticide composed of a mixture of 100 g carbaryl 85 WP and 20 kg maize meal was applied per row to control seedling pests. Dimethoate 40 EC (1 mL/L water) was applied at 3 and 10 weeks after crop emergence (WACE) to control leaf and pod insects. Weeds were controlled through hand hoeing at 2 and 5 WACE. At physiological maturity, plants from the net plot (three central rows, 4 m long) of each plot were hand harvested. The plants were air dried, and the beans in their pods were stored in a cold room at 4 °C.

The major objective of the seed tests was to determine the seed-borne fungal infection level and germination quality of non-discoloured and discoloured bean seed harvested from the three different planting dates. Therefore, bean seed for similar treatments from the two sites was mixed in a 1:1 ratio before seed tests were carried out. The seed tests were conducted in a seed pathology laboratory, 2 months after harvesting seed from the previous planting date. Preliminary work was done to grade the seed from each planting date into three seed categories: non-discoloured (no visible blemishes, lacerations or necrotic spots on seed coat), discoloured and unsorted seeds. This grading was done whilst shelling the bean pods in order to prevent surface contamination from other seeds. An experiment was then carried out to determine the effect of planting date on the germination quality and seed-borne fungal

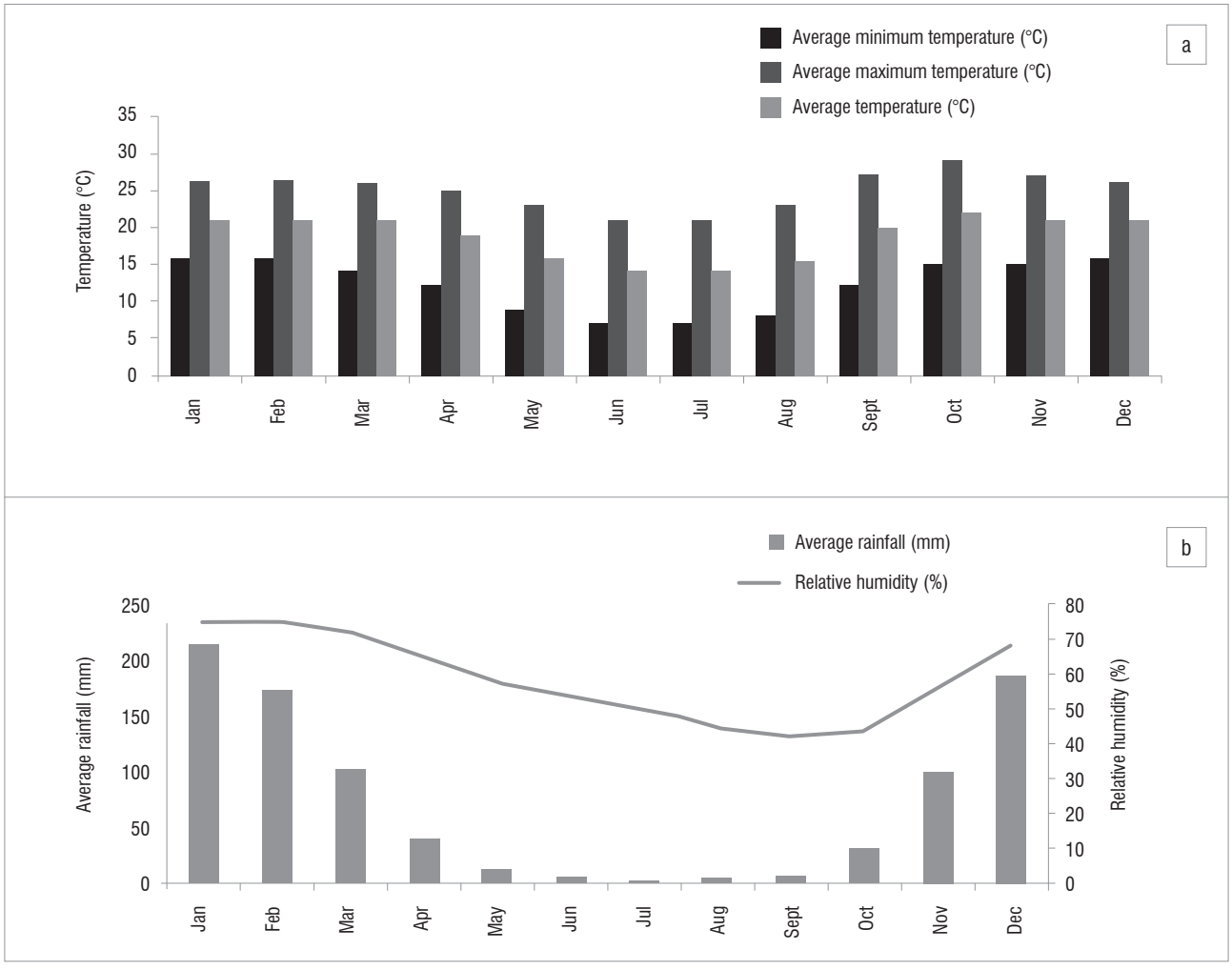

Figure 1: Average (a) temperatures and (b) humidity and rainfall for Harare, Zimbabwe.

infection levels of the non-discoloured seed, the discoloured seed and the unsorted seed. Three planting dates were tested – early summer (October planting), mid-summer (December planting) and late summer (February planting). The design of the experiment was a split-plot, with planting date as the main plot factor and seed category as the sub-plot factor to give nine treatment combinations.

The experiment comprised a germination test and a blotter test for fungal pathogens. Each treatment was replicated four times and the replicates were randomly assigned to the different blocks according to incubator shelf level. For each replicate, 50 bean seeds were used, to give a total of 200 seeds per treatment and to meet the requirement of the International Seed Testing Association (ISTA).[19] The 50 seeds of each replicate were plated between square wet blotter sheets 500 mm × 500 mm in size and placed according to their respective blocks in an incubator room under full light and temperature of 24–28 °C. The germination test was evaluated 9 days after incubation. Germination results were recorded according to the rules and regulations of ISTA.[19] The test results were therefore categorised as percentage normal, abnormal and non-germinated seeds.

The blotter technique was used to isolate the following seed-borne pathogens in all nine treatments: *Colletotrichum* spp., *Phaeoisariopsis* spp., *Fusarium* spp., *Macrophomina* spp. and *Rhizoctonia* spp. Each treatment had 200 seeds[19] and was represented by replicates of 50 seeds each. From the working samples, 10 seeds were counted randomly and plated in Petri dishes equidistantly as rings. The Petri dishes were lined with three layers of filter paper that was soaked in distilled water. Five such Petri dishes were prepared to represent a replicate of each treatment. The Petri dishes were incubated for 7 days at 22 °C, and subjected to alternating 12-h darkness and 12-h near ultraviolet light. Filter papers in the Petri dishes were rehydrated after 4 days of incubation. At the end of the incubation period, each seed was examined thoroughly under different magnifications of a stereomicroscope (model-S209, Motic Deutschland GmbH, Wetzlar, Germany) for growth of the fungi. Slides were prepared to observe any fruiting structures under higher magnifications (× 40 – Hund H 500 series, Hund Wetzlar, North Rhine-Westphalia, Germany) as a way of confirming the identifications. The fungal species were identified according to various descriptions.[18,20-22] Whenever identifiable growth of a fungus was seen on a seed, the respective seed was considered infected even if only one fructification was observed. Disease incidence was quantified by calculating the percentage of seeds infected by a particular pathogen.

Analysis of variance (ANOVA) was performed on germination and infection percentage data with significance at $p < 0.05$ using 5% least significant difference. The ANOVA was carried out using GenStat Release 12.1 statistical software.[23] Data were tested for conformity with the assumptions underlying ANOVA, including homogeneity of variance tests, before being subjected to ANOVA. Seed quality improvement was calculated as the difference in normal germination or seed-borne fungi between non-discoloured and unsorted seed, expressed as a percentage of the value obtained for unsorted seed.

Results and discussion

Early and late planting produced the most non-discoloured seed (Table 1). The highest percentage of discoloured seed was obtained from the mid-summer season planting (Table 1).

Table 1: Effect of planting date on seed discolouration

	Non-discoloured seed (%)	Discoloured seed (%)
Early summer	45.8[b]	54.2[b]
Mid-summer	38.7[c]	61.3[a]
Late summer	47.0[b]	53.0[b]
$p<0.01$; Cv % 6.3		

Means followed by the same letter are not significantly different (p>0.05)
Cv, coefficient of variation

The interaction between planting date and seed category was significant ($p<0.001$). Non-discoloured seed from the early- and late-season planting dates had a significantly higher germination percentage than that from the mid-season planting date (Figure 2). For unsorted seed, the lowest normal germination was obtained from the mid-season planting date. However, the difference in germination between non-discoloured and unsorted seed was highest in the early-season planted seed. This finding implies that seed sorting based on discolourations for improving germination quality is more effective on seed from the early-season planting date than other planting dates. By proper choice of planting date and hand sorting alone, farmers may obtain bean seed which is nearly equal to certified seed in germination quality (80% or higher).

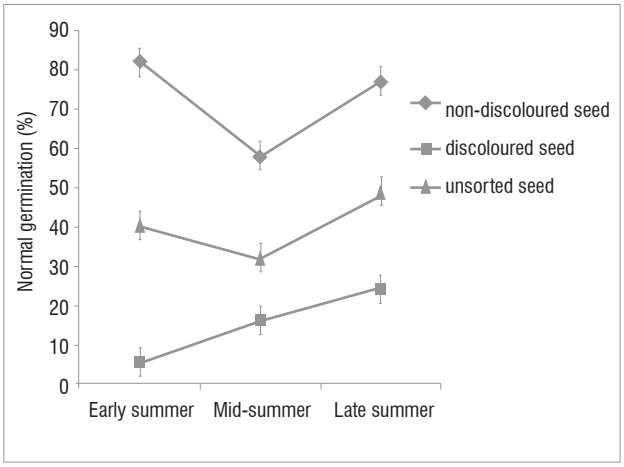

Figure 2: Effect of planting date and seed category on normal germination.

