

# SOUTH AFRICAN Journal of Science

Extreme rainfall in  
the Western Cape,  
South Africa

An examination of the  
failure of African Bank

Ebola: the role  
of science and  
non-science in the  
uptake of information

Women's  
representation in  
national science  
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Heavy rainfall. In an article  
on page 43, De Waal and  
colleagues explore increases in  
extreme rainfall in the Western  
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## Review Article

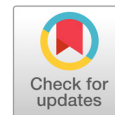
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## Worlds of awards

The Oscars, BAFTAs, the Golden Globe Awards, the Palm d'Or (the Cannes Film Festival), the Sundance Film Festival Awards, New York Film Critics Circle Awards – and literally hundreds and hundreds of national awards – recognise and idolise the stars of the movie, stage and television worlds. In sport, the Olympic Games, the FIFA and CAF awards, the Laureus, the International Sport Award, the PGA, the Formula 1 Grand Prix, World Swimming Masters Championships and the Tennis Grand Slams – also amongst hundreds of others – recognise and venerate (and sell to an audience) the world's top sportspeople. And in both arenas the stars and near stars are all rewarded with handsome earnings.

Yet in the world of science there are just three or four high-level equivalents: the Nobel Prizes; the Holberg Prize, the Fields Medals and the Abel Prize. Of course, there are also innumerable national and organisational awards for scientists. In South Africa, the Harry Oppenheimer Fellowships Award, the Gold Medal of the Academy of Science of South Africa (ASSAf), the Alan Paton Award and the six National Orders at their various levels – including those made to high achievers other than scientists of course – are amongst them. Internationally, however, it is really just the Nobel and the Holberg Prizes, and possibly the Fields Medals, that command international interest and (at times) fame, although rarely wealth.

In this issue of the SAJS, however, we foreground and celebrate awards and honours made to South African scientists who have gained fame locally and internationally for the major contributions they have made to science in their fields, and whose work has changed the lives of thousands of people around the world.

Altogether, there are 55 scientists whose honours are highlighted in this issue. Two have gained recognition from possibly surprising sources: Prof. Glenda Gray and Dr Stephanie Fanucchi. Prof. Gray, Chief Executive Officer and President of the Medical Research Council, has been recognised by *Time* magazine as one of the top 100 most influential people in the world for 2017. Dr Fanucchi, a cell biologist, is a senior researcher at the Council for Scientific and Industrial Research and was awarded one of just 15 L'Oréal/UNESCO International Rising Talent Awards for 2017. Dr Fanucchi was also a finalist for the 2016/2017 TW Kambule-NSTF Award for Emerging Researchers. These leading women scientists and their work are the subjects of two News and Views items in this issue.

The other 53 scientists have been honoured in a book published by ASSAf – called simply and appropriately *Legends of South African Science*. ASSAf set a very strict condition to be met for anyone to be included in the book: 'legends' had to have been a recipient of at least one of South Africa's top awards – the ASSAf Science-for-Society Gold

Medal, National Orders of Mapungubwe or Baobab bestowed by the President, or the Harry Oppenheimer Fellowship. The book was launched on 25 July 2017, and is reviewed in this issue. Without pre-empting the review there is, however, a notable observation that emerges from the book as far as awards are concerned.

This observation is the amazing range and number of awards (*over and above the requirement by ASSAf*) that the 53 legends have received and named as their three most valued awards. These 53 scientists have listed amongst them 104 additional awards. If their other, unlisted awards and duplicates, were to be included, the number would almost certainly more than double. As a simple example, both Arthur Chaskalson and Friedel Sellschop were awarded honorary doctorates by five universities – none of which are listed in their top three awards.

Recently, the National Science and Technology Forum (NSTF) named the winners in its nine categories of excellence in a wide range of fields – all of which have both scientific and social merit. The winner in the category of 'Over a lifetime achievement by an individual' was SAJS Associate Editor Prof. Nicolas Beukes of the University of Johannesburg. We hope to carry Commentaries or Reviews from some of the winners over the next six issues of the Journal.

Why should awards and recognition be important enough to highlight in this issue of SAJS – through the Leader, two News and Views items and a Book Review? The reasons for having and for recognising the legends of science are innumerable.

We all need entertainment in our lives – whether it be through watching films or plays, listening to a Rachmaninov piano concerto, watching a nail-biting football match or the Wimbledon finals, or reading a great novel. Palaeoanthropological discoveries have revealed that recreation has been a part of human life for thousands of years – whether in the form of music, dancing, storytelling or jewellery making.

But we also need new knowledge, for its own sake and for its application – jobs, economic and social growth, better health and safer lives – and for the ability to keep doing better as the challenges we face grow greater. Science is the source and foundation of what makes it possible to meet all of those needs. It makes sense, then, to recognise, reward and value the people who make that happen. Science (and its applications) are frequently taken for granted rather than being understood as fundamental and essential parts of ordinary lives – our own and others. But it needs to be so understood – if we cannot recognise and respect our own community of scientists, how might we ever spread the word more widely?





# Mother-to-child transmission of HIV and South Africa's 'HIV warrior'

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*Professor Glenda Gray is the President and CEO of the South African Medical Research Council; Director of International Programmes for HIV Vaccines Trial Network and the Programmes' co-principal investigator; Chairperson of the Board of the Global Alliance for Chronic Diseases; co-founder of the internationally recognised Perinatal HIV Research Unit in Soweto, South Africa; and the former Executive Director of the Perinatal HIV Research Unit, an affiliate of Wits University. Professor Gray is a member of the Institute of Medicine of the US National Academies and also of the Academy of Science of South Africa and she chairs its Standing Committee on Health. Time magazine named her as one of the 100 most influential people in the world in 2017.*

HIV/AIDS – a spectrum of conditions caused by infection with the human immunodeficiency virus – is one of the major international infections experienced in the 20th and 21st centuries. Primarily spread by unprotected sex, the virus can also be transmitted from an infected mother to her newly born baby, and it is in this area of extreme risk that Professor Gray, a trained paediatrician, has devoted much of her work – while also playing a critical role in fighting ignorance, evasion and AIDS denialism.

While HIV infections were spreading across the world, the South African apartheid government's response was largely characterised by evasion, and for most of the population, ignorance was the predominant state of affairs. HIV and AIDS were diseases that were not spoken about. This situation was bad enough, and allowed the infection to spread without acknowledgement, but the real problem began under the Presidency of Thabo Mbeki who, along with his Minister of Health, steadfastly denied the existence of HIV and AIDS and undermined work that had been started.

Under these circumstances, Professor Gray's work in fighting ignorance and denialism became critical. She points out that she watched HIV 'explode' in South Africa during the 1990s, with increasing numbers of men, women and children succumbing to the effects of AIDS. She found herself battling the disease on two fronts: the government (which required determination and courage) and the virus (which required research). It was this combination of battles that turned her from being the doctor she had trained to be into a researcher. It was her intention that the research would not only serve to challenge the disease and its progress between and within individuals, but also provide the evidence needed to challenge denialism. It was a time when the wards of hospitals were increasingly filled with women and men; but it was especially with children amongst whom deaths started increasing.

In response to this situation, Professor Gray started, with Dr James McIntyre, a perinatal HIV clinic at Baragwanath Hospital in 1993 – one of the first in South Africa to provide testing and counselling for pregnant women, and to reach out to the surrounding community. In 1996, the clinic became, in addition to its other work, a research unit at Wits. In the same year, and in order to take the research work further, the UNAIDS PETRA (PErinatal TRANsmiSSion) study looked at various durations of AZT/3TC therapy to reduce perinatal transmission. PETRA was a multicentred trial, for which Professor Gray was one of the investigators and she enrolled women for the study at Chris Hani Baragwanath Hospital.

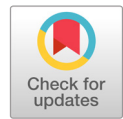
Lives are not compartmentalised: people's activities overlap, and at times they blend. So it is over-simplifying Professor Gray's life to suggest that the years to 1996 were those of a paediatrician and activist researcher – and that those that followed have been the work of a world specialist in mother-to-child transmission research. Mother-to-child transmission had been a driving concern for her from the start. But as her international profile grew, she began to encounter opposition to her ideas. Her research had made it clear that using powdered formula instead of breastfeeding could reduce mother-to-child infection, and she rapidly became the foe of those who promoted breastfeeding and who despised the idea of the formulas. She unhesitatingly took on the challenge and views and opinions began, slowly, to change.

Professor Gray took up the cause of poor rural women after the discovery of AZT; she pointed out that women in developing countries could not afford the 14-week course of treatment or did not learn about AZT until it was too late for them to start the treatment. But promoting the use of formulas for breastfeeding, and pointing out the limitations of AZT for many women who needed treatment, left unanswered the question of what alternatives there might be. So she and her research unit joined a clinical trial to find the most cost-effective treatment at the lowest dose, reasoning that an unaffordable drug might as well not exist for those most in need of it.

Adhering to stringent ethical requirements, the researchers proposed that the clinical trial stage of their work should include a test for the new drug that the research had produced. This part of the study would assess the effectiveness of the drug against a placebo. The editor of the *New England Journal of Medicine* was outraged. So Professor Gray took the proposal to the community identified for the trials and asked for their opinions. They agreed to work with the researchers and the trials of the new drug showed clearly that the drug, using a shorter and less expensive process, was successful.

However, the South African government, under President Mbeki, refused permission for the drug to be used and hospital superintendents followed, for the most part, what they considered to be government policy so that not even important drugs were used. It was not until former President Nelson Mandela endorsed the idea of the treatment that could save lives – in direct contradiction of the views of Mbeki – that the drug became available to South Africans.

Apart from her responsibilities at the Medical Research Council, and her other major commitments, Professor Gray's work now involves assisting in the efforts of other South African scientists who are working on the development of a vaccine.



# Discovering new host-directed therapies to treat inflammation

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*Dr Fanucchi is a South African born cell biologist who was recently awarded the 2017 L'Oreal/UNESCO International Rising Talent Award (15 of which are awarded worldwide annually); she was also a finalist for the 2016/2017 TW Kambule-NSTF Award for Emerging Researchers. Dr Fanucchi works as a senior scientist in Prof. Musa Mhlanga's laboratory; Prof. Mhlanga is the Director of the Biomedical and Translational Research Initiative, which is a new biomedical translational focused initiative lead by the Council for Scientific and Industrial Research and the University of Cape Town and funded by the Department of Science and Technology.*

In 2003, an article published in *Time* magazine referred to inflammation as the 'silent killer'. It was around this time that medical doctors and scientists from different backgrounds started to realise that many disease states, including various cancers and autoimmune diseases, had an inflammatory basis. This important realisation revealed that we need to rethink how we treat these diseases. In particular, we need to carefully consider how inflammation impacts disease progression.