The planting date × seed category interaction was significant for *Colletotrichum* spp., *Fusarium* spp., *Macrophomina* spp. and *Rhizoctonia* spp. (Table 2). Non-discoloured seed from all the planting dates had equally low levels of infection by *Colletotrichum* spp. (Figure 3a). However, unsorted seed from the early- and mid-season planting dates had higher levels of infection than that from the late-season planting date. For *Fusarium* spp., the interaction between planting date and seed category showed that all planting dates had equal levels of infection in unsorted seed, but for non-discoloured seed, the early-summer planting date had the lowest level of infection (Figure 3b). This result implies that the visible symptoms of this pathogen (based on discolouration) were expressed the most in early-planted seed.

Table 2: Analysis of variance for the effects of planting date and seed category on seed-borne fungi

	df	*Macrophomina* spp.	*Colletotrichum* spp.	*Fusarium* spp.	*Rhizoctonia* spp.	*Phaeoisariopsis* spp.
Planting date × seed category	4	***	***	**	**	ns
Seed category	2	***	***	***	***	***
Planting date	2	***	***	ns	***	***
Coefficient of variation (%)		16.7	19.1	20.6	27.6	25.9

*p<0.05; **p<0.01; ***p<0.0001*

df, degrees of freedom; ns, not significant

For *Macrophomina* spp., non-discoloured seed from the early- and mid-summer planting date had a lower level of infection than the late season

planting (Figure 3c). *Rhizoctonia* spp. were absent from non-discoloured seed of all planting dates (Figure 3d). However, the highest infection levels for this pathogen in unsorted and discoloured seed were obtained in seed from the early-planted crop (Figure 3d).

The interaction between planting date and seed category was not significantly different for *Phaeoisariopsis* spp. Seed category (sub-plot) and planting date (main plot) effects were, however, significant (Table 3). These results suggest that unsorted seed was more infected by *Phaeoisariopsis* spp. The early-season planted seed was significantly less infected by this pathogen when compared with seed from the mid- and late-season planting dates (Table 3).

The greatest improvement in the quality of bean seed from different planting dates through hand sorting based on seed discolouration was obtained from early-planted seed (Table 4). As shown in Figure 1, in the early-summer season (October), less rainfall was received compared to mid and late summer (December to February). In addition, the highest temperature and lowest relative humidity were also observed in early summer. Most fungal pathogens are known to prefer wet and warmer conditions for infection and growth.[14] It is therefore expected that the early season planting date would be the least conducive for proliferation of the fungal pathogens during the crop's early growth. It also appears that *Rhizoctonia* spp. can be eliminated from seed lots by hand sorting based on discolourations (Table 4). It is therefore recommended that farmers can eliminate this pathogen simply by removing discoloured seed from the seed lot. *Rhizoctonia* spp. are necrotic fungi that rapidly kill host cells, living saprophytically on the dead tissues.[13] Severe infection of the bean seed by necrotrophic fungi can result in extensive seed discolouration.

Table 3: Means for seed category and planting date effects on *Phaeoisariopsis* spp.

Seed category	
Discoloured seed	6.67[a]
Non-discoloured seed	2.17[c]
Unsorted seed	4.67[b]
Planting date	
Early season	1.29[b]
Mid-season	5.65[a]
Late season	6.57[a]

Means followed by the same letter are not significantly different (p>0.05)

Results also indicated that *Phaeoisariopsis* spp. could be reduced from early-planted seed based on discolourations (Table 4). Reduction of this

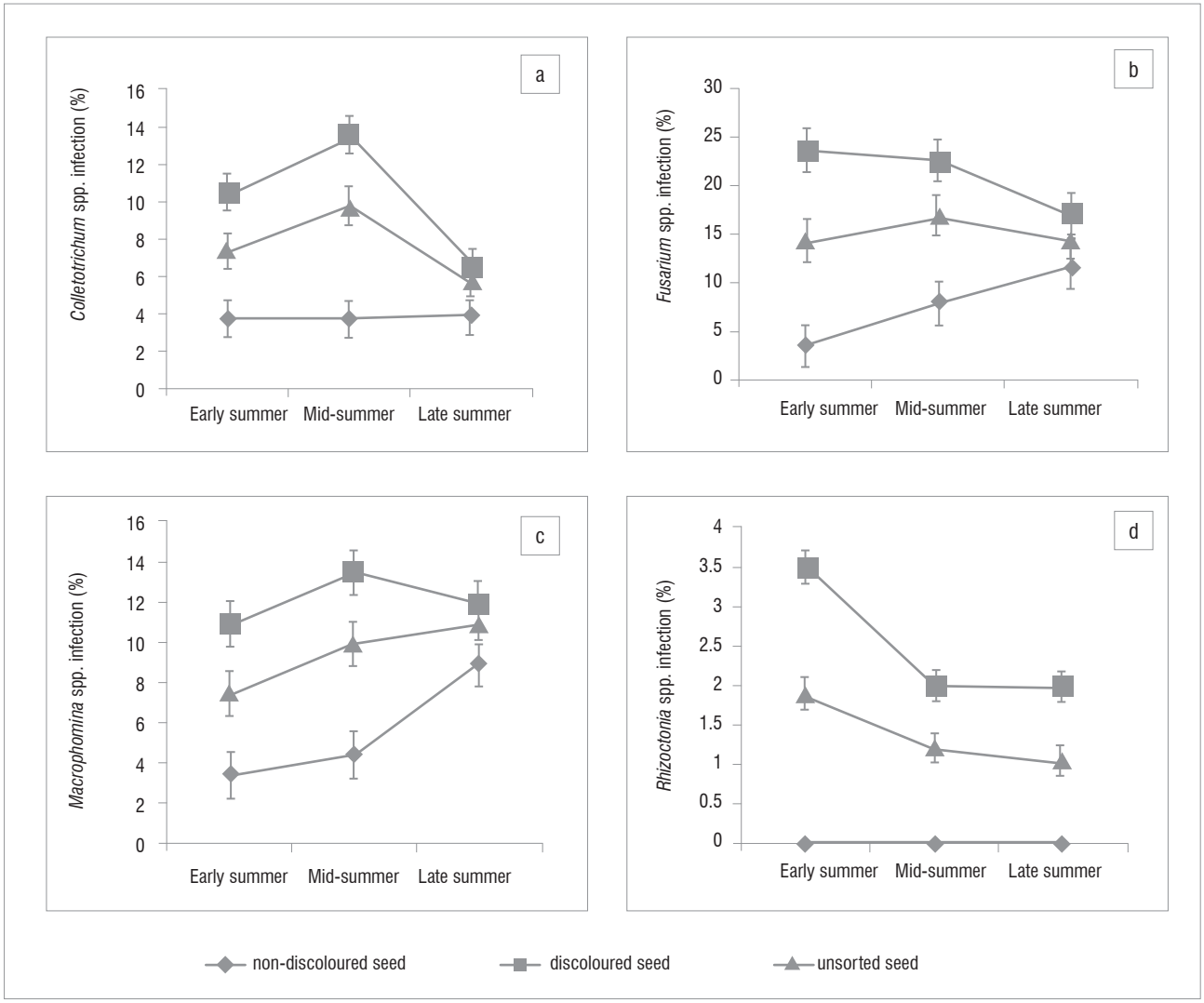

Figure 3: Interaction effect of planting date and seed category on seed infection by (a) *Colletotrichum* spp., (b) *Fusarium* spp., (c) *Macrophomina* spp. and (d) *Rhizoctonia* spp.

pathogen was 96% (Table 4). The reduction of infection levels by hand sorting needs to be confirmed with field trials. There is currently no information on thresholds or economic injury level for these seed-borne fungal pathogens in bean seed.

The Spearman's rank correlation matrix (Table 5) showed that *Colletotrichum* spp. were the chief pathogen affecting normal germination of unsorted seed (r_s = -0.856). *Colletotrichum lindemuthianum* is the causal agent of bean anthracnose, a disease that causes serious crop loss in developing countries.[24] It is one of the predominant seed-borne pathogens recorded in smallholder farming areas of Zimbabwe.[12] Bioassays showed that 55% of the farm-retained seed was infected by the pathogen and, in severe cases, it caused up to 100% yield loss.

Fusarium spp. were another dominant pathogen affecting normal germination of non-discoloured seed (r_s = -0.829) (Table 5). This may be explained by the fact that *Fusarium* is a biotrophic fungus.[25] Deep penetration by biotrophic fungi results in hyphae being located in tissues of the embryo and cotyledons, and, in this case, the fungal pathogens may present no visible macroscopic symptoms. Biotrophic seed-borne fungi can also be found as intercellular mycelia and beneath the epidermal cell layers inside the bean seed coat, and in this case, they still present no visible symptoms. This implies that some infested seed may not display macroscopic symptoms, thereby making visual inspection and hand sorting of seeds less effective.[9] An additional test would, therefore, be required in such cases to check for the presence of seed-borne infections, especially in seed production. It can also be noted that the red speckled bean seed discolourations can occur as a result of other pathogens such as bacteria and viruses. Further research is needed to investigate the effectiveness of visual inspection of seed from different sources on reduction of these other pathogens. DNA sequencing could be useful as a rapid data collection tool for these studies.

Conclusions and recommendations

Planting date affects the extent of bean seed discolouration by seed-borne fungal pathogens such as *Colletotrichum* spp., *Macrophomina* spp., *Phaeoisariopsis* spp. and *Fusarium* spp. It appears that the visual symptoms for these pathogens are generally better expressed in early-planted seed, resulting in better seed quality from this planting date after visual inspection and hand sorting. *Rhizoctonia* spp., however, can be totally eliminated based on seed discolouration, regardless of planting date.

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Authors' contributions

E.D. performed the experiments, and collected and analysed the data. J.S. was the project leader and made conceptual contributions. M.F. assisted in the data analyses and interpretation of the results. All authors contributed equally to the writing of the manuscript.

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Table 4: Improvement in quality of bean seed from different planting dates through hand sorting based on seed discolouration

	Germination improvement (%)	Reduction in fungal pathogens (%)				
		***Macrophomina* spp.**	***Colletotrichum* spp.**	***Fusarium* spp.**	***Rhizoctonia* spp.**	***Phaeoisariopsis* spp.**
Early season	102.00[a]	53.76[a]	49.39[b]	75.59[a]	100	96.00[a]
Mid-season	79.80[b]	56.88[a]	61.40[a]	52.63[b]	100	43.17[b]
Late season	57.43[c]	29.42[b]	13.60[c]	20.19[c]	100	51.29[b]
***p*-value**	***	**	***	***	ns	**

*p<0.05; **p<0.01; ***p<0.0001; ns, not significant

Means followed by the same letter superscript are not significantly different.

Table 5: Spearman rank correlation matrix for relationships between normal germination and seed-borne fungi in unsorted, non-discoloured and discoloured seed

	Normal germination		
	Unsorted seed	**Non-discoloured seed**	**Discoloured seed**
Colletotrichum spp.	-0.856***	-0.053ns	-0.414**
Phaeoisariopsis spp.	-0.014ns	-0.597**	-0.345*
Macrophomina spp.	-0.216ns	0.053ns	-0.257*
Fusarium spp.	-0.383*	-0.829***	0.144ns
Rhizoctonia spp.	-0.519**	–	-0.616***

*p<0.05; **p<0.01; ***p<0.0001; ns, not significant

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Biofilm formation in surface and drinking water distribution systems in Mafikeng, South Africa

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Poor quality source water and poorly treated reused wastewater may result in poor quality drinking water that has a higher potential to form biofilms. A biofilm is a group of microorganisms which adhere to a surface. We investigated biofilm growth in the drinking water distribution systems in the Mafikeng area, in the North-West Province of South Africa. Analysis was conducted to determine the presence of faecal coliforms, total coliforms, *Pseudomonas* spp. and *Aeromonas* spp. in the biofilms. Biofilms were grown on a device that contained copper and galvanised steel coupons. A mini tap filter – a point-of-use treatment device which can be used at a single faucet – was also used to collect samples. Scanning electron microscopy demonstrated that multi-species biofilms developed on all the coupons as well as on the point-of-use filters. Galvanised steel and carbon filters had the highest density of biofilm. Total coliforms, faecal coliforms and *Pseudomonas* spp. were isolated from raw water biofilm coupons only. *Aeromonas* spp. and *Pseudomonas* spp. were isolated from filters. The susceptibility of selected isolates was tested against 11 antibiotics of clinical interest. The most prevalent antibiotic resistance phenotype observed was KF-AP-C-E-OT-K-TM-A. The presence of virulence genes was determined using the polymerase chain reaction. These results indicate that bacteria present in the water have the ability to colonise as biofilms and drinking water biofilms may be a reservoir for opportunistic bacteria including *Pseudomonas* and *Aeromonas* species.

Introduction

Water is a vital resource for life and access to safe drinking water is a basic right of every individual.[1] South Africa is a semi-arid country with very little rainfall, resulting in high water stress; as such, individuals in many communities struggle to access potable water.[2] Water scarcity problems can be addressed through the recycling of municipal wastewater for reuse in households – a practice which is increasing worldwide.[3] However, reclaimed water may be a major source of pathogenic and opportunistic microorganisms, as well as pharmaceutical waste products.[4] The presence of pathogenic microorganisms in treated water sources usually is because they are able to survive the treatment process. Moreover, in most developing countries, water-treatment plants are usually faced with maintenance problems and a lack of qualified personnel.

In aquatic environments, microorganisms have the ability to adhere to solid surfaces and form biofilms.[5] Biofilms are bacterial communities embedded in a polysaccharide matrix, which gives them the opportunity to resist destruction by antibiotics, environmental stress, biocides and detergents.[6] Bacterial regrowth in the distribution system may result from the detachment of biofilm bacteria, which increases the risk of infection in humans when the water is consumed.[6] Generally, most water distribution systems are characterised by the presence of biofilms, regardless of purity, the type of pipe material used for distribution or the presence of a disinfectant.[7] Bacteria in drinking water systems can therefore grow in bulk water and as biofilms attached to the walls of pipes.[8] Moreover, the development of biofilms inside water distribution pipes facilitates the propagation of mixed microbial populations and is considered the main source of planktonic bacteria in water supply systems.[9] This problem is further aggravated by the presence of opportunistic pathogens such as *Pseudomonas, Aeromonas, Klebsiella, Mycobacter, Escherichia coli, Helicobacter, Salmonella* and *Legionella* spp. that may increase the health risks associated with the consumption of water from these sources.[10]

Different materials – such as cast iron galvanised steel, stainless steel, copper and polyethylene – have been used to manufacture water distribution pipes and these materials favour biofilm formation in the water distribution systems.[7,11,12] Differences in the pipe materials greatly favour the survival of different bacterial species.[13] The presence of biofilms in drinking water distribution pipes usually leads to a number of undesirable effects on the quality of water that is supplied to consumers.[14] The development of biofilms in copper pipes facilitates cuprosolvency which increases the release of copper into the distribution system.[15] Furthermore, increased carbon influences the growth of heterotrophic plate count bacteria which are also involved in the corrosion of copper.[15] The corrosion of lead-containing plumbing materials increases the chances of lead contamination in tap water, which can cause adverse health effects in humans, especially children.[16] Detachment of bacteria from the biofilms may affect the quality of the water.[17] Therefore, the deterioration of the quality of drinking water as a result of biofilm formation is a major concern for most municipal supply agencies and communities. Biofilms are present in spite of different treatment processes; the occurrence of biofilms in drinking water is attributed to bacterial resistance to disinfectants, ability of the bacterial species to resist chemical compounds released from pipe materials and species association which increases the proportion of viable cells.[18,19] Moreover, the use of different disinfectant methods may have long-term effects on the biofilm community.[20] Biofilms consisting of *Pseudomonas aeruginosa* and different faecal bacterial species have been detected in water distribution systems, even in countries that have more advanced water-treatment facilities.[21,22]

Mafikeng is the capital of the North West Province of South Africa. This city uses both groundwater as well as dam water for drinking water production. Some areas receive a mixture of the two water types and others receive only one or the other. The purification plant for the surface water is at the Modimola Dam and receives treated

wastewater. The water purification plant is downstream from the sewage treatment plant and is thus a semi-closed water conservation system.

The study was designed to investigate the biofilm forming ability, antibiotic resistance and virulence gene determinants of biofilm bacteria, especially *Pseudomonas* and *Aeromonas* species, in the water distribution systems in Mafikeng.

Materials and methods

Sampling area

Biofilm forming devices were installed at different sites within the water distribution system in the Mafikeng–Mmabatho area: (1) raw untreated water from the Modimola Dam, (2) treated water from household taps, received from the Modimola Dam treatment plant, (3) treated water from Molopo Eye, a natural spring and (4) water from the Modimola Dam treatment plant mixed with chlorinated water from Molopo Eye (mixed water).

Biofilm formation devices

To study biofilm growth, a flow system technique that utilises a biofilm developing device was used (Figure 1). The biofilm developing device pipe system was made from clear plastic pipe with a diameter of 16 mm. The device was installed with copper and galvanised coupons to serve as solid surfaces onto which bacteria could adhere and form biofilms. Coupons were held in place by screws. The device was mounted horizontally to the main pipe of a building of the North-West University in Mafikeng (Figure 1). This building receives mixed water. The coupons were installed at the different sampling points for 6 months. Mini tap filters (Figure 2) – which are point-of-use (POU) treatment devices which can be used at a single faucet under constant flow – were also used to form biofilms during the second collection. The filters were placed on cold water taps in participating locations that received treated groundwater (Molopo Eye water), only Modimola Dam water or mixed water (North-West University, Mafikeng campus). The filters remained at these sampling points for 4 months.

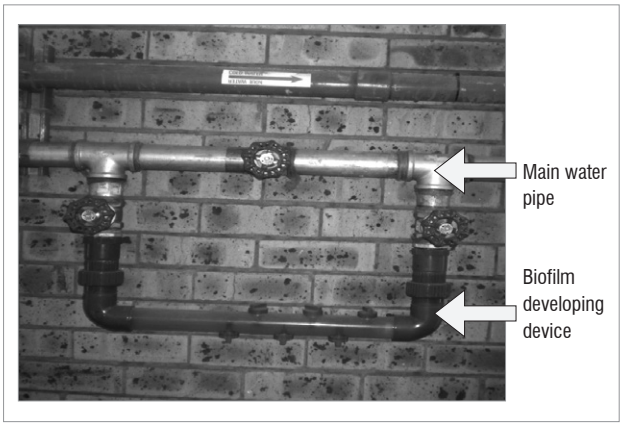


Figure 1: Biofilm developing device attached to a main water pipe of a building at the North-West University in Mafikeng.

Sampling of biofilm

Biofilm samples were analysed twice during the study period. To collect samples, the pipes containing biofilm developing devices were closed with valves before they were disconnected and the coupons were removed using sterile forceps. The filters in the mini tap filter devices were aseptically removed from the cartridge. Coupons were placed immediately into sterile 100-mL Schott bottles that contained water from the particular sampling site. Samples were transported on ice to the laboratory for analysis. Upon arrival in the laboratory, the coupons were removed from the bottles. Those coupons intended for scanning electron microscopy were stored in 100% alcohol and the remaining coupons were analysed for bacterial growth.

Figure 2: Mini tap filter – a point-of-use water-treatment device – which was used to collect biofilms.

Scanning electron microscopy

The biofilm structure was investigated using scanning electron microscopy (SEM). Biofilm samples were fixed by 2.5% glutaraldehyde and 2% osmium tetroxide, dehydrated sequentially in increasing concentrations of ethanol (70%, 90% and 100%) for 15 min and critically dried in liquid carbon dioxide. The samples were mounted on SEM stubs using double-sided carbon tape. These stubs were then carbon coated. Finally, the samples were super coated with gold/palladium and viewed using a Philips XL30 scanning electron microscope (Philips, Aachen, Germany). Enlargements ranged from 63X to 20 000X.