Inflammation is a so-called double-edged sword: you need it to clear infection and heal wounded tissues, but, if inflammation is not carefully regulated, it leads to many diseases such as various cancers, inflammatory bowel disease, rheumatoid arthritis and even sepsis. Sepsis or systemic inflammatory response syndrome is a serious inflammatory illness that is associated with a very high morbidity. There are 20–30 million sepsis cases reported each year, and it has been estimated that a sepsis-related death occurs every 3–4 s.<sup>1</sup> The most common cause of sepsis is a bacterial infection, with viral and fungal infections contributing a smaller percentage. Once infected, the immune cells launch an attack to eliminate the infectious agent. The resultant inflammatory process helps the body to recover from the pathogen and repair damaged tissues. In a normal immune response, the body is able to precisely control the inflammatory response. However, in the case of sepsis and other inflammatory disorders, this process is not properly regulated, leading to the uncontrolled activation of the immune system and exacerbated levels of inflammatory processes. In these circumstances, the immune cells are not only targeting the infected or diseased tissue, but healthy tissue as well, leading to lethal consequences. Therefore, the ability to intervene and dampen excessive inflammation is the subject of intense research.

Cancer is another inflammatory-based disease that has a major influence on life expectancy. Every year, more than 14 million people worldwide are diagnosed with cancer.<sup>2</sup> In South Africa, about 100 000 people are diagnosed with cancer every year, with an average survival rate of ~60% across all cancer types; with prostate, breast and colon cancer among the most prevalent.<sup>2</sup> The immune system is composed of multiple cell types, which act synergistically to recognise and eliminate diseased or cancer cells. However, cancer cells are able to 'hide' from the immune system and in doing so are able to evade immune responses and escape eradication by immune cells. Recently, some exciting therapies have been able to 'unmask' immune cells so they are able to recognise cancer cells to kill them. These immunotherapies target immune checkpoint molecules and represent a promising new way to treat cancer.<sup>3</sup> In some patients, these therapies have resulted in the successful reactivation of the immune system to kill the cancer cells, but unfortunately, this is not always the case. In other patients, immunotherapy leads to the overactivation of the immune system, elevated levels of inflammation and death. Clearly, current approaches to treat inflammatory disorders are not always successful. Thus there is a critical need to gain a detailed understanding of these processes, so we can develop new therapies and refine current ones.

At a cellular level, inflammation involves the sensing of the pathogen or disease causative agent which leads to the induction of signal transduction pathways. These pathways activate transcriptional regulators that switch on immune genes that encode various inflammatory mediators (e.g. cytokines). Therefore, inflammation is controlled at the level of gene regulation – which can be described in simple terms as the ability of genes to be switched on and off. This is a highly complex process that is not fully understood.

Major technical advances in biology are significantly advancing our understanding of gene regulation. For example, it took more than 10 years to sequence the human genome – a process that can now be completed in 1 to 2 days. Other important advancements include the ability to make discrete edits to DNA using gene editing tools, such as CRISPR/Cas9 and the ability to use microscopy-based tools to visualise RNA and DNA at a single cell level. In the last decade, using a combination of these tools, scientists have made some very important discoveries in the field of gene regulation.

One surprising discovery is that the folding of DNA in the nucleus is not random. In almost every cell of the ~1 billion cells in the human body, there is a nucleus that contains DNA, or cellular blueprint. If you removed all the DNA from each nucleus and stretched it out, it would form a string longer than 1 m. This DNA has to be packaged to fit inside the nucleus, which is one-fiftieth the size of a grain of sand. Therefore, a large quantity of DNA is packaged in a small space, and regions of DNA interact or 'kiss'. In a study in 2013, we showed that these 'gene kissing' interactions were important to the regulation of interacting genes.<sup>4</sup> This study, combined with many others, revealed that we need to carefully consider how the folding of DNA in the nucleus impacts how genes are switched on.<sup>4,5</sup> This is especially relevant in processes such as inflammation, which are ultimately controlled by how immune genes are switched on and off.

DNA can be transcribed, or made, into RNA which is then made into protein. Another surprising recent discovery was that the majority of genome is transcribed into RNA, and that not all of this RNA is made into protein. This subset of RNA is referred to as long non-coding RNA or simply lncRNAs. Thousands of lncRNAs are made, yet few have been characterised. Therefore, they represent an entirely new, exciting and unexplored area of drug targets.

LncRNAs may act as intermediates that link information carried in the three-dimensional folding of DNA to gene regulation. Within the DNA sequence there are various types of regulatory or enhancer sequences that fine-tune gene expression. In certain circumstances, these regulatory sequences are located very far away from genes in one-dimensional space. However, because of the compaction and looping of DNA, these enhancer elements can contact genes in three-dimensional space. Recently it has been shown that enhancer loci can be transcribed into a novel class of lncRNAs, termed enhancer RNAs (eRNAs).<sup>6</sup> These eRNAs may regulate genes via diverse mechanisms that include the tethering of transcriptional regulators near to target gene(s). One of the greatest challenges associated with characterising lncRNAs is the inability to predict their function based on DNA sequence. Therefore, despite their abundance, a very low percentage of the thousands of annotated 'enhancer-derived' lncRNAs have been assigned a function.

Recently, we explored how lncRNAs and three-dimensional chromatin interactions regulate immune gene regulation. In this ongoing study, we identify a new class of 'enhancer-like' lncRNAs. We show that the three-dimensional folding of DNA in the nucleus brings these 'enhancer-like' lncRNAs in close proximity to immune genes, allowing them to 'kiss' and regulate the immune genes. Further, we have shown that it is possible to use small molecule inhibitors to 'drug' this response. As opposed to the commonly used strategy of targeting the pathogen, these

drugs represent a new way to target host inflammation directly. Moving forward, we are collaborating with a number of pharma and biotech partners to test these inhibitors. Although these studies are still in very early stages, we are very hopeful that these drugs will be a new way to treat inflammation, and diseases such as cancer.

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# Building needs-based healthcare technology competencies across Africa

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Needs-based technology innovation for better health on the African continent requires that African countries develop a strong health technology research and development base, grounded in an understanding of the local context. The discipline of biomedical engineering plays an important developmental role in this regard, through research and training to advance health technology capacity. In recognition of this strategic imperative, the African Biomedical Engineering Consortium (ABEC) was founded in 2012, with the vision of building and nurturing the competencies required to support a robust and dynamic health technology sector.

Six members of ABEC in six African countries – Addis Ababa University (Ethiopia), Cairo University (Egypt), Kenyatta University (Kenya), the Mbarara University of Science and Technology (Uganda), the University of Cape Town (South Africa) and the University of Lagos (Nigeria) – along with the University of Pisa (Italy), have made a successful bid for an Intra-Africa Mobility Scheme grant funded by the European Commission. The scheme is run under the European Commission's Pan-African Programme and is modelled on Europe's well-established and successful Erasmus-Mundus programme. As part of the Roadmap 2014–2017 of the Joint Africa–EU Strategy, the Intra-Africa Mobility Scheme underlines the contribution of higher education towards economic and social development and the potential of academic mobility to improve the quality of higher education.

The funded project, *African Biomedical Engineering Mobility*, is coordinated by Kenyatta University. It will, over a period of 5 years, build human and institutional capacity in Africa for needs-based health technology research and development through postgraduate student and staff mobility within the continent. Its specific objectives include: enhancing the biomedical engineering research and teaching skills of university lecturers in Africa; establishing a solid task force of African biomedical engineers through postgraduate training; harmonising postgraduate biomedical engineering curricula to ensure a consistent level of academic quality across institutions; and creating a platform for sustained collaboration across Africa for research and teaching in biomedical engineering.

The project will specifically focus on the development of health technology competencies that address the needs of Africa, and more generally on skills that enable graduates to consider and achieve contextual suitability in technology development. Application areas include: rehabilitation engineering to address disabilities that often result from war or late diagnosis of disease; medical devices that are robust to a variety of climatic conditions, interruptions in power supply, and low levels of technological competence in the user; diagnostic tools that may be used in areas remote from clinics and health facilities; and image analysis tools to address the shortage of specialist radiologists in remote and resource-limited settings.

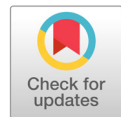
Up to 22 master's and 10 PhD candidates will benefit from the project. They will have an opportunity for training at partner institutions outside their home countries, and will gain skills and specialisations not offered at their home institutions. In addition, nine staff members will undertake teaching and research visits across the partner institutions. Overall, the project will enhance graduate employability; improve staff research profiles and teaching competencies; build institutional research capacity; and promote inter-university collaboration, while also supporting innovation to address health challenges from an African perspective.

## Acknowledgement

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# STIAS–Wallenberg Roundtable on mHealth: Towards a roadmap for image-based mobile technologies for health care

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The fifth STIAS–Wallenberg Roundtable was held in February 2017 at the Stellenbosch Institute for Advanced Study (STIAS). The theme was ‘Image-based Mobile Technology for Diagnostics and Treatment to Improve Access and Equity in Health Care’. The overarching aim was to provide a forum for stakeholders to discuss the possibilities that current developments in image-based mobile health (mHealth) offer for timely, accurate and equitable health-care delivery, as well the challenges that their development and implementation may entail for potential users and beneficiaries. The emphasis was on the need to find solutions and to map out a future roadmap for the implementation, expansion and up-scaling of image-based mHealth to improve health care, particularly in resource-constrained settings.

For the past 5 years, the Marianne and Marcus Wallenberg Foundation has supported an annual Roundtable during which representatives from South Africa, Sweden and the broader international community can engage in dialogue and debate around a central theme, typically one related to current global challenges but particularly focusing on their local manifestation. Previous Roundtable themes were ‘Energy’, ‘Mental Health’, ‘Agricultural Transformation’ and ‘Innovation for Prosperity’.

This year’s event attracted over 60 participants from 16 countries and provided an opportunity for intense cross-sectoral and cross-disciplinary discussions and networking. There was representation from the clinical, research, policy, business, media and social sectors. Sessions ranged from overviews of the landscape; unpacking the practical experiences and case studies of using mHealth in clinical settings; and overcoming challenges in implementation; to barriers and facilitators; and the need for leadership and change agents. The aim was to facilitate cross-pollination rather than focus on obstacles and barriers, and to inform the wider community, in particular policymakers, about the possibilities in mHealth.

Technology in health care has obvious benefits, like improving patient management options and outcomes, as well as secondary potential benefits like fewer referrals, reduced costs and time saved. It can also assist in diminishing professional isolation and promoting recruitment and retention in rural areas. This, in turn, can contribute to more equitable systems in global health care in resource-poor settings in high-income as well as low- and middle-income countries.

However, with many mHealth projects the challenge seems to be facilitating the initial adoption and sustained implementation in the health system, a lack of consideration for the perspective of the users, and that the technologies are not used to their full potential.

The emphasis therefore throughout the Roundtable was on the need for a patient-centred or end-user focus; the need to move away from endless pilot studies to scale-up of successful interventions; the need for appropriate policy and regulation including data safety, ethical issues and the protection of patients; and, the need to ensure equity and that issues of cost and access (particularly connectivity) do not further divide the world.

The complexity of the health-care ecosystem was emphasised by a number of speakers, as was the need for enabling policies and for mHealth not to remain isolated within a specific sector. Mohammed Dalwai, Co-founder and COO of Essential EMGuidance and President of the Board of Doctors Without Borders (South Africa) focused on the need to move away from pilot studies and to start studying the clinical impact and the practicalities of scaling up successful interventions. He pointed out that often projects are not scaled up because of regulatory issues. He stressed the need for a government mHealth body and a national eHealth strategy in South Africa.