Isolation of bacteria from the biofilm

Bacteria were isolated using standard methods. Biofilm bacteria on the coupons were removed by swabbing the surfaces with a sterile cotton swab dipped in sterile nutrient broth and immediately streaking it onto selective media for the isolation of targeted organisms. The media used were: mFC agar for the isolation of faecal coliforms, mEndo for total coliforms and *Aeromonas* selective agar for *Aeromonas* and *Pseudomonas* species. All the media used were Biolab agars from Merck (Johannesburg, South Africa). The plates were incubated aerobically at 35 °C for 24 h, except for mFC agar plates which were incubated at 45 °C for 24 h. Blue colonies from mFC agar and metallic-sheen colonies from mEndo agar were considered as presumptive faecal coliforms and total coliforms, respectively. Moreover, yellow and green colonies on *Aeromonas* selective agar represented *Aeromonas* and *Pseudomonas* species, respectively. These isolates were sub-cultured on the respective selective media and plates were incubated aerobically at 35 °C and 45 °C, respectively, for 24 h. Presumptive pure colonies were subjected to specific preliminary and confirmatory biochemical tests. All pure isolates were Gram stained using standard methods.

Preliminary biochemical tests

Triple sugar iron agar test

The triple sugar iron (TSI) test can also be used as a confirmation test for *E. coli*. The TSI agar obtained from Biolab (Merck, Johannesburg, South Africa) was used to determine the ability of isolated organisms to utilise the substrates glucose, sucrose and lactose at sample concentrations of 0.1%, 1.0% and 1.0%, respectively. The test was performed as per the instructions of the manufacturer and evaluated based on the formation of gas and hydrogen sulphide and fermentation of carbohydrates to produce acids. TSI agar slants were prepared in sterile 15-mL McCartney bottles. The slants were streak and stab inoculated with a sterile inoculation needle containing the selected colony. Following inoculation, the slants

were incubated at 37 °C for 24 h. The colour of the slant and butt was recorded (red or yellow) as well as the production of hydrogen sulphide (when the agar blackened) and formation of gas (when the agar split).

Oxidase test

This test was performed using the Test Oxidase™ reagent (PL.390) from Mast Diagnostics (Nesto, Wirral, UK) in accordance with the manufacturer's published protocol. A well-isolated pure colony was placed on filter paper using a sterile wire loop. A drop of Test Oxidase™ reagent was added to the filter paper and mixed. After 30 s the filter was observed for a colour change. Isolates that produced a purple colour were presumptively considered to be *E. coli*. Oxidase positive colonies were taken as presumptive *Aeromonas* isolates.

Analytical profile index test

The analytical profile index (API) 20E test was performed in accordance with the manufacturer's protocol (BioMeriéux, Marcy l'Etoile, France). An API 20E strip was used to identify Enterobacteriaceae and other non-fastidious, Gram-negative rods. The strips were inoculated and incubated at 37 °C for 24 h. The indices obtained after reading the results were interpreted using the API web software (BioMeriéux®). The organisms were identified to species level.

Antimicrobial susceptibility test

An antibiotic susceptibility test was performed using the Kirby–Bauer disc diffusion method. The following antibiotic discs (Mast Diagnostics, UK) were used at the final concentrations that are indicated: ampicillin (AP) 10 μg, cephalothin (KF) 5 μg, streptomycin (S) 10 μg, erythromycin (E) 15 μg, chloramphenicol (C) 30 μg, neomycin (NE) 30 μg, amoxycillin (A) 10 μg, ciprofloxacin (CIP) 5 μg, trimethoprim (TM) 25 μg, kanamycin (K) 30 μg, oxytetracycline (OT) 30 μg. These antibiotics were chosen because either they are used in both humans and other animals or they have been reported to be resistant in previous studies.

Three colonies were picked from each sample and each colony was transferred into 3 mL of sterile distilled water to prepare a bacterial suspension. Aliquots of 1 mL from each suspension were spread plated on Mueller–Hinton agar plates. Antibiotic discs were applied to the plates using sterile needles and the plates were incubated at 37 °C for 24 h. After incubation, the antibiotic inhibition zone diameters were measured. Results obtained were used to classify isolates as being resistant, intermediate resistant or susceptible to a particular antibiotic using standard reference values according to the US National Committee for Clinical Laboratory Standards (now called the Clinical and Laboratory Standards Institute). Multiple antibiotic resistance phenotypes were generated for isolates that showed resistance to three or more antibiotics.

Confirmatory DNA test

Genomic DNA extraction

Genomic DNA was extracted from all the presumptive *Pseudomonas* and *Aeromonas* isolates using the alkaline lysis method. The concentration and quality of the extracted DNA in solution were determined using a spectrophotometer (NanoDrop ND 1000, Thermo Scientific, USA) and 1% (w/v) agarose gel electrophoresis. The latter was also used for determining the integrity of the genomic DNA.

Polymerase chain reaction for identifying species

The identities of the presumptive *Pseudomonas* species were confirmed through amplification of the *toxA*[24] and *ecfX*[25] gene determinants and *Aeromonas* species were confirmed through *gyrB*[23] amplification. Polymerase chain reactions (PCRs) were performed using oligonucleotide primer combinations under the cycling conditions given in Table 1. Standard 25-μL reactions that consisted of 1 μg/μL of the template DNA, 50 pmol of each oligonucleotide primer set, 1X PCR master mix and RNase free water were prepared. Amplifications were performed using a Peltier Thermal Cycler (model-PTC-220DYAD™ DNA ENGINE, MJ Research Inc., Waltham, MA, USA). All PCR reagents used were Fermentas (USA) products supplied by Inqaba Biotec Pty Ltd (Pretoria, South Africa). PCR products were subjected to 1% (w/v) agarose gel electrophoresis.

Polymerase chain reaction for detection of virulence gene markers

Pseudomonas species were screened for the presence of the *exoA, exoS* and *exoT* virulence gene determinants[26] while a specific PCR for the detection of *aerA* and *hylH* genes was performed on all positively identified *Aeromonas* species[27]. PCRs were performed using oligonucleotide primer combinations under the cycling conditions given in Table 2. Amplifications were performed using a Peltier Thermal Cycler (model-PTC-220DYAD™ DNA ENGINE). The reactions were prepared in 25-μL volumes that constituted 1 μg/μL of the template DNA, 50 pmol of each oligonucleotide primer set, 1X PCR master mix and RNase free water. All PCR reagents used were Fermentas (USA) products supplied by Inqaba Biotech Pty Ltd (Pretoria, South Africa). PCR products were subjected to 2% (w/v) agarose gel electrophoresis.

Electrophoresis of polymerase chain reaction products

Products of the PCRs were separated by electrophoresis on 2% (w/v) agarose gel. Electrophoresis was conducted in a horizontal Pharmacia Biotech equipment system (model Hoefer HE 99X; Amersham Pharmacia Biotech, Uppsala, Sweden) for 2 h at 60 V using 1X TAE buffer (40 mM Tris, 1 mM EDTA and 20 mM glacial acetic acid, pH 8.0). Each gel contained a 100-bp DNA molecular weight marker (Fermentas, Hanover,

Table 1: Oligonucleotide primers used for specific detection of *Aeromonas* and *Pseudomonas* species

Primer	Oligonucleotide sequence (5'-3')	Target gene and size (bp)	PCR cycling conditions
ECF1	ATGGATGAGCGCTTCCGTG	*ecfX* (528)	35x 94 °C for 45 s
ECF2	TCATCCTTGCCTCCCTG		58 °C for 45 s
			72 °C for 60 s
GyrPA-398	CCTGACCATCCGTCGCCACAAC	*gyrB* (222)	35x 94 °C for 45 s
GyrPA- 620	CGCAGCAGGATGCCGACGCC		66 °C for 45 s
			72 °C for 60 s
ETA1	GACAACGCCCTCAGCATCACCAGC	*toxA* (367)	35x 94 °C for 45 s
ETA2	CGCTGGCCCATTCGCTCCAGCGCT		66 °C for 45 s
			72 °C for 60 s

PCR, polymerase chain reaction: initial denaturing step of 95 °C for 5 min and final strand extension of 72 °C for 5 min

Table 2: Oligonucleotide primers used to detect virulence genes in *Pseudomonas* and *Aeromonas* species

Gene	Oligonucleotide sequence	Target gene and size (bp)	PCR cycling conditions
exoA	F: 5' AACCAGCTCAGCCACATGTC 3' R: 5' CGCTGGCCCATTCGCTCCAGCGCT 3'	*exoA* (396)	30x 94 °C for 1 min 68 °C for 1 min 72 °C for 1 min
exoS	F: 5' GCGAGGTCAGCAGAGTATCG 3' R: 5' TTCGGCGTCACTGTGGATGC 3'	*exoS* (118)	36x 94 °C for 30 s 58 °C for 30 s 68 °C for 1 min
exoT	F: 5' AATCGCCGTCCAACTGCATGCG 3' R: 5' TGTTCGCCGAGGTACTGCTC 3'	*exoT* (152)	36x 94 °C for 30 s 58 °C for 30 s 68 °C for 1 min
aerA	Aer 2F: 5'AGCGGCAGAGCCCGTCTATCCA3' Aer 2R: 5'AGTTGGTGGCGGTGTCGTAGCG3'	*aerA* (416)	30x 95 °C for 2 min 55 °C for 1 min 72 °C for 1 min
hylH	Hyl 2F: 5'GGCCCGTGGCCCGAAGATGCAGG3' Hyl 2R: 5'CAGTCCCACCCACTTC3'	*hylH* (597)	30x 95 °C for 2 min 55 °C for 1 min 72 °C for 1 min

Polymerase chain reaction (PCR) cycling conditions: exoA*: initial denaturing step of 95 °C for 2 min and final strand extension of 72 °C for 7 min;* exoS *and* exoT*: initial denaturing step of 94 °C for 2 min and final strand extension of 68 °C for 7 min;* aerA *and* hylH*: initial denaturing step of 95 °C for 5 min and final strand extension of 72 °C for 7 min.*

MD, USA). The gels were stained in ethidium bromide (0.1 μg/ml) for 15 min and amplicons were visualised under UV light. A Gene Genius Bio imaging system (Syngene, Synoptics, Cambridge, UK) was used to capture the image using GeneSnap (version 3.07.01) software (Syngene, Synoptics) to determine the relative size of amplicons.

Results

Occurrence and diversity of microorganisms in the biofilms

Table 3 indicates the different types of organisms isolated from the biofilm. The results indicate only the numbers of isolates that were positive for the various categories when subjected to preliminary tests (TSI, oxidase and, in the case of *Pseudomonas* spp. and *Aeromonas* spp., API 20E). It is evident from Table 3 that total coliforms and faecal coliforms were present in the biofilms from the raw water from Modimola Dam but were not detected in the biofilms of the treated water from Modimola Dam. Furthermore, *Aeromonas* and *Pseudomonas* spp. were detected in the biofilms of the raw dam water as well as the drinking water from the POU devices. Only *Pseudomonas* spp. (27) were isolated from the biofilm of the Modimola Dam raw water (Table 3), whereas both *Aeromonas* spp. and *Pseudomonas* spp. were found in the biofilms of the treated Modimola Dam drinking water and the mixed water.

Figures 3 to 5 depict the surfaces of coupons and filters exposed to raw water (Figure 3) and treated water distribution systems (Figures 4 and 5). Different organisms were isolated from the metal surfaces. The SEM revealed the existence of bacterial cells within the biofilm matrix, with a greater amount of bacterial cells found on the galvanised coupons than on the copper coupons (Figures 3 to 5). From these micrographs, it was also evident that high bacterial densities were found in biofilms from the raw water of the Modimola Dam as well as from the drinking water distribution system in Mafikeng. The dam water is treated and supplied to homes for consumption.

When the coupons were removed from the biofilm development device, a green colour was noticed on the copper coupons; this colour is attributed to the corrosion products that are visible (like crystals) in the SEM (Figure 4b). Attached cells in association with exopolysaccharide were visible in galvanised, copper and POU filter surfaces in the SEMs (Figures 3 to 5). It is therefore suggested that the suspended cells have the potential to attach to the surface and participate during biofilm formation. An extensive sponge-like exopolysaccharide layer can be seen on the galvanised coupons in association with bacterial cells (Figure 3a). Figure 5 (POU filters) shows evidence of biofilm formation on the surface of filters from mixed water, dam water and water from the Molopo Eye. Rod-shaped bacteria are the dominating organisms in the biofilm and the aggregation of rod-shaped bacteria entangled in the exopolysaccharide, as seen in the micrographs, usually reflect a mature biofilm. It was found that galvanised coupons from raw and treated water contained thicker biofilms than did the copper coupons. Of the treated water from the three sites, coupons from the mixed water were colonised by a variety of bacteria.

If biofilms contain any pathogenic bacteria, the detachment of biofilms could release these bacteria into drinking water and affect risk levels of consumers.[7] In another study, coliform bacteria – originating from biofilms observed on rubber-coated valves – were isolated from drinking water distribution systems.[21] Coliforms were not detected in the present study, but that does not mean that they were absent.

Antimicrobial susceptibility test

All the organisms were subjected to an antibiotic sensitivity test using 11 antibiotics of clinical importance. Multiple antibiotic resistance phenotypes were generated for isolates resistant to three or more drugs; the results are shown in Table 4.

All the isolates tested were resistant to ampicillin, amoxicillin, cephalothin, erythromycin, chloramphenicol and trimethoprim. All the organisms tested were susceptible to ciprofloxacin. Four different multiple antibiotic resistance patterns were observed and all the isolates were resistant to three or more classes of antibiotics. The highest level of resistance – with the phenotype KF-AP-C-E-OT-K-TM-A, indicating resistance to eight drugs – was observed for isolates from biofilms. From these results, it is evident that ciprofloxacin and streptomycin were the most effective, because all or a large proportion of the isolates were susceptible to both. These results indicate that biofilm grown organisms may serve as

Table 3: Bacteria isolated from biofilms and cultivated on different growth media

Site of biofilm development device	mEndo (total coliforms)	mFC (faecal coliforms)	*Aeromonas* selective medium supplemented with ampicillin	
			Aeromonas	*Pseudomonas*
Raw water: Modimola Dam	Present	Present	Absent	Present
Mixed water: Mmabatho	Absent	Absent	Absent	Absent
POU filter: Treated dam water	Absent	Absent	Present	Present
POU filter: Mixed water	Absent	Absent	Present	Present
POU filter: Molopo Eye	Absent	Absent	Absent	Absent

POU, point of use

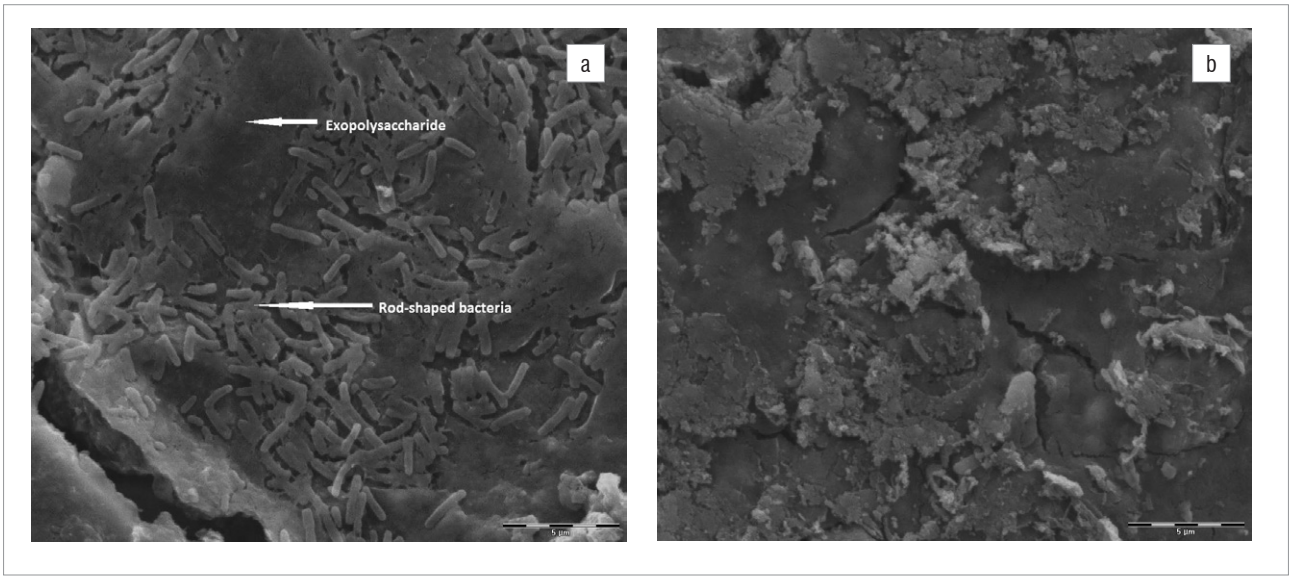


Figure 3: Electron micrographs of biofilm from Modimola Dam collected using (a) galvanised coupons or (b) copper coupons.

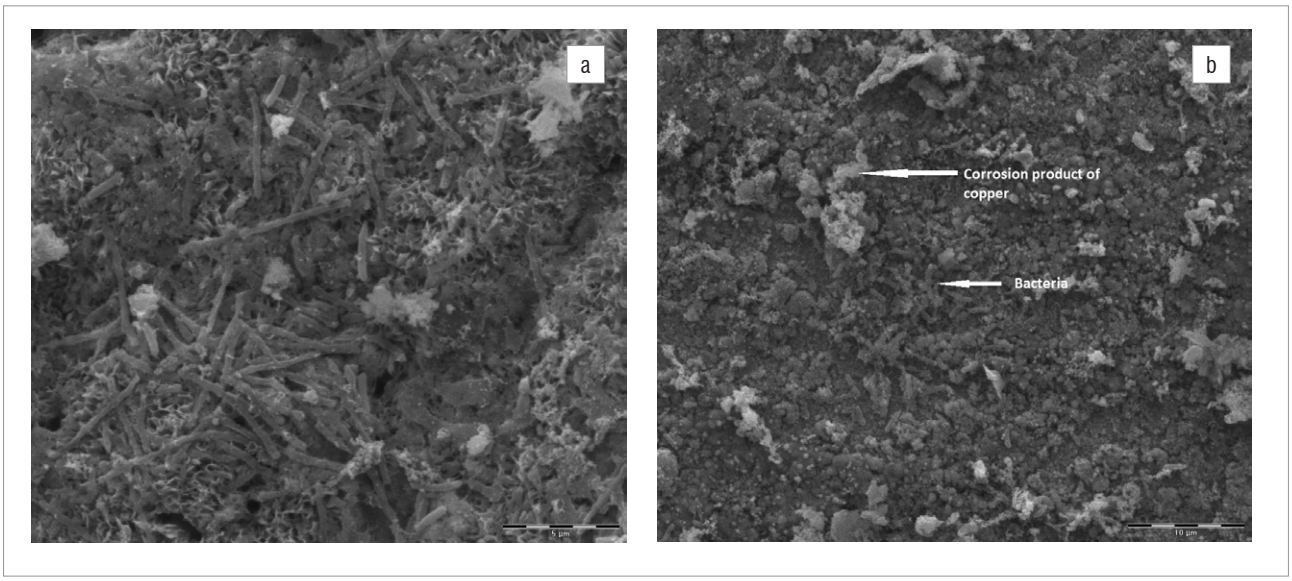


Figure 4: Electron micrographs of biofilm from mixed water collected using (a) galvanised coupons or (b) copper coupons.

a reservoir for antibiotic-resistant organisms, and therefore may have the potential to cause infections. This finding is a cause for concern, particularly for infants, the elderly and immunocompromised individuals in the Mafikeng community.