## Lessons from case studies

Among the case studies presented was an interesting presentation on the use of mobile technology in the recent Ebola crisis. Ousmane Ly, Director General for eHealth in the Mali Ministry of Health, pointed out that ICT had played a substantial role in the emergency response but he also noted that many of the tools developed during the outbreak are not used anymore.

A detailed presentation was also given on an image-based app used to assist in the diagnosis of burn injuries, which brings together a multidisciplinary team from the Karolinska Institute in Sweden, the Western Cape government and the Universities of Cape Town and Stellenbosch.

The project uses a smartphone-based app to transmit images and other data of burn injuries for diagnostic, treatment and referral advice. In its most recent version, the burns component has been added to an existing app (the Vula app) which is used for other disease conditions. The app is being tested in sites in the Western Cape in South Africa (to be expanded in 2017 to encompass the whole province, as well as sites in Durban, a number of sites in Tanzania and, eventually, Ethiopia). Besides using images, the app is front-loaded with drop-down questions which aid in diagnosis and treatment decisions. This information triggers an inbuilt management protocol consisting of general care advice, and a link to an expert to provide case-specific advice.

South Africa, in particular, suffers from a quadruple burden of disease with injuries, interpersonal violence and traffic-related deaths ranking alongside HIV/AIDS and tuberculosis, infectious diseases and a rising epidemic of

non-communicable disease. The problem of burns injuries in South Africa is big and rising. Burns are associated with shack fires as well as scalding during household chores, with the winter months regarded as 'burn season' by emergency services.

The project had to overcome some initial challenges related to comparing images from different phones and also ensuring that the quality of images from darker skins are as good as those from lighter skins. Nonetheless, current results show that the app is easy to use, does not require extensive training, and that the resulting diagnoses are as good as those based on bedside diagnosis.

Studies on the acceptability of the app as well as comparing treatment outcomes with and without the app are being undertaken. The possibility of machine-learning burn diagnostics and the creation of algorithms to offer an automated diagnosis and treatment response are also currently being investigated although this implementation remains a long way off.

### Users involvement in development

A recurring theme was the need to ensure early involvement of both health-care personnel and, where possible, patients in app development with the aim of overcoming practical, on-the-ground challenges and ensuring that technology is guided by needs. Presentations by nurses Halima Adam and John Bosco Kamugisha from Uganda highlighted some of these challenges – including cost, Internet accessibility and airtime; power shortages; lack of training; use of personal phones and safety issues around phones; data accuracy and security.

### mHealth as the new normal

The need for mHealth to become the new normal was emphasised by various presenters. Speaking of the future possibilities, Jan Gulliksen of KTH Royal Institute of Technology in Sweden emphasised the need for societal digitisation – not just in developing technologies for context but rather for changing the context, and increasing skills for a digital society.

Johan Lundin of the University of Helsinki added to this theme by pointing out that up to 80% of communication in future will be image based and that adding in artificial intelligence will change the face of mobile diagnostics.

The need to focus on apps that can go viral was emphasised by Stefan Fölster, Head: Reform Institute, Stockholm. He outlined four main criteria that make this possible: there should be no extra cost for the end user (so not all apps should rely on smartphones); the adopting agency should be able to recoup the costs; mHealth should not raise costs by raising demand more than the cost savings allow; and, there should not be duplication of other mHealth investments. He also pointed out the need to look for technology leaps, for example, artificial intelligence and systems that learn along the way.

Isaac Bogosh of the University of Toronto cautioned, however, about the need for quality. He pointed out that the goal of mobile microscopy must be to deliver equitable health care by bringing quality laboratory diagnosis to low-resource settings. He encouraged more validation research in real-world settings but also emphasised the need to resist the urge to build the cheapest microscopes that sacrifice image quality. He called for robust devices with sufficient optics designed for efficient throughput.

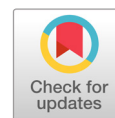
### Generating the roadmap

The Roundtable group work and plenary discussions focused on five key questions:

1. How should the most important barriers to the implementation of image-based mHealth in the clinical setting be overcome?
2. How can frontline health-care workers be enabled to adopt image-based mHealth in their practice?
3. Which are the key strategies to overcome organisational challenges to the implementation of image-based mHealth within the health sector?
4. Which are the key strategies to overcome technical challenges in implementing image-based mHealth within the health sector?
5. For each category of stakeholders represented, what are the most important priorities to build and sustain leadership in mHealth?

These questions generated statements which were prioritised by voting in the final session. The results will form the basis of the Roadmap which will be published and disseminated in the coming months.





## The drive behind the legends of South African science

### BOOK TITLE:

Legends of South African science

### BOOK COVER:



### EDITOR:

Academy of Science of South Africa (ASSAf)

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### REVIEWER:

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There is a long tradition of books which – through a compilation of biographies – seek to achieve a particular goal of the author that is distinct from the purely narrative-historical. Thus Plutarch's *Lives of the Noble Greeks and Romans* is a second-century series of biographies of famous men (and they were regrettably all men) designed to illustrate the moral virtues or failings which they had in common and to explore the influence of that elusive trait – character – on the lives of his subjects. In the 16th century, Vasari wrote his *Lives of the Artists*, intending thereby to map the course of the 'rebirth' of European civilisation that we call the Renaissance.

The Academy of Science of South Africa (ASSAf) has now published a book comprising a set of biographical pieces on 53 eminent South African scholars and scientists who are all elected Academy Members but who in addition have been admitted to national orders by the Presidency, and/or have been awarded the country's largest and most prestigious individual research grant, the Harry Oppenheimer Award, and/or have been awarded the Science-for-Society Gold Medal of the Academy itself. The text is the work of a team of experienced writers who have mostly used an interview-style format to enliven their stories. A few of the subjects are deceased, and in these instances close colleagues have provided the necessary material. As might be expected, the tone of all the pieces is sympathetic rather than critical, with the special features of 'defining moments' and 'little-known information' often providing engaging revelations in each narrative.

Coming back to the issue of a possible underlying purpose or goal of this compilation, one is struck by the high level of energy and industry displayed by virtually all of these individuals. In the extreme case, we have the late Friedel Sellschop alternately using a standing and a sitting desk to keep awake during long nocturnal work sessions, with a swim in reserve in case these measures failed. The old adage of 'allocating a difficult task to the busiest person' is borne out by the incredible combination of intellectual and organisational work that most of these scholars have managed to stuff into their lives. One feels compelled to ask whether success breeds a confident appetite for work of all kinds, or whether it is the other way round – I suspect it is both of these mechanisms working in tandem.

South Africa has a small scholarly community relative to comparator countries in Europe and North America. It is likely that the small size of this community is another reason for the almost superhuman efforts that need to be made by local scholars to compete internationally in their science. And yet they also have made massive individual contributions to higher education and to science and innovation organisation and policy, especially so if one bears in mind that local teaching loads are also much heavier than those in more advanced countries (this aspect is regrettably underplayed in most of the narratives in this book).

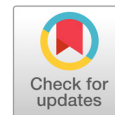
Interestingly, most of the careers show a general unwillingness (or inability) of the people concerned to concentrate different activities into discrete phases – research activity is almost never 'let go' even if it is purely supervisory (there are of course a few notable exceptions). Some of the younger scholars have already been raised to senior administrative positions and are 'holding on for dear life' to the 'in-their-prime' phase of their research careers.

Because the writers of these narratives have used the journalistic art of the written-up interview rather than historiography or the information-crowded 'condensed CV', the stories are highly readable in the main, with some stand-outs and few if any failures. There is not an ivory tower in sight – the research fields are highly relevant to South Africa's economy in particular and its society in general. Even a highly distinguished cosmologist like George Ellis has extensively busied himself with the social and developmental problems here on earth. Whether it be the pressing issues of urban water supply and sanitation (Eugene Cloete and George Ekama), food security (Jill Farrant, Patricia Berjak and Walter Marasas), the forest-based economy (Michael and Brenda Wingfield) and school mathematics education (Jill Adler and Mamokgethi Phakeng), or the immense challenges of tuberculosis (Valerie Mizrahi and Paul van Helden) and HIV infection (Hoosen Coovadia, Quarraisha and Salim Abdool Karim, Helen Rees, Olive Shisana, Anna Coutoudis and Glenda Gray), these scholars have achieved world-class status by expertly exploiting local niches doubling as serious national problems.

Some of the stories contain surprising or very amusing information. Who would have imagined that the immediate ex-president of the CSIR (Sibusiso Sibisi) has completed the Two Oceans, Comrades and Boston Marathons, *and* is a swimmer, cyclist and rower as well? That Bongani Mayosi and his now-professorial wife have competed in ballroom dancing in Oxford? That a botanist working on drought-resistant plants (Jill Farrant) is known as Mapula ('mother of rain') in her home province of Limpopo, and that every member of Phuti Ngoepe's immediate family has a PhD? Occasionally, the writers also provide a memorable turn of phrase. For example, Daya Reddy is described as a man 'who doesn't buckle under pressure but his knowledge of things that do buckle under pressure is second to none'.

I began this review by looking at the underlying goal of making a particular compilation of biographies. I concluded that the goal of this set of well-written (multi-author) interview-based accounts of selected ASSAf Members was to bring out the enormous energy and scholarly vitality displayed by every member of the entire group – something which seems to have its origin partly in the confidence borne of personal success, and partly in the local situation of a country forced to punch above its weight, so to speak.

I come now to the likely impact of this book. It is only by reading it through that the above-mentioned underlying message will be brought home – but how many in this busy day and age will actually do that? Individual stories are likely to be highly inspirational to young minds, suggesting that their serial re-publication in popular media may be a useful option. Coffee-table or journal-display usage in government, business and educational establishments may be helpful in spreading the message. The biggest and most direct impact will be on university students at both undergraduate and postgraduate levels, if only copies of the book can be made available to them in some way that is not extravagantly expensive yet efficient and effective.

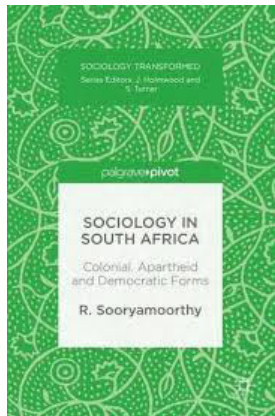


## The unique yet universal voice of South African sociology

### BOOK TITLE:

Sociology in South Africa:  
Colonial, apartheid and  
democratic forms

### BOOK COVER:



### AUTHOR:

Radhamany Sooryamoorthy

### ISBN:

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### PUBLISHER:

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org/10.17159/sajs.2017/a0219](http://dx.doi.org/10.17159/sajs.2017/a0219)

Globalisation has opened opportunities for cross-national links between sociological communities with nodes of scholars linked to each other in cyberspace. But there is a grave danger in the global age of a kind of pseudo-universalism. It is only through an understanding of our different histories that we can arrive at an understanding of the many voices in our discipline. We need to remind ourselves that path-breaking cultural creativity in world history has often come, not from the centre, but from the periphery of cultural worlds. This is the challenge facing South African social scientists: to find a critical space and a voice that is at once both particular, unique, and at the same time universal.

Sooryamoorthy has made a valuable contribution to global sociology by producing the first full book-length study of the development and nature of South African sociology. He draws extensively on the already published literature as well as interesting and original scientometric data. He has given South African sociology a voice within the global system of social knowledge production.