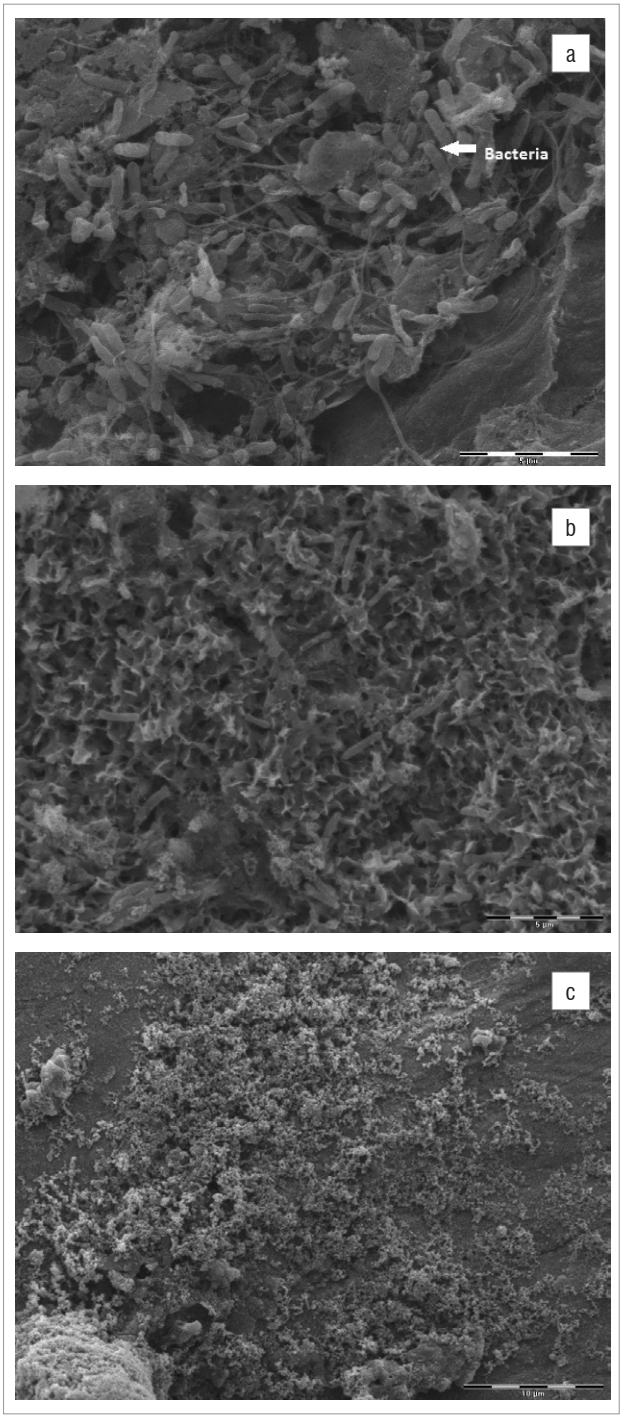


Figure 5: Electron micrographs of biofilm collected using carbon filters from (a) mixed water, (b) Modimola Dam and (c) Molopo Eye.

Identification and detection of virulence gene isolates were done using *gyrB*, *toxA* and *ecfX* gene fragments through PCR. The *gyrB* and *ecfX* gene fragments were amplified. Specific PCR assays for the detection of virulence genes (*aerA* and *hylH* in *Aeromonas* and *exoA*, *exoS* and *exoT* in *Pseudomonas*) produced DNA fragments of the expected size of some of the markers. Of the 39 isolates that were screened, the combination of virulence genes detected in the isolates from the different areas are shown in Table 5. *Aeromonas* spp. that were isolated from biofilms from Modimola Dam raw water (8 of 12) and mixed water (1 of 10) harboured the *hylH* gene (Figure 6). These genes were more prevalent in isolates from raw dam water. However, *aerA* genes were not detected in the isolates from either site. The *exoA* gene (Figure 7) was detected in *Pseudomonas* spp. from the raw water biofilm and biofilm isolates from the treated dam water. Isolates from the biofilms from all sites harboured *exoT* genes (Figure 8). However, none of the *Pseudomonas* spp. isolates possessed the *exoS* gene.

Table 4: Prevalent antibiotic resistance phenotype of biofilm

Site	Isolate	Antibiotic resistance phenotype
Dam	Faecal coliforms	KF-AP-C-E-OT-TM-S-A-NE
	Total coliforms	KF-AP-C-E-OT-TM-A-NE
	Pseudomonas	KF-AP-C-E-OT-TM-A
Treated dam water	*Aeromonas*	KF-AP-C-E-OT-TM-A
	Pseudomonas	KF-AP-C-E-OT-TM-A
Mixed water	*Pseudomonas*	KF-AP-C-E-TM-A
	Aeromonas	KF-AP-C-E-OT-TM-A

KF, cephalothin; AP, ampicillin; C, chloramphenicol; E, erythromycin; OT, oxytetracycline; TM, trimethoprim; S, streptomycin; A, amoxicillin; NE, neomycin.

Discussion

Water is a vital component of life but can serve as an important vehicle for the dissemination of potential pathogens to humans.[21] Source water that receives sewage effluent may be polluted with opportunistic pathogenic microorganisms and pharmaceuticals.[28] Modimola Dam receives treated sewage effluent. Organisms that survived the treatment process may be able to grow in the aquatic environment. A further concern is that, at times, the treatment processes fail and the potential exists for the presence of opportunistic pathogens such as *Aeromonas hydrophila* and *Pseudomonas aeruginosa*. Both of these species have a tendency to form biofilms. This study was thus aimed at determining whether *Aeromonas* spp. and *Pseudomonas* spp. occur in biofilms in the drinking water of Mafikeng.

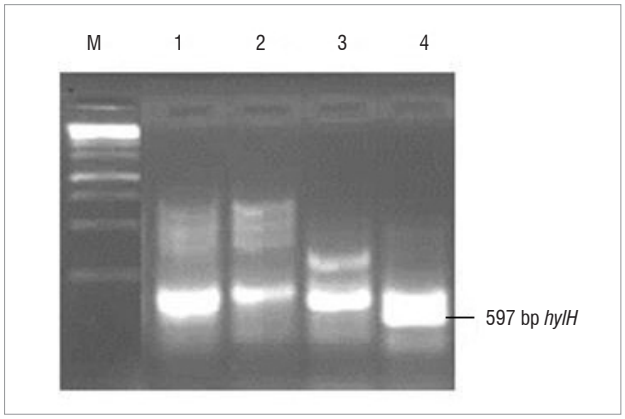
Organisms isolated in this study include faecal coliforms, total coliforms, *Aeromonas* and *Pseudomonas.* In a similar study, heterotrophic bacteria were isolated from biofilms in copper plumbing, which included a wide variety of organisms.[10] *Aeromonas* species are implicated in gastroenteritis and are generally considered to be waterborne pathogens[29] while *Pseudomonas* species are opportunistic pathogens that cause nosocomial infections in susceptible patients[30]. Moreover, it is very difficult to eradicate *Pseudomonas* species because of their high intrinsic resistance to a variety of antibiotics, including β-lactams, aminoglycosides and fluroquinolones.[31] *Aeromonas* has the potential to grow in water distribution systems, especially in biofilms, where it is resistant to chlorination and produces many different putative virulence factors.[32] Isolates that are resistant to chlorine may be present in tap water that is intended for human consumption, and which therefore causes disease in humans.

The regrowth and formation of biofilms in drinking water distribution pipes has been detected even in countries with advanced water-treatment and health-care facilities.[21] The presence of biofilms has been found to cause significant corrosion of pipe materials and, subsequently, the addition of inorganic and organic matter, which results in a poor aesthetic quality of water.[12] Moreover, free chlorine reacts with compounds present in biofilms inside water pipes, producing an unpleasant taste and odour.[11] Adherent bacteria are more resistant to antimicrobial agents and could contribute to the planktonic cells present in the bulk water. The prevalence of planktonic bacteria in drinking water may be a result of sloughing of the biofilm – an assumption which is supported by the observation of planktonic bacterial episodes in treated drinking water.[5]

Table 5: Virulence gene determinants detected in isolates from the different areas

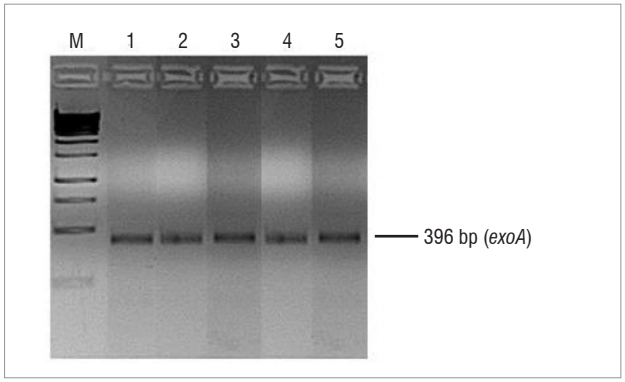
Site	Isolate	*Aeromonas* species		*Pseudomonas* species		
		aerA	*hylH*	*exoA*	*exoS*	*exoT*
Treated dam water	*Pseudomonas*	NT	NT	3	0	11
	Aeromonas	0	8	NT	NT	NT
Mixed water	*Pseudomonas*	NT	NT	0	0	6
	Aeromonas	0	1	NT	NT	NT
Raw dam water	*Pseudomonas*	NT	NT	2	0	4

NT, not tested



Lane M: 1-kb DNA ladder; Lanes 1–4: hylH *gene fragments from* Aeromonas *species isolated from different sites.*

Figure 6: Image of an agarose (1% w/v) gel depicting the *hylH* gene from *Aeromonas* species.

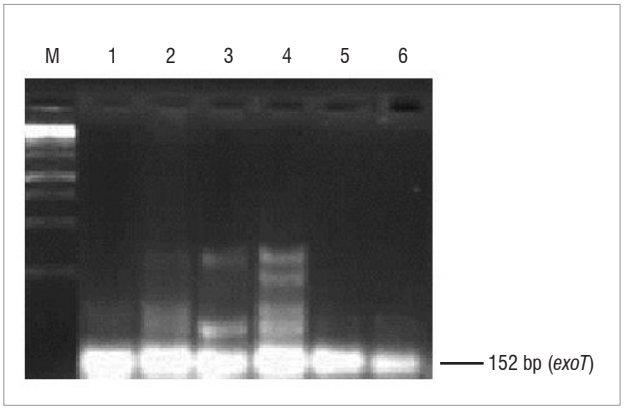


Lane M: 1-kb DNA ladder; Lanes 1–5: exoA *gene fragments from* Pseudomonas *species isolated from different sites.*

Figure 7: Image of an agarose (1% w/v) gel depicting the *exoA* gene from *Pseudomonas* species.

Biofilm formation is facilitated by many factors including available nutrients, characteristics of the pipe material, disinfectants used, physico-chemical parameters and the ability of the microorganisms to resist destruction by antimicrobial agents.[33] The significant release of nutrients from the surface material to the water promotes the growth of bacteria.[18]

Cementitious, metallic and plastic materials are the three most commonly used types of plumbing materials. The plumbing materials chosen for this study were copper and galvanised steel, which are commonly used in domestic plumbing systems in South Africa. Our results demonstrate biofilm formation on both of the plumbing materials that were used. In another study, a higher density of bacteria was observed on polyethylene and polyvinylchloride surfaces than on galvanised steel.[34] In the present study, thicker biofilms were observed on galvanised steel than on copper. However, biofilms on galvanised steel coupons were not compared with those on polyethylene and polyvinylchloride surfaces. It has been observed that biofilms on copper had low concentrations of culturable bacteria.[35] It is thus not uncommon to find low levels of culturable bacteria in biofilms on copper coupons. Moreover, it has been reported that the formation of biofilms was slower on copper pipes than on polyethylene pipes. However, after 200 days there was no difference in microbial numbers in biofilms between the two pipe materials.[18] This finding implies that in the case of long-term use, biofilm levels on metal surfaces will be similar to those on polyethylene and polyvinylchloride surfaces. However, as a consequence of their nature, biofilms on metal surfaces will contribute to microbial-induced corrosion, which can increase the metal concentration in water distributed by copper pipes,[15] which has the potential to cause health problems.



Lane M: 1-kb DNA ladder; Lanes 1–6: exoT *gene fragments from* Pseudomonas *species isolated from different sites.*

Figure 8: Image of an agarose (1% w/v) gel depicting the *exoT* gene from *Pseudomonas* species.

In the present study, we did not focus on the corrosion potential of the biofilms but rather on whether or not *Pseudomonas* and *Aeromonas* spp. colonise the biofilms. It has been previously demonstrated that *Pseudomonas* spp. are opportunistic pathogens that can integrate into drinking water biofilms on materials which are relevant for domestic plumbing systems.[35] Biofilms have been implicated in human infections and are particularly recalcitrant to antibiotic compounds.[30,36] Final water produced by the water-treatment plant must comply with the South African National Standard (SANS) 241:2011 for drinking water.[37]

No total coliforms or faecal coliforms were detected in biofilms from the treated drinking water, which thus complied with the SANS 241 standard of 0 CFU/100 mL. This finding is an indication that the treatment process was effective in removing total coliforms and faecal coliforms from the raw water. However, *Pseudomonas* and *Aeromonas* spp. were isolated

from the biofilms of treated and filtered water. This may be an indication of deteriorating water quality. High levels of *Pseudomonas* spp. in water may cause taste, odour and turbidity problems.[38] There is no available SANS 241 standard for *Pseudomonas* and *Aeromonas* spp. in drinking water.

Identities of the organisms were confirmed through PCR using *gyrB*, *toxA, ecfX, aerA* and *hylH* gene fragments. The *ecfX* gene encodes an extra cytoplasmic function sigma factor, which may be involved in haem uptake or virulence[39], whereas the *gyrB* gene encodes the DNA gyrase subunit B, a protein which plays a crucial role in the DNA replication process[40] and the *toxA* gene encodes the exotoxin A precursor[25]. PCR assays targeting the *ecfX* and *gyrB* genes are highly suitable for the identification of *P. aeruginosa.*[25,39] Application of the PCR technique to target *gyrB, aerA* and *hylH* genes is an excellent molecular chronometer for screening potentially virulent *Aeromonas* species in food and the environment.[40,41]

One rational approach to determine whether *Pseudomonas* and *Aeromonas* spp. have the potential to be virulent is the assessment of virulence phenotypes and screening for specific virulence genes. *Pseudomonas* and *Aeromonas* spp. isolated in the present study carried some gene sequences encoding toxic proteins, indicating the potential of these organisms to cause diseases in humans. The ability of *Pseudomonas* spp. to express these virulence determinants also enhances their capabilities to produce biofilms.[36] *Pseudomonas aeruginosa* is able to synthesise a large number of virulence proteins that greatly influence pathogenesis.[26] *Pseudomonas* species produce extracellular compounds which promote adhesion and the ability of the isolates to attach to surfaces, thereby also increasing the virulence properties. The pathogenicity of *Aeromonas* is complex and multifactorial and has been linked to exotoxins such as cytolytic enterotoxin, haemolysin/aerolysin, (*aerA, hylH, hylA, alt* and *ast*), lipase and protease and various other cell-associated factors.[27,32] Screening for specific cytotoxin and haemolysin genes appeared to be the most effective way of detecting and characterising *Aeromonas* virulence factors.[41]

The desired gene fragments were successfully amplified, which indicates the presence of virulent *Pseudomonas* and *Aeromonas* spp. in biofilms from drinking water. From the molecular data it was demonstrated that the *exoA, exoT* and *hylH* genes were successfully used for the detection of virulent *Pseudomonas* and *Aeromonas* spp. in raw and drinking water biofilm samples. It is thus important to perform molecular confirmation of isolates to ensure accurate results.

Detection of these genes amongst the *Pseudomonas* and *Aeromonas* spp. isolated from the drinking water sources of Mafikeng is cause for concern and should be further investigated. PCR assays could provide a powerful supplement to the conventional methods for a more accurate risk assessment and monitoring of potentially virulent *Pseudomonas* and *Aeromonas* spp. in the environment.

Conclusion

Bacterial biofilms were detected in all water sources that were sampled and opportunistic pathogens such as *Pseudomonas* and *Aeromonas* species were isolated from biofilms in raw water from the Modimola Dam, drinking water and mixed water. These isolates were found to harbour virulence gene determinants indicating that they have the potential to cause diseases in humans. Therefore, it is important to constantly determine the occurrence of these species in water bodies and drinking water distribution systems, in particular, and to determine whether conditions prevail that may allow these opportunistic species to survive water purification processes. Such a strategy will be of particular importance in scenarios in which treated wastewater is reused for drinking water. A clear understanding of the different mechanisms by which biofilm bacteria harbour and distribute virulence factors, as well as protect themselves from the action of disinfectants and antibiotics, is vital to formulate control and management strategies.

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Authors' contributions

S.G.M. is the main author of the article and performed all the research work. C.B. supervised the work and guided the main author and M.M. co-supervised the work.

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Durham versus Durban: Quantifying productivity in astrophysics research

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Quantifying and rewarding research productivity is a contentious issue. In South Africa, there are at least two systems in wide use: peer assessment (as used by the National Research Foundation in providing researchers with individual ratings) and a simple publication count (used by the Department of Higher Education and Training to incentivise research output). At the University of KwaZulu-Natal (UKZN), the latter is used to grade the research performance of staff; however, this metric penalises those academics who work in large teams, as is increasingly common in astronomy. To test for correspondence between this metric and perceived research quality, I conducted a case study of the Extragalactic and Cosmology Group at Durham University in the UK, which is one of the leading astrophysics research groups in the world. I found that 44–74% of the permanent academic staff within this research group would not meet the research productivity target applied at UKZN in 2014. Given the disparity between this result and the esteem in which the research of the Durham group is held, I suggest that alternative methods of recognising and rewarding research output by funding agencies and universities should be explored, with an emphasis on quality rather than quantity.

Research productivity

Research productivity at the University of KwaZulu-Natal is measured in terms of publication units (PUs). Following the Department of Higher Education and Training scheme, 60 PUs are awarded per publication in a journal on the Thomson Reuters Web of Science (WoS) Science Citation Index.[1] However, this number is divided by the number of co-authors – hence, a paper with 10 authors will result in 6 PUs being awarded to each staff member who is an author. The graduation of a PhD student also amounts to an award of 60 PUs in this system.

In this article, the focus is on astrophysics. In this field, like in many other areas of science, there has been a steady increase in the average number of authors per journal publication over the last few decades.[2-4] Hence, long lists of authors are increasingly common (on average, seven authors per paper in the period 2006–2010[4]), and the authors of such papers are awarded small numbers of PUs. The productivity of researchers in the College of Agriculture, Engineering and Science at UKZN is judged according to whether staff have met a target number of PUs in the calendar year, and the target does not vary with discipline. Peer evaluation and citation metrics are not used to assess research quality. Table 1 lists the research productivity targets at UKZN in 2014. Note that higher targets are set for higher academic ranks (i.e. the target increases proportionally from Lecturer to Senior Lecturer to Associate Professor to Professor).

Table 1: Relationship between target number of publication units and performance management score at the University of KwaZulu-Natal (2014) as a function of academic rank

	Target number of publication units			
Performance management score	**Lecturer**	**Senior Lecturer**	**Associate Professor**	**Professor**
1	0–29	0–44	0–59	0–74
2	30–59	45–89	60–119	75–149
3	60	90	120	150
4	>60	>90	>120	>150

Note: 3 is the expected performance management score; scores of 2 and 1 are 'underperforming' and 'severely underperforming', respectively.

A case study: Durham University

In order to determine if the system used to quantify research productivity at UKZN is a good predictor of the esteem in which researchers are held, I have applied it to the permanent academic staff in the Extragalactic and Cosmology Group at Durham University.[5] According to Thomson Reuters, Durham was the top-rated university in Europe in space sciences research over the period 1998–2008 in terms of citations per paper.[6] Moreover, Durham University is ranked 66 in the world according to the Times Higher Education university rankings in physical sciences 2013–2014.[7] I make the assumption here that Durham's placing in these rankings is as a result of the efforts of a majority of the staff, and is not driven by one or two individuals.

In astronomy, the standard bibliographic database in use is the NASA Astrophysics Data System (ADS).[8,9] This database provides a variety of information, including citation counts; but, in this article, I used only its author count function in order to calculate the number of PUs per paper that would be awarded to an author based at UKZN. A Python script was used to extract the 2013 publications list for a given author from ADS, and to calculate their total number of PUs and the corresponding performance management (PM) score according to their academic rank (Table 1). Note that only articles published in journals on the WoS list were considered.