Sooryamoorthy identifies three phases in the development of sociology in South Africa. The first phase, from 1900 to 1947, is described as 'sociology in colonial times'. Sociologists during this period were primarily concerned with social problems such as poverty amongst white people. The trigger for the study of poverty was the Carnegie Commission on the Poor White Problem in South Africa. The Carnegie Commission (1932) into the so-called 'poor white problem' came to serve as a blueprint for the apartheid policies that were to follow in the next phase.

It is during the second phase, the apartheid phase from 1948 to 1993, that sociology emerges as an independent discipline, separate from departments of social work. Only five doctoral theses were written during the first phase and there was no South African journal of sociology. Initially divided into two competitive strands of sociology along language lines, with separate professional associations and journals, these divisions came sharply to the fore in the 1980s when the multiracial Association of Southern African Sociologists (ASSA), the alternative to the conservative Suid Afrikaanse Sociologie Vereniging (SASOV), became an exciting forum for a group of engaged social scientists concerned with the transformation of South Africa. Although these divisions mirrored the language cleavage, they came to reflect a much deeper division between the more established positivist and functionalist tradition held in the Afrikaans-speaking universities, and the critical and neo-Marxist sociology associated with the emerging democratic movement inside South Africa in the 1980s. While Sooryamoorthy's useful analysis of journal publications captures this development, particularly the growth of labour studies, his analysis of the data set of the Web of Science reveals very little about this innovative moment (from which Burawoy<sup>1</sup> derived his notion of public sociology) in the history of South African sociology.

The third phase, sociology in a democratic South Africa, from 1994 to 2015, opened with much promise. In 1993, the two rival associations had merged to create the South African Sociological Association (SASA) and the advent of democracy after years of struggle had created a deep interest in South African society. But with only 178 members by 2015, South African sociology remained a small community. The advent of democracy had shifted the centre of stage away from the social movements that led the democratisation process, towards the state whose demands were for more technically policy-oriented research. Government was committed to repositioning South African higher education institutions to global technological and economic competitiveness. To achieve this goal it was necessary to restructure universities as sites of new knowledge production and technological innovation. In the face of these pressures some universities totally abandoned their departments of sociology and redeployed academics to fit into 'programmes'. As Sooryamoorthy politely observes, 'sociology had to adjust and adapt to this environment when it entered its third phase in the democratic era'.

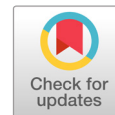
What is the state of sociology today? South African sociology has internationalised: indeed it successfully hosted in 2006 the World Congress of Sociology. The output in international publications has dramatically increased. But some of the features of the past continue; the indifference to quantitative methodology goes back, Sooryamoorthy suggests, to historic antipathies between Afrikaans- and English-language universities. The fragmentation and lack of specialisation, Sooryamoorthy suggests, is an 'outcome of reactions to the changing social realities – labour studies, health studies or studies on crime'. In spite of growing international contact, Sooryamoorthy found international collaboration in only 3% of the publications of the *South African Review of Sociology* journal between 1995 and 2012 (p. 125). Furthermore, Sooryamoorthy observes that 'an acceptable composition and proportion of black staff has not been realized to represent the population'. He estimates that only 35% of sociology staff in the universities are black. Above all, the articulation of an African-centred sociology has not engaged sociologists, either as a sub-discipline of African studies or as a sub-discipline of traditional sociology.

What of the future? Sooryamoorthy cites favourably the case of labour studies in South Africa 'that developed a body of knowledge based in the local patterns of social relations and the local struggles from these patterns'. He argues that offering specialist programmes and engaging in relevant sociological research will 'encourage the government and policymakers to make use of the findings for policy-based programmes'. It is an interesting observation but to sustain a special area of sociology that is both unique and universal will require greater resources, both in terms of people and finance, than is currently available in South African universities.

*Sociology in South Africa: Colonial, Apartheid and Democratic Forms* is a balanced and informative account of South African sociology. Hopefully it will inspire a new generation of sociologists to develop the African-centred sociology that is so desperately needed in this southern tip of Africa.

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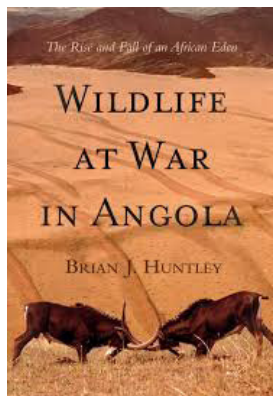


## An environmental history of Angola

### BOOK TITLE:

Wildlife at war in Angola: The rise and fall of an African Eden

### BOOK COVER:



### AUTHOR:

Brian J. Huntley

### ISBN:

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In stark contrast to other countries in the southern third of Africa, very little is known about the ecosystems, vegetation and wildlife of Angola. In almost 500 years of colonial rule, the nation of Portugal profited from the extraction from Angola of resources in the form of slaves, ivory, timber, diamonds and oil, but re-invested very little into development, or into the conservation of the country's considerable wealth and diversity of landscapes and wildlife. The remarkably small settler community was dominated by poor and relatively uneducated Portuguese citizens, including a large proportion of exiled criminals. However, in the early 1970s, moves were afoot to strengthen the Angolan national park system, and to place the management of parks on a sound scientific footing. It was a brief but promising period in Angola's conservation history – one in which this book's author, Brian Huntley, played an important role.

Huntley was appointed in 1971 as a scientific advisor to the colonial government, and was broadly tasked with documenting the status of the existing protected area network, and making proposals for their management and, where necessary, expansion. Unfortunately, the events that followed Angola's independence in 1975 (including open warfare between rival liberation movements, and invasion of Angola by the South African Defence Force) forced Huntley to leave. However, he never lost interest in Angola, and the collapse of South Africa's apartheid policies in 1990 made it possible for him to re-establish contact with Angolan colleagues and to regularly follow up on initiatives related to conservation and ecosystem management in Angola over the next 25 years. This book provides a very personal, first-hand account of the history and challenges facing wildlife and environmental conservation in Angola – a topic that has not been addressed adequately before, and one which Huntley is eminently qualified to write.

Angola has a rather depressing history, with its 500-year colonial past being marked by four phases: commencing with a slave state, followed by a penal colony, an era of forced labour, and a failed programme of agricultural settlement. In all of this, there was one brief window of relative peace in the early 1970s, which was characterised by some optimism regarding the development, conservation and management of a protected area network in Angola. This network included a wide range of spectacularly beautiful landscapes that abounded with wild animals, including eland, oryx, springbuck, zebra, buffalo, lechwe, roan, bushbuck, reedbuck, elephant and rhino. Pride of place went to the giant sable antelope, which remains the country's national symbol; this sub-species inhabited the miombo woodlands of central Angola, and was a much sought-after prize by trophy hunters over many decades. Readers are provided with a background to the national parks, the ecology of different vegetation types and their importance as habitats for the large fauna. A chapter is devoted to the discovery and ecology of the desert plant *Welwitschia mirabilis*, a 'living fossil' gymnosperm that symbolises the Namib Desert. However, the brief period of environmental progress was halted by the escalation in 1975 of what turned out to be a 41-year-long war, which brought terrible misery to most Angolans, and saw the almost total destruction of the nation's forests and wildlife.

The book takes the reader through the effects of war, with a special focus on the environmental consequences. A recurrent theme in the book is that to understand what has happened in Angola, one has to understand its history. Although Angola was home to a few dedicated conservationists, the country as a whole has always lacked the critical mass of environmentally aware people that would have led to the development of a national conservation ethic. This lack is attributed to several factors, including that 99% of the Angolan population was excluded from participating in political processes, the absence of genuine multi-generational Portuguese settlers, and low levels of educational and professional training among the colonists. There was thus no civic voice for conservation that could pressure the government to take action, and exploitation of the environment was the order of the pre-independence period.

Independence from Portugal in 1975 did not see an end to the war. The MPLA was in government in Luanda, but Jonas Savimbi's UNITA movement (with support from South Africa), remained in control of vast tracts of rural Angola, where it survived by continued exploitation of the country's resources (mainly in the form of 'blood diamonds'). This finally ended in 2002 when Savimbi was killed in a skirmish with MPLA forces. However, the intervening period between independence and the end of the war had seen the rise of an urban, kleptocratic government in which a very small number of people in power amassed enormous wealth through resource exploitation, leaving the vast majority of Angolans in abject poverty. Any connection that there was to the natural environment was lost in a rapidly urbanising population. The collapse of agriculture left rural populations with no choice but to make a living through continued unsustainable utilisation of whatever natural resources they could access. In reality, this was the bushmeat trade, mopping up whatever was left of the wildlife; and the charcoal trade, based on unsustainable exploitation of woodland and forest trees.

Management of Angola's protected areas in the post-independence era has been limited, and characterised by political and official indifference or corruption. The few management interventions that have taken place have gone against almost every established principle of sustainable and effective conservation management (usually with the goal of enriching politicians or officials). Some examples that are provided in the book include the erection of highly expensive entrance gates to non-functional and degraded parks (in a country where it is close to impossible to obtain a tourist visa); ploughing up large tracts of natural vegetation to plant maize and citrus to attract elephants; the creation of fenced 'zoos' stocked with mammal species that have never occurred in the area; granting of mining leases over much of the protected area; erecting hundreds of kilometres of fences that start nowhere and end nowhere; and establishing a network of water points in arid zones, allowing permanent occupation by previously nomadic pastoralists and leading to environmental destruction. The situation seems almost hopeless, but, surprisingly, there are still a few people working for conservation in Angola. The final

chapter dwells on this hope, pointing to possible solutions that could be implemented following the perhaps inevitable collapse of the current crony-capitalist kleptocracy.

It is almost impossible to do justice to a book like this in such a short review. The depth and breadth of coverage is remarkable, spanning history and politics over a vast area, based largely on the personal and first-hand experience of a dedicated career ecologist. The important thing


is that all of the information is placed into the context of environmental management and conservation – something that no other book on Angola has done. It is a very well-written and absorbing book, and one that deserves to be read by serious conservationists globally, be they practitioners, policymakers or funders. It is also a serious warning to South Africans about what could become of their environment if the current trends of self-enrichment among the political elite are allowed to continue.





# The age of fossil StW573 ('Little Foot'): Reply to comments by Stratford et al. (2017)

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We reply to comments by Stratford et al.<sup>1</sup> on our article<sup>2</sup> ‘The age of fossil StW573 (‘Little Foot’): An alternative interpretation of <sup>26</sup>Al/<sup>10</sup>Be burial data’, in which we revisit the burial age reported by Granger et al.<sup>3</sup> for the sediments encasing the fossil and the data on which this was based.

The history of the discovery of fossil StW573 and the subsequent controversy concerning its age is well documented.<sup>3-10</sup> The burial isochron age of  $3.67 \pm 0.16$  Ma, obtained by Granger et al.<sup>3</sup> via regression of <sup>26</sup>Al and <sup>10</sup>Be concentrations in quartz samples taken from the deposit encasing the fossil, has been broadly accepted as the final settlement of the debate.

As Stratford et al.<sup>1</sup> emphasise, the potential importance of the fossil in the timeline of hominin evolution is huge. It is for that reason that we re-examined the data in order to find if this reported burial age truly represents the only possible interpretation of these data for yielding the age of the fossil. We found that one aspect of the data, not considered by Granger et al.<sup>3</sup>, prohibited an age older than 2.8 Ma for the fossil, and in order to resolve the paradox we proposed a two-stage burial scenario, with the sediment material encasing StW573 having been derived from a higher level cave chamber, rather than directly from the surface. Concluding, we state that, as this scenario ‘can reconcile the indicated 2.8 Ma maximum age for the fossil with the much older isochron date, it deserves serious consideration’<sup>2</sup>.

The discussion has now been re-opened. In their comment, Stratford et al.<sup>1</sup> conclude that our analysis is ‘purely hypothetical and based on unjustifiable assumptions rather than observations and measurements’, and state further that ‘all data and observations are consistent with a single episode of deposition contemporaneous with StW573 at  $3.67 \pm 0.17$  (sic) Ma’.

They reach this conclusion based on 11 points characterised as ‘a series of assumptions that are unjustified and based on demonstrably incorrect interpretations of the cave structure and stratigraphy’<sup>1</sup>. Here we address these points, which were fortunately numbered so that the reader is spared any repetition.

Point 1: This issue is semantic. In geochronology, a ‘lower’ and ‘upper’ age limit is commonly understood to mean the minimum and maximum age for a possible age range. There is thus no contradiction with Clarke<sup>7</sup> as the authors claim.

Point 2: This is a substantive argument which will be considered in the discussion below.

Point 3: The detailed microstratigraphic work referred to by the authors is limited to a small portion of Member 2 in the Silberberg Grotto and restricted to a distal part of the debris cone, removed from the point where sediment entered the Grotto. If this sediment entry point had opened up, or been modified as a result of a collapse or a shift in the sediment passageways higher in the chamber, proximal effects like collapse blocks, may only be seen in the immediate vicinity of a modified entry point. No detailed stratigraphic work exists for most of the Silberberg Grotto that contradicts such a scenario. The authors also state here that ‘the whole depth of Member 2...is stratified consistently and conformably – indicative of a long and progressive accumulation’. Note that Granger et al.’s<sup>3</sup> samples 3 and 9, taken at a vertical distance of between 2.8 m and 3.3 m in the deposit, have the same burial age well within their uncertainty limits of ca 0.8 Ma and 0.2 Ma, respectively. For a theoretical isochron to be valid, the samples included in the regression must have been deposited over a (geologically speaking) short period of time, consistent with rapid changes in the sedimentary regime. The statement is further in direct contradiction to their statement on ‘a single episode of deposition’ quoted above.

Point 4: It appears to be assumed here that all secondary deposits would have to be similar to each other. However, secondary deposits will vary as a function of many parameters including cave geometry, sedimentation rates, proximity to sediment entry points and provenance. In addition we want to restate that we do not envisage that the StW573 skeleton was redeposited over a great distance, but that instead the animal fell into the Silberberg Grotto at the time the sediments in the Grotto accumulated; in our view the sediments surrounding the fossil were redeposited, not the fossil itself.

Point 5: In Figure 1 of Stratford et al.<sup>1</sup>, the corrected position of the collapsed block shows the walkway ending in the middle of it. As can be seen in our Figure 2b, the walkway abuts on the south side of it. However, the precise position of the collapsed block is less important than the fact that it unequivocally documents the previous existence of a cave chamber above the eastern end of the present Silberberg Grotto (shown in yellow in our Figure 2a). This suggests any opening in the roof of the Silberberg Grotto was connected to a higher level chamber in the cave, and at the time of deposition of Member 2 was unlikely to connect directly to the surface. We further emphasise again that, following the erosion rate of about 5 m/Ma reported by Granger et al.<sup>3</sup>, the land surface at Sterkfontein should have been about 14 m higher at 2.8 Ma than it is today, and thus there was room for a cave chamber above the Silberberg Grotto at that time. The suggestion of a previous upper cave above Silberberg Grotto is thus not entirely speculative, as Stratford et al.<sup>1</sup> claim. The fact that the collapse blocks occur in Member 4 to reflect roof collapse of an upper chamber, has no bearing on how such collapse would have affected sedimentation processes in the deeper Silberberg Grotto, other than the fact that sudden changes in the sedimentary regime in the cave did occur. The point we are making is twofold: an upper chamber probably existed above the Silberberg Grotto, and the sediment passageway connecting the Silberberg Grotto with an upper chamber could have changed its geometry over time. We did not, and do not, explicitly posit that this upper cave was separate from the one that contained Member 4 (now in the open excavation), but from outcrop observations this cannot be excluded either.

Point 6: Whilst Bruxelles et al.<sup>11</sup> do not interpret the sediments surrounding StW573 as being debris flows, we point out that their descriptions of the sediments are entirely consistent with debris flows. The fact that the body was mummified does not exclude this interpretation. The dried out body may have been enveloped by the debris flow, in a manner similar to that described for *A. sediba* at the Malapa site (Dirks et al.<sup>12</sup>).

Point 7: This comment is puzzling. The chert fragments must indeed have been derived from a few metres below surface, as indicated by their aggregate <sup>10</sup>Be and <sup>26</sup>Al concentrations. That is all we know for certain. We do not see an essential difference between our wording and that of Granger et al.<sup>3</sup> Stratford et al.'s<sup>1</sup> assertion here that they have to come from the same chamber is unfounded.

Point 8: Here the authors criticise our reference to the shelf stones as evidence that the Silberberg Grotto was once flooded. The work cited in this instance (and with this interpretation) was Clarke<sup>13</sup> who reported shelf stones attached to stubby stalactites. Thus the authors indirectly criticise the work of one of their number.

Point 9: Of the boreholes drilled around the Sterkfontein open excavation,<sup>14</sup> BH1 is immediately south of the east end of the Silberberg Grotto, and shows calcified clastic cave sediments and calcite speleothems from the surface down to a depth of 16 m. BH5, drilled immediately north of the west end of the Grotto, shows dolomite down to 7.5 m and then cave sediments down to 21.5 m. The flowstone at the base of the cave sediments in BH1 was dated at  $2.80 \pm 0.28$  Ma by U-Pb (logging and age from Pickering and Kramers<sup>9</sup>). Thus it is not true that M4 and M5 in the open excavation represent the only higher level cave fills in the vicinity of Silberberg Grotto. The argument that the lack of *Australopithecus africanus* fossils in Member 2 indicates that therefore it cannot be derived from more hominin-rich reworked sediments, now potentially included in Member 4, would assume detailed knowledge of the timing and provenance of the Member 2 sediment. This type of information is not available.

Point 10: On 26 February 2009, one of us (J.K.) visited StW573 in the company of Ron Clarke and the late Tim Partridge. On that occasion the flowstones around the fossil (F2, F3 and F4) were examined and J.K. pointed out that these flowstones would most likely turn out to be fracture fillings once the fossil was excavated and the outcrop clear. This was subsequently confirmed by Bruxelles et al.<sup>11</sup> (therefore the statement that we 'admit' the intrusive character of these flowstones is strange and inconsistent with the actual facts). However, despite having both visited the locality several times, we have seen no evidence to convince us that the lowest flowstone, F1, is not a stratigraphic one. Also, Bruxelles et al.<sup>11</sup> hardly describe this flowstone and present no such evidence. In our discussion of the palaeomagnetic results of Herries and Shaw<sup>10</sup> we clearly mention both possibilities for F1 and discuss the consequences.

Point 11: The most reliable currently available age range for Member 3 of Makapansgat is 2.58–2.85 Ma (Herries et al.<sup>15</sup>), not 3 Ma as quoted<sup>1</sup>. We admit that this age is older than 2.5 Ma and apologise for the error. This range is nevertheless much younger than 3.67 Ma.

Thus of the 'assumptions that are unjustified and based on demonstrably incorrect interpretations of the cave structure and stratigraphy'<sup>1</sup>, Points 1 and 3–11, most of which are marginal to our arguments, have been answered and can be put aside. We now turn to the core issues, which are our analysis of data on two chert fragments and questions around the isochron itself, referring to Point 2 as well as Stratford et al.'s<sup>1</sup> conclusion.

In Point 2, Stratford et al.<sup>1</sup> find no fundamental fault in our direct calculation of the underground production rate of <sup>10</sup>Be and <sup>26</sup>Al, but criticise the fact that no uncertainty limits were given, and state (1) that we used a constant erosion rate, (2) that we fixed the <sup>26</sup>Al/<sup>10</sup>Be production rate at 8.1, (3) that depth, density and erosion rates in the past are not known with sufficient confidence and (4) that production rates at depth cannot be calculated exactly, citing Balco<sup>16</sup>, an excellent review that became available online in February 2017, when our paper was in press. They further state that their isochron regression solves directly for underground production rates, implying that our estimates were unnecessary.

The methods and parameters we used are documented in our paper. The key parameters for the production rates, i.e. probability factors and effective cross sections, were taken from Balco et al.<sup>17</sup>, where they are given without error limits, making error propagation difficult. We did not fix the <sup>26</sup>Al/<sup>10</sup>Be production rate, but calculated <sup>26</sup>Al and <sup>10</sup>Be separately. We used both a zero erosion model and one with an erosion rate of 5 m/Ma (as found by Granger et al.<sup>3</sup>). The depth of StW573 below the present day surface (23 m) was taken from Clarke<sup>13</sup> although Partridge et al.<sup>6</sup> give 25 m, which would yield lower production rates. The density is discussed in terms of likely porosity. Obviously there are uncertainties, but we have chosen to err on the conservative side.

Our finding of lower in-situ production rates than those derived from Granger et al.'s<sup>3</sup> isochron regression is not based on the direct calculation alone. A second approach is based on one of the samples analysed by Granger et al.<sup>3</sup> – MC2A – which was considered 'reworked' and not included in the isochron regression. We found that the combination of <sup>26</sup>Al and <sup>10</sup>Be concentrations in this sample are impossible if the in-situ production rates yielded by the isochron regression are assumed.<sup>2</sup> As we describe<sup>2</sup>, the upper limits of production rates for which the <sup>26</sup>Al and <sup>10</sup>Be concentrations in MC2A are realistic coincide with the range of directly calculated values. The fact that Stratford et al.<sup>1</sup> do not comment on this indicates that they accept it.

We also point out that two of the samples included in the isochron regression of Granger et al.<sup>3</sup> are composites: 'STM2 dark', consisting of material from ST1, 2, 8 and 9, and 'STM2 light', consisting of material from ST1 and 2, selected according to the presence or absence of Fe-Mn oxide staining. Using data from composite samples in a regression can be compared to homogenising a sample to show it is homogeneous. As a result of this practice, the uncertainty limits given for the isochron regression of Granger et al.<sup>3</sup> as well as the underground production rates derived from it are underestimated by an unknown amount. Our lower values for the in-situ produced <sup>26</sup>Al and <sup>10</sup>Be are likely to fit comfortably within the real uncertainty limits from the isochron regression and are thus not in conflict with these.

Notwithstanding the above caveat, we did not deconstruct the isochron as Stratford et al.<sup>1</sup> claim. We merely queried the interpretation of it by Granger et al.<sup>3</sup> There are two questions here: (1) how long has the sediment material (on average) been underground and (2) how old is the sedimentary deposit containing StW573? The isochron addresses the first question, and our approach the second one. This approach is quite robust as long as the analytical results and their given precision are accurate, which we have no reason to doubt. The fact that the apparent maximum age for the deposit is derived from one sample only can be compared to a situation in which the maximum age for a sedimentary unit is given by the youngest detrital zircon found in it, which is nothing new.

Our proposal of previous burial of the sediment material in an upper cave chamber was made to reconcile the apparent contradiction between the  $3.67 \pm 0.16$  Ma isochron date and our 2.8 Ma maximum age for the deposit. We explored whether such previous burial (over a long and variable period of time) could still produce the observed isochron, and concluded that this was possible. This exploration elicited no criticism from Stratford et al.<sup>1</sup> The inverse order of the three burial ages of Partridge et al.<sup>6</sup> with stratigraphy (although within error), noted also by Herries and Shaw<sup>10</sup>, can also be understood as a result of previous burial.

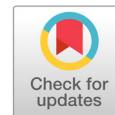
We conclude that none of the points raised by Stratford et al.<sup>1</sup> invalidates our data analysis and the two-staged burial hypothesis. We have proposed a way in which this two-staged scenario can be tested, namely by doing more analyses on originally surface-derived samples to test for burial age heterogeneity outside the now available better uncertainty limits. Although this has not been responded to by Stratford et al.<sup>1</sup>, it is a viable way forward. The discussion on the age of StW573, 'Little Foot', should not be dismissed. While this discussion may appear somewhat arcane at the moment, the age of this remarkable and complete *Australopithecus* fossil will become extremely important in the timeline of hominin evolution once its complete description has been published.



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# Banking regulations: An examination of the failure of African Bank using Merton's structural model

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The business of banking involves the taking of deposits and the making of loans. Banking balance sheets are typically highly leveraged, with equity capital generally dwarfed by debt capital. Banks are regulated entities; the nature of regulation does not, generally, consider the market prices of the securities issued by a particular bank. In this contribution, we evaluate the capacity of the Merton structural model to provide insight into a bank's financial health in the context of the failure of African Bank in 2014.

## African Bank Ltd.

African Bank Ltd. was placed in curatorship on 10 August 2014.<sup>1</sup> This occurrence took place against a backdrop of a significant capital raise in 2013 with detailed remedial action undertaken by management.<sup>2,3</sup> In March<sup>4</sup> and April<sup>5</sup> of 2016, a restructured African Bank emerged from curatorship, with significant losses imposed on creditors and shareholders.

The failure of African Bank was a shock to the South African markets and introduced significant systemic risk in the South African financial system. Could this risk have been highlighted at an earlier stage? Was there a way to avoid this outcome?

## Banking regulation

Banking is a highly regulated industry globally. This level of oversight is justified as banks are institutions that take deposits from the public and generally have highly leveraged balance sheets given their capacity to create money via the fractional reserving requirement. Regulation encompasses both supervision of the activities undertaken and monitoring of exposures against prudential guidelines and limits.

Global best practice for supervision, with the US banking industry as a specific example<sup>6,7</sup>, encompasses both on-site examinations and off-site surveillance. Off-site surveillance provides an ongoing impression of bank performance. On-site examinations are the primary supervisory tool during which banks are assessed across various risk and operational factors. These factors are captured in a so-called CAMELS assessment, that is, capital protection (C), asset quality (A), management competence (M), earnings strength (E), liquidity (L) and, more recently, aspects pertaining to the overall financial system (S). The combination of a given bank's performance across these factors results in a single score or rating being generated for the given bank.<sup>7</sup> Remedial action, where necessary, across the factors will be communicated to the bank concerned and progress on improvements monitored thereafter. CAMELS type assessments are generally infrequent (certainly no more than once per year), with ongoing off-site surveillance incorporating the modelling of likely changes to these ratings.

The Basel Committee on Banking Supervision provides the global regulatory capital framework for the banking industry. This Committee sets the standards for prudential regulation of banks via risk-based capital measures.<sup>8</sup> The application of these standards is dependent on information provided by the banks, including the application of the bank's internal models and evaluation of risk. These standards are the primary tool for off-site surveillance.

In practice neither the supervision nor the exposure monitoring undertaken was sufficient to prevent African Bank's woes.

## Market prices and bank financial health

An alternative approach to the evaluation of a bank's financial health is to consider information embedded in the market prices of a company's securities, including both debt and equity instruments. This approach draws heavily on the structural model of Merton<sup>9</sup>. We consider the credit risk (i.e. the likelihood of default) of the bank concerned as a financial put option (i.e. the right, but not the obligation to sell an asset at a fixed price within a predetermined period) on the underlying assets of the firm – the put is struck at the face value of the obligations of the firm. The equity of the bank is a financial call option (the right, but not the obligation to buy an asset at a fixed price within a predetermined period) on the underlying assets of the firm, struck at the face value of the obligations of the firm.

The measure commonly used is the so-called distance-to-default<sup>10</sup> (DTD), which incorporates the relative leverage of the firm as well as the volatility of its underlying assets. We define default with reference to a fixed time horizon (1 year, here and generally) as taking place when the assets of the firm are insufficient to meet the liabilities of the firm. We follow the approach described in Allen and Powell<sup>11</sup> and model the underlying assets as a stochastic variable and set DTD equal to the difference between the value of a firm's assets and the value of a firm's liabilities, divided by the standard deviation of the firm's assets (over our given time horizon).

Merton<sup>12</sup> relates equity value and firm asset value as follows:

$$E = VN(d_1) - e^{-rT}FN(d_2), \quad \text{Equation 1}$$

where  $E$  is the market value of firm equity,  $V$  is the value of the firm's assets,  $F$  is the face value of the firm's debt (zero coupon),  $r$  is the risk free rate,  $N$  is the cumulative standard normal distribution function and  $T$  is the time horizon.

Furthermore,

$$d_1 = \frac{1n\left(\frac{V}{F}\right) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad \text{Equation 2}$$

and

$$d_2 = d_1 - \sigma\sqrt{T}, \quad \text{Equation 3}$$

where  $\sigma$  is the annualised standard deviation of asset returns (referred to as volatility).

Market prices are observable for the securities issued by the firm. The asset value and asset volatility of the firm are not directly observable; however, they can be estimated (as discussed in Milne<sup>10</sup>, for example).

Asset value is generally modelled as the sum of debt and equity, and asset volatility can be derived when given a value for underlying equity volatility, i.e.

$$\sigma = \left(\frac{V}{E}\right) N(d_1) \sigma_E, \quad \text{Equation 4}$$

where  $\sigma_E$  is the standard deviation of equity returns.

A more complex estimate of asset value and asset volatility can be derived given prices for two securities issued by the underlying firm that can be valued as options on the underlying assets of the firm (e.g. equity as a call option and debt as a combination of a put option and a risk-free asset).

Distance-to-default (DTD) is usually defined as:

$$DTD = \frac{1n\left(\frac{V}{F}\right) + (r - \sigma^2/2)T}{\sigma\sqrt{T}} \quad \text{Equation 5}$$

## Data

African Bank's activities were funded by a combination of debt instruments (both domestic and foreign), preference shares and ordinary shares. All the data we use in this analysis are sourced from Bloomberg, and the raw, unadjusted prices are used for equity.

We consider African Bank Ltd. equity and debt trading data from March 2005 up to August 2014, when the bank was placed into curatorship. We consider so-called price return data only. We consider the curatorship to be a default event.

Our analysis includes the ordinary shares and preference shares listed on the Johannesburg Stock Exchange (JSE) Securities Exchange and the debt instruments issued by African Bank denominated in South African rand and other currencies. We incorporate published balance sheet information in the form of total liabilities in our estimate of total debt. We make use of closing levels for the 1-year swap rate; this term is consistent with the 1-year time horizon applied in the calculation of DTD.

It is important at this stage to highlight significant weaknesses in the underlying data. Whilst the historical data for equity trading activity and preference share trading activity are representative of market activity daily, with two-way pricing and significant volumes executed, the data available on listed debt instruments, both domestic and foreign, are deeply suspect. No measure of actual trading activity is recorded and any price movements observed appear to be with reference to a change in an underlying benchmark only. In effect, the credit spread reflected in the historical prices is more akin to that at the time of issue rather than the prevailing level. We include these data in parts of our analysis below; however, the results are not satisfactory, in that they suggest either that the debt market was oblivious to the events unfolding at African Bank, or that the prices did not reflect market reality. Neither conclusion casts a favourable light on prevailing market practice.

## Methodology

We calculate the DTD on a daily basis, given levels for asset value and asset volatility. We consider data for the period March 2005 to August 2014, where available. We have data for equity value (both ordinary shares and preference shares), realised equity volatility and

debt value. We solve for asset value and asset volatility in three distinct ways using the equations above as detailed below.

In assessing the output, we consider a DTD value of one or below to be a significant warning signal as it indicates a high probability of distress in future; in effect, there is a one third chance that the asset value will drop below the value of the debt obligations at the 1-year time horizon.

In the first instance (DTD1), we follow the literature<sup>10,12</sup> and solve for equity as a call option on the assets struck at a level that takes account of total liabilities and the total quantum of preference shares issued. Balance sheet liabilities are grossed up for the 1-year term at a rate equivalent to the 1-year swap rate plus a spread commensurate with African Bank's funding costs over the period. This spread is set to 250 basis points, which is consistent with the average spread paid by African Bank on its DMTN programme.<sup>13,14</sup> The grossed-up balance sheet liabilities are denoted as X. Preference share nominals are grossed-up for the 1-year term at a rate equivalent to the cash yield on the nominal of the instrument prevailing at the time. The grossed-up preference share nominal is denoted by Y. Asset volatility is calculated as per Milne<sup>10</sup>, namely realised equity volatility adjusted for firm leverage.

In the second instance (DTD2), we solve for asset value and asset volatility as two simultaneous equations in two unknowns, where we are given values for equity and preference shares. Equity is valued as above (in DTD1); however, the preference shares are valued as a call-spread (i.e. simultaneous purchase and sale of an equal number of call options that differ only in their strike price) on the assets of the company, where the two strikes are [X] and [X+Y]. In effect, the preference share's claim to the assets of the company is limited by the prior claim of the balance sheet liabilities and the nominal outstanding of the preference shares.

In the third instance (DTD3), we solve for asset value and asset volatility as two simultaneous equations in two unknowns, where we are given values for equity and debt. We make use of a single debt instrument and imply a credit spread from the traded price of the debt instrument. This credit spread is then interpreted as a simple 1-year put option on the assets of the company struck at [X].

We make use of the listed ABL10A bond. It was issued in March 2010, carried a coupon of 11.5%, and was due to mature in March 2015. The ABL10A bond was benchmarked on issue against the R201 bond issued by the South African government (coupon of 8.75% maturing in December 2014). The choice of this bond is motivated by the tenor of the instrument during the period under review. We recognise that the positive yield spread of the ABL10A bond over the relevant government issued benchmark instrument incorporates more than a premium for default risk, including instrument liquidity and investor duration preferences. However, our focus is on the changes in value of equity and debt; and as such we do not adjust the prices of the bond to reflect any other information.

## Results

The results of applying the three distinct methods are shown below. In assessing these results, we wish to understand whether the application of Merton's model provided any forewarning of the future failure of African Bank. In effect, we ask ourselves if the changes in the prices of debt and equity provide insight into the changes in the values of the underlying assets and their volatility.

To illustrate the interaction between asset value, equity value, asset volatility, equity volatility, and DTD, we graph equity value against asset value, and DTD against asset volatility and equity volatility. The general behaviour of equity value and asset value is consistent across DTD1, DTD2 and DTD3; as such we show only the output for DTD1 in Figure 1. We note that equity value changes are generally an amplification of changes in asset value. The general behaviour of DTD against asset volatility and equity volatility varies across DTD1, DTD2 and DTD3. We show the graph of DTD against asset volatility and equity volatility for DTD1 in Figure 2. Our focus is on the values of DTD compared to the levels of asset volatility and equity volatility. We briefly describe the behaviour for each of DTD1, DTD2 and DTD3 and we show the key differences in the three approaches in Table 1, highlighting values as at

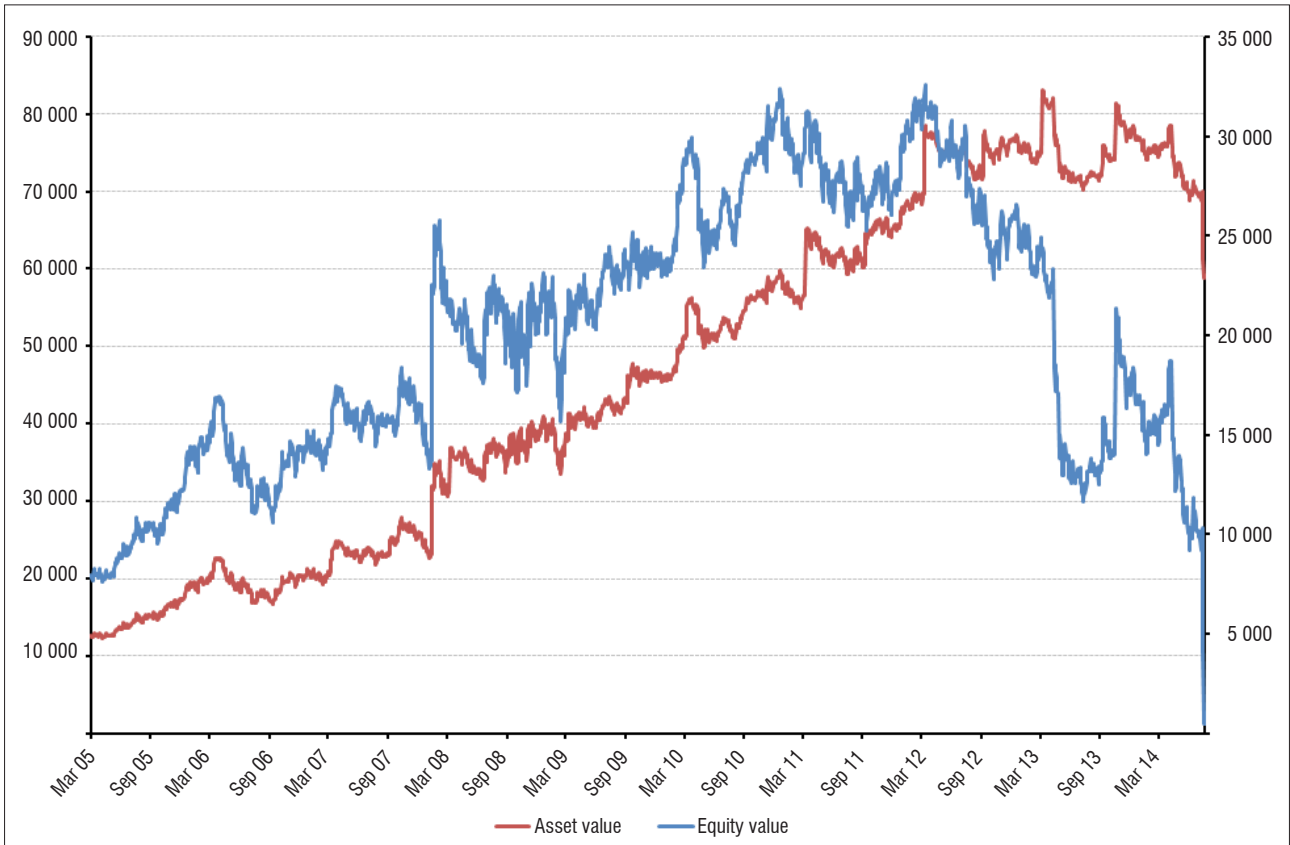


Figure 1: Asset value and equity value under the first distance-to-default scenario (DTD1).

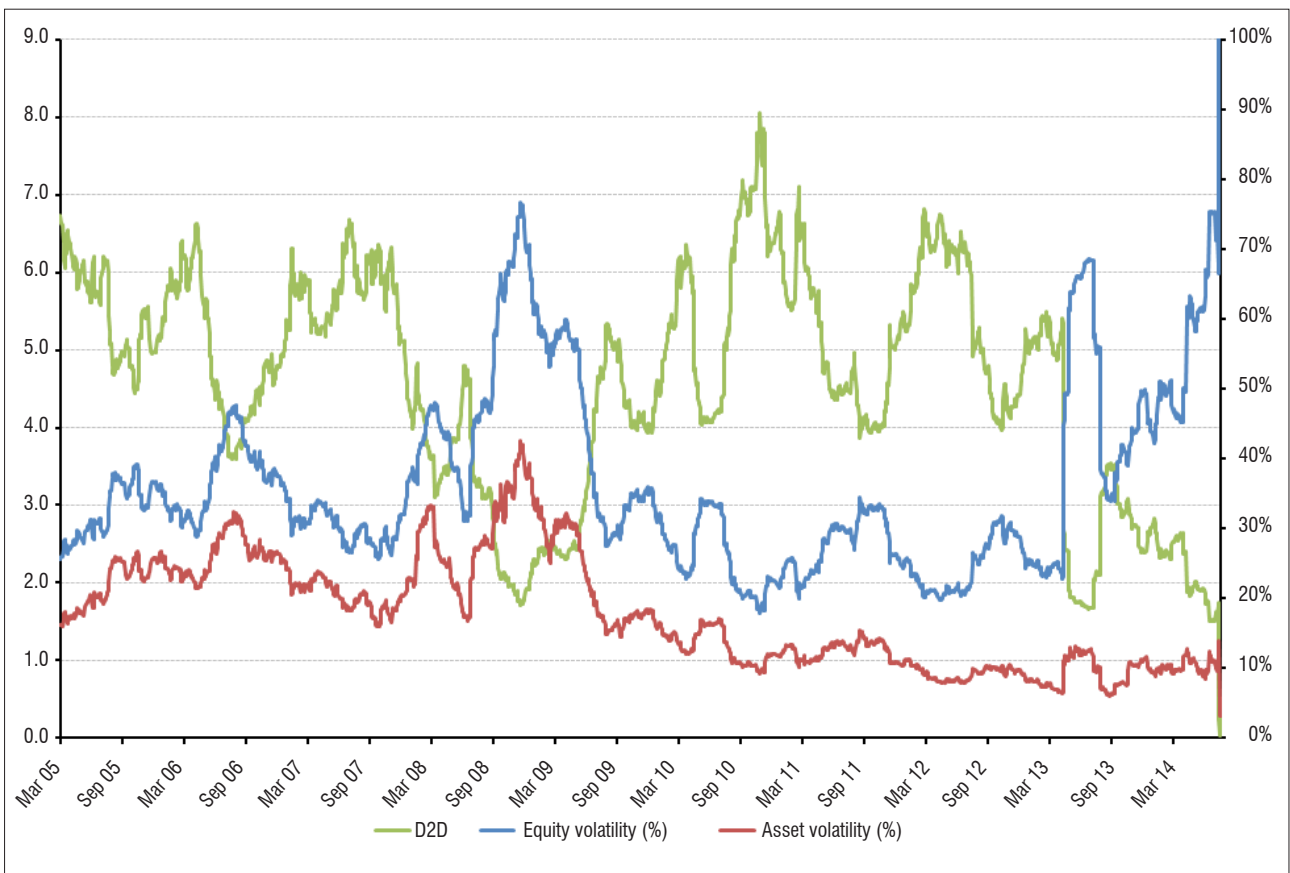


Figure 2: Equity volatility and asset volatility under the first distance-to-default scenario (DTD1).

the capital raise by African Bank in 2013 and on the days leading up to and including curatorship.

In the case of DTD1, we note that the DTD peaks above eight and declines to zero when the bank is placed in curatorship. DTD is fairly volatile, dropping to two at the peak of the global financial crisis in 2008, but recovering dramatically thereafter. DTD drops below one only in the days prior to default. In the case of DTD1, of particular interest is the behaviour of asset volatility which declines to a level of approximately 10% by the end of July 2014, in spite of the obvious uncertainty prevailing at the time. Asset volatility drops further as African Bank moves into curatorship. This drop is a direct result of using realised equity volatility to determine asset volatility, where asset volatility is linked to equity volatility by a leverage ratio. In this case, the increase in equity volatility is more than offset by the observed increase in leverage. To be clear, we would expect an increase in asset volatility as a result of the very large observed changes in the underlying asset price.

In the case of DTD2, we note that the DTD declines from a peak of approximately six to close to zero when the bank is placed in curatorship. DTD first drops below one in 2008, in the grips of the global financial crisis, recovers somewhat in 2010, only to drop below one again in 2012 and remain there until default. The calculated DTD suggests financial stress from the initiation of the global financial crisis all the way through to the bank being placed in curatorship.

The general behaviour of DTD in DTD2 suggests financial weakness much earlier than in DTD1; however, the results are marred by the erratic behaviour of the calculated variables, namely asset volatility and DTD. Calculated asset volatility is in excess of 50% for much of the period analysed. DTD does not follow the significant improvement in equity value after 2008 and tracks close to one all the way to default. This observation can be ascribed to the somewhat volatile price history of the associated preference shares and our assumption that the price of the

preference share is driven primarily by changes in the underlying asset value and asset volatility.

We note that so-called perpetual, non-cumulative, non-participating preference shares as a Tier 1 capital raising exercise for banks in South Africa enjoyed much popularity prior to 2006. These instruments suffered a significant price decline as an asset class (i.e. across all issuing banks) in the period up to 2011 (Figure 3). This decline coincided with the introduction of a dividend tax by the South African Revenue Services. To adjust for this behaviour, we consider a shorter period for DTD2, namely January 2012 to August 2014, and we normalise the price series for the preference shares such that the initial value in January 2012 is set to par. In this instance we note that the DTD declines from a peak above five in January 2012 to below zero just prior to the bank being placed in curatorship. DTD first drops below one in June 2013, around the announcement of the rights issue<sup>2</sup> in August 2013, and remains there until default. We note that asset volatility in both iterations of DTD2 are higher than those of DTD1, with significant increases observed by the end of 2012; however, they too show a decline in asset volatility as we move towards August 2014 and curatorship.

In the case of DTD3, we consider the period March 2010 to August 2014. We note that the mark-to-market spread over the reference bond declines from a level of approximately 320 basis points at issue to 200 basis points in August 2014 when African Bank is placed in curatorship. In effect, the marked credit spread is lower at default than at issue. There appears to be limited actual trading that results in adjustments to the effective mark-to-market as the spread to the benchmark bond is broadly constant for extended periods of time (Figure 4). As a result, we note that the DTD is just above one in March 2010 and drifts down from May 2013 to be just below zero on default. The observed credit spread and the resultant calculated values for DTD are incongruous with the events unfolding at the time. In the case of DTD3, almost perversely,



Figure 3: African Bank Ltd. (ABL) preference share versus the average of other bank issues.



Figure 4: Bond spreads versus equity value.

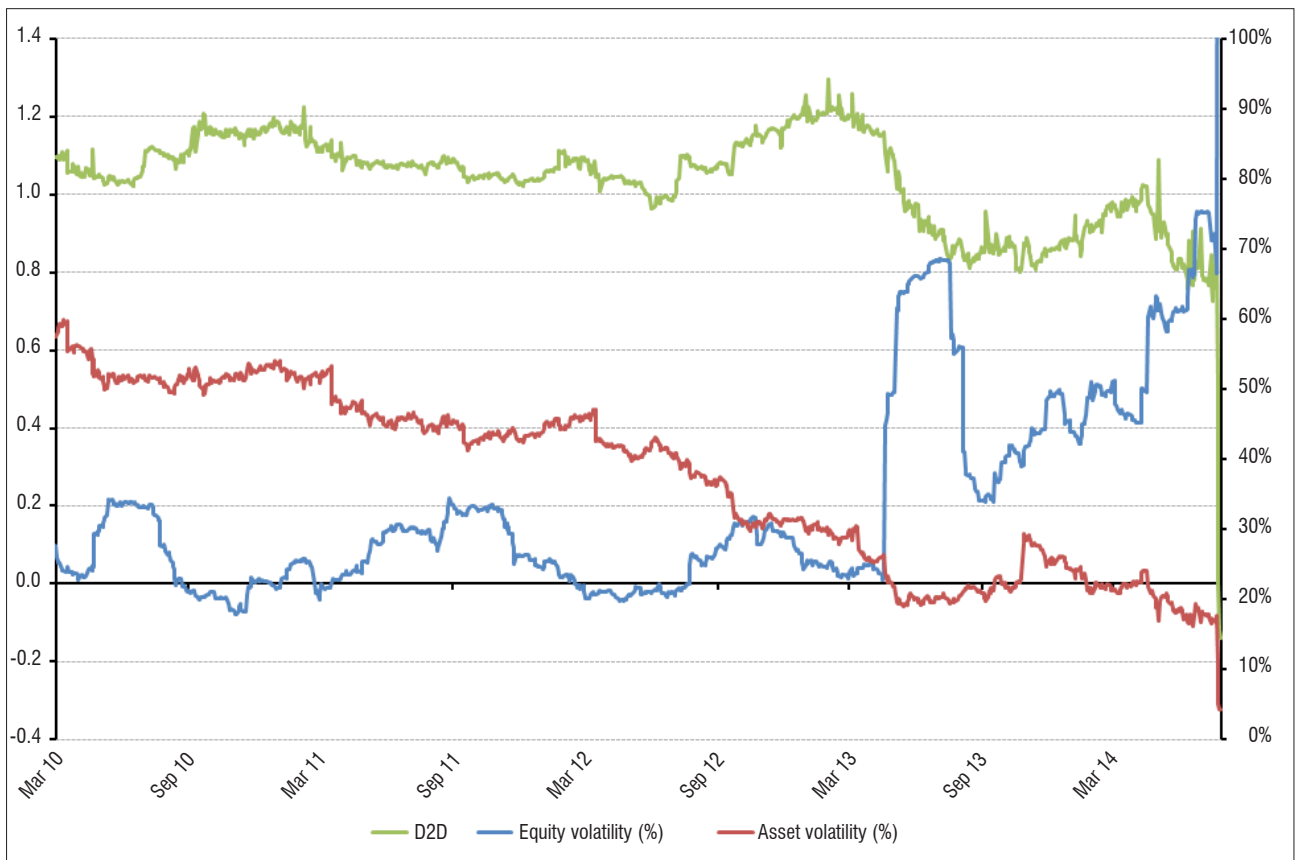


Figure 5: Equity volatility and asset volatility under the third distance-to-default scenario (DTD3).

Table 1: Equity and asset volatility and distance-to-default (DTD) over time

Date	30 Dec 2005	31 Dec 2007	31 Dec 2008	31 Dec 2010	31 Dec 2012	3 May 2013	31 Jul 2013	31 Dec 2013	31 Jul 2014	7 Aug 2014	8 Aug 2014
<b>DTD1</b>											
Equity value	36%	32%	70%	23%	27%	45%	68%	80%	72%	387%	397%
Asset value	28%	22%	43%	14%	11%	12%	12%	19%	10%	5%	3%
Distance-to-default	5.38	5.48	2.03	6.83	4.85	2.7	1.69	1.38	1.59	0.04	0.26
<b>DTD2</b>											
Equity value	36%	32%	70%	23%	27%	45%	68%	80%	72%	387%	397%
Asset value	74%	76%	77%	64%	49%	40%	34%	34%	26%	14%	20%
Distance-to-default	1.7	1.25	0.83	1.13	0.81	0.65	0.45	0.52	0.26	-0.84	-1.32
<b>DTD2 (adjusted)</b>											
Equity value					27%	45%	68%	80%	72%	387%	397%
Asset value					31%	28%	25%	24%	19%	11%	17%
Distance-to-default					1.6	1.2	0.85	0.97	0.58	-0.7	-1.22
<b>DTD3</b>											
Equity value				23%	27%	45%	68%	80%	72%	387%	397%
Asset value				61%	37%	28%	23%	26%	17%	5%	4%
Distance-to-default				1.23	1.27	1.18	0.91	0.87	0.76	0	-0.12

the asset volatility is seen to move dramatically lower over the period (Figure 5). This is a direct result of the effective credit spread declining whilst leverage increased and the realised risk in the underlying asset ballooned.

In Table 1, we show equity volatility, asset volatility and DTD for each of the methods applied at regular intervals across a wide term with particular focus on periods of significant change in the capital structure of African Bank.

In all the approaches detailed above, the market data show a wide variation in the financial health of African Bank over the period, covering periods of no stress (with DTD in excess of four) to periods of potential stress (with DTD less than two). The introduction of the African Bank preference share into the analysis shows a wider variation of output.

The recovery of financial health from the stresses associated with the global financial crisis in 2008 proved to be short-lived. The adjusted DTD2 approach shows that the market was highlighting significant risks of financial stress as early as December 2012. The DTD3 approach shows very little variability in the financial health of African Bank over a period of excessive volatility and significant corporate activity. This can be attributed to the static spreads applied to the closing prices of listed African Bank debt which did not reflect the fundamental changes in the financial health of African Bank.

We believe that the analysis above suggests that the consideration of market data provides significant explanatory and predictive output regarding the potential for future bank failures. As is the case with all analysis, the quality of the data is key. Closing prices in the absence of arms-length transactions between market participants do not reflect market prices and should be treated with suspicion.

## Conclusion

The Merton structural model and the DTD measure provide valuable insight into the financial position of a bank. These measures must be incorporated in the regulatory process undertaken on banks and

should be an essential component of the toolkit for any financial market professional evaluating the performance and standing of a bank.

Traditional regulation and supervision did not prevent the failure of African Bank. A considered evaluation of market prices offered an early warning signal for impending distress; however, not all market prices are of equal quality and some are categorically suspect. The equity and preference share markets for securities issued by African Bank showed significant weakness and stress in the period leading up to the effective default of the institution. This feature was not mirrored by the closing price data available for the debt instruments issued by African Bank. It is our belief that the closing prices on these instruments did not reflect market conditions at all; as such they offered almost no value to the financial markets. The investment process encompasses a wide range of data evaluation and information assembly, but is undermined by the quality of the data available for debt instruments. The prices available must capture the tradeable market or they should not be made available at all.

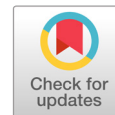
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# Nanotechnology in South Africa – Challenges in evaluating the impact on development

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Nanotechnology has captured global attention as the technological platform of the next industrial revolution.<sup>1</sup> South Africa is one of the few countries from the global South that have adopted nanotechnology with the aim of enhancing global competitiveness and sustainable economic growth. As early as 2005, South Africa displayed an interest in nanotechnology by publishing and subsequently implementing the nanotechnology strategy and an associated 10-year plan.<sup>2</sup> The strategy explicitly outlined the country's niche areas in the application of nanotechnology, namely water, energy, health care, chemical- and bio-processing, mining and minerals, and advanced materials and manufacturing.<sup>3</sup> The applications focused specifically on areas that were expected to benefit the country, as the overall goal was to support development. About 10 years have elapsed since the strategy was implemented and the question has inevitably arisen as to how the technology has contributed to the development of the country. We argue that it is not easy to measure the impact of nanotechnology on development.

## South Africa's nanotechnology strategy

The South African National Nanotechnology Strategy focuses on four priority areas of intervention: the establishment of characterisation centres (national multi-user facilities), the creation of research and innovation networks (to enhance interdisciplinary, national and international collaboration), the building of human capacity, and the establishment of flagship projects (to demonstrate the benefits of nanotechnology).<sup>4</sup> These interventions are meant to facilitate the realisation of the country's vision of economic growth, poverty reduction and enhancing quality of life. The strategy identifies two development clusters – industrial and social.<sup>3</sup> The former targets mining, minerals, chemical- and bio-processing, and materials and manufacturing, while the latter focuses on the provision of clean and purified water, affordable and renewable energy, and improved primary health care.

Since the implementation of the strategy, South Africa has established two national nanotechnology innovation centres – at the Council for Scientific and Industrial Research (CSIR) and at MINTEK.<sup>5</sup> These centres collaborate with other national institutions in the design and modelling of novel nanostructured materials as well as in the application of nanotechnologies in the fields of water, health, mining and minerals.<sup>2</sup> In addition, Centres of Excellence are spread across universities in South Africa. The country has created research and innovation networks, both nationally and internationally, to enhance collaboration in nanotechnology. For example, the India–Brazil–South Africa (IBSA) project provides a platform for collaborative research in nanotechnology among scientists and organisations from these countries.<sup>6</sup>

In terms of human capacity development, South Africa is actively engaged in building a critical mass of graduates skilled in nanoscience and nanotechnology. A dedicated postgraduate programme has been introduced, with four South African universities collaboratively presenting a master's degree.<sup>7</sup> Furthermore, the country has set up flagship projects on the application of nanotechnology in water, energy, health, chemical- and bio-processing, mining and minerals and advanced materials and manufacturing. The investment in the flagship projects has yielded considerable outputs; for example, by 2015, 464 postgraduate students had been trained, 92 postdoctoral fellows supported, 326 collaborations established, 352 articles published in highly cited journals, 80 conference proceedings recorded and 17 patents registered.<sup>8</sup>

Thus, the strategy's priority areas of intervention – projects, facilities