I performed these calculations for all 27 permanent staff listed as being part of the Extragalactic and Cosmology Group at Durham.[5] (In the case of one staff member, the calculation was based on the publications for 2013 listed on their staff profile page, rather than ADS output; the ADS query is based on only the author's surname and first initial, so common names such as Li (or Smith) can lead to spuriously large PUs and PM scores by matching multiple authors.) Emeritus staff were also excluded. Readers in the UK system were assumed to be equivalent to Associate Professors in the South African university sector.

Results and discussion

Figure 1 shows the number of PUs produced by each staff member at Durham in 2013 in comparison to the target level (PM score = 3) for each academic rank at UKZN (Table 1).

As can clearly be seen, academics in the Durham Extragalactic and Cosmology Group do not meet the research productivity target applied at UKZN: based on publications, 37% of the staff produced fewer than 60 PUs (the expected performance of a Lecturer at UKZN) in 2013, despite only 26% of the staff being at Lecturer level. Taking into account the different performance levels expected at higher academic ranks, 74% of Durham staff produced fewer than the expected number of PUs. It is clear that the UKZN research productivity metric does not reflect the high regard in which this research group is held.[6,7] I also note that the correlation between academic rank and research output is weak, with only Lecturers producing significantly fewer PUs on average (median: 51.4 PUs) than higher ranks (78.4, 75.2 and 77.7 PUs for Senior Lecturers, Associate Professors and Professors, respectively).

The above analysis does not, however, take into account the graduation of PhD students. This figure is more difficult to quantify, but can be estimated using information on the Extragalactic and Cosmology Group's staff web page.[5] In June 2014, a total of 48 postgraduate students are listed as being part of the Durham group, resulting in an average of 1.7 students per academic staff member. For the purposes of this estimate I will assume that all listed students are at PhD level. Assuming that students are distributed equally among all 27 staff members, that the number of students remains constant, and that a student graduates every 3 years (an optimistic estimate[10]), then 16 students should graduate per year, boosting each staff member's research productivity by 35.6 PUs on average. The result of this boost is shown as the dashed line in Figure 1. The inclusion of PhD student graduation clearly results in a significant improvement towards the UKZN productivity target. Nevertheless, even with this optimistic estimate of the PhD graduation rate, 44% of Durham staff would be below the expected research productivity level at UKZN.

Finally, I note that I have not taken into account that some of the staff classified as Lecturers are in fact currently Senior Research Fellows with (presumably) limited teaching duties, and therefore it is likely they have more time to devote to research than the average Lecturer at UKZN. Thus, even with the optimistic figures used in this analysis, it is clear that the research productivity metric applied at UKZN is not well aligned with the productivity of researchers based at world-leading research centres in astrophysics, such as at Durham University.

Conclusion

I have performed a simple analysis of the research productivity of the Extragalactic and Cosmology Group at Durham University using the metric applied at UKZN. I found that, in 2013, almost half of the staff in this group attained fewer PUs than would be expected of them at UKZN, even with an optimistic estimate of the PhD student graduation rate at Durham. However, the Durham group is regarded as producing world-leading research in astrophysics.[6] I conclude that the quantity of research produced, as measured using the PUs system, does not necessarily reflect the quality of research, and it is the latter that leads to international recognition such as that enjoyed by the Durham group. I suggest that alternative methods of recognising and rewarding research output at South African institutions should be explored. These methods might include citation metrics, in which case caution should be applied, as the typical number of citations per article varies widely across fields, and even within sub-fields. Peer evaluation, through reading of actual articles, while difficult, subjective and time consuming, is perhaps the fairest way for the value of research to be assessed.

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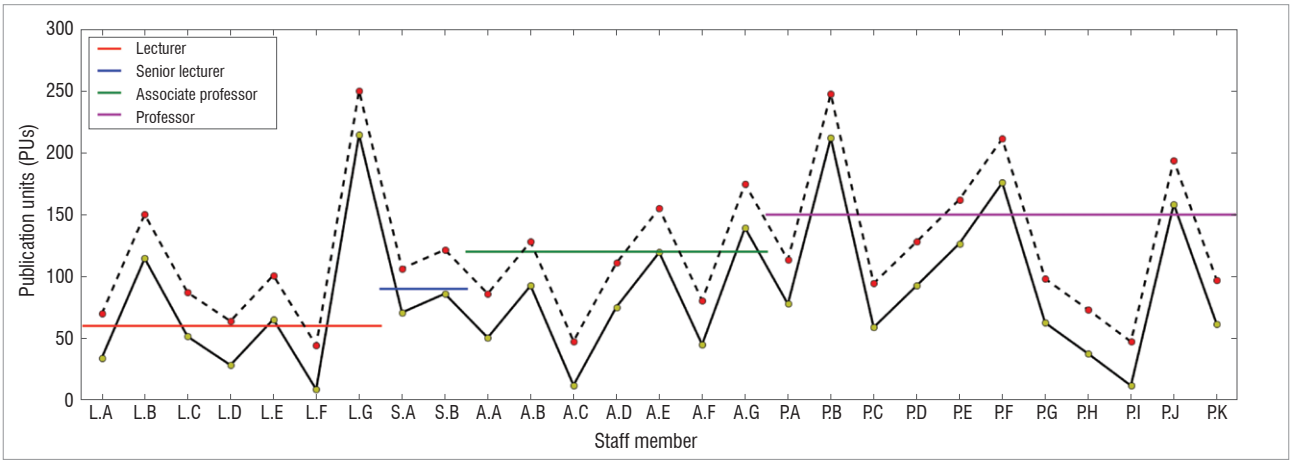

Figure 1: Publication units for permanent academic staff in the Extragalactic and Cosmology Group at Durham University for 2013. Data were extracted from the NASA Astrophysics Data System[8,9] and only publications on the Web of Science list were considered (solid black line). Lecturers, Senior Lecturers, Associate Professors and Professors are labelled L, S, A, P, respectively. Thus 'S.B' refers to 'Senior Lecturer B'. The horizontal coloured lines indicate the expected research productivity level based on academic rank at the University of KwaZulu-Natal in 2014 (Table 1); more than two thirds of staff in the Durham group do not meet these targets based on publications alone. The dashed line shows an optimistic projection for how the output of each academic would be boosted by graduating PhD students. Even after this projection is applied, 44% of the Durham staff would not meet these targets.

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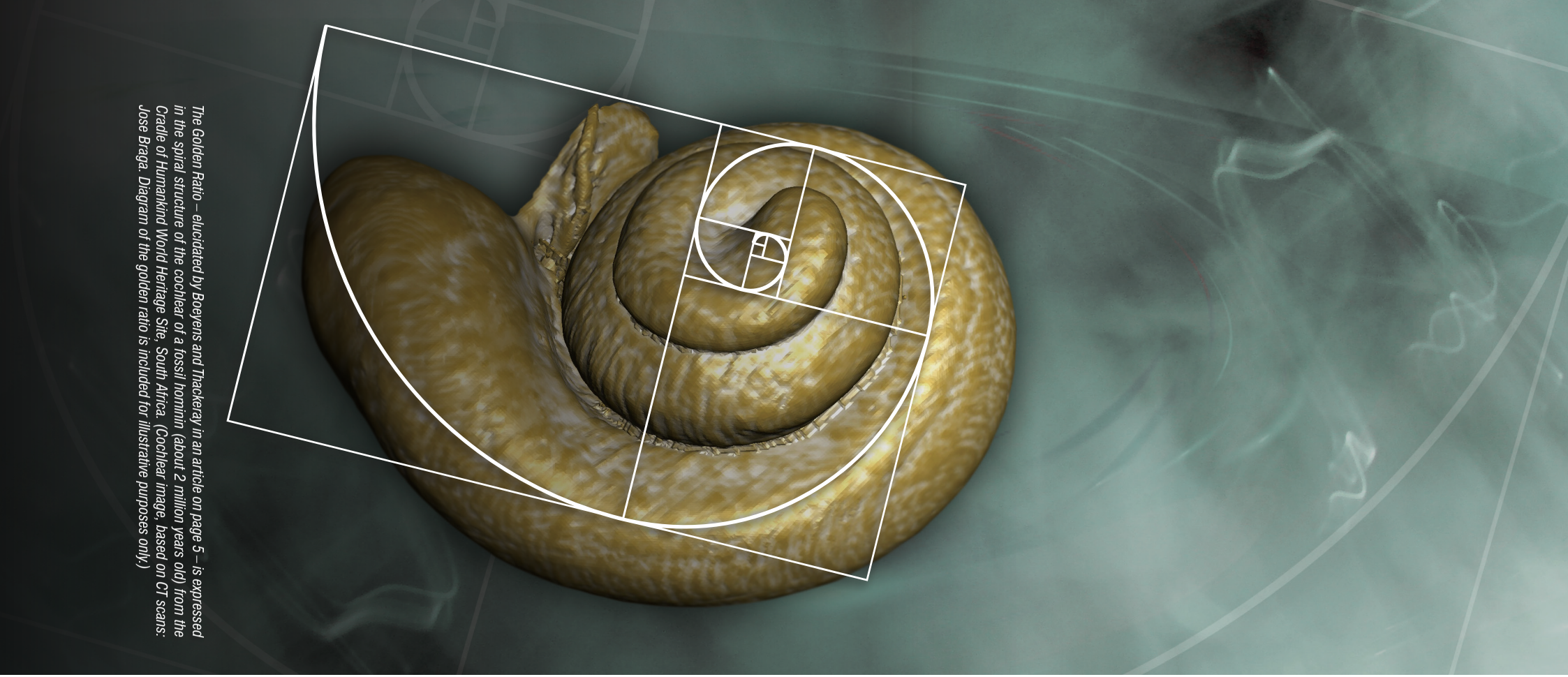

The Golden Ratio – elucidated by Boeyens and Thackeray in an article on page 5 – is expressed in the spiral structure of the cochlear of a fossil hominin (about 2 million years old) from the Cradle of Humankind World Heritage Site, South Africa. (Cochlear image, based on CT scans: Jose Braga. Diagram of the golden ratio is included for illustrative purposes only.)

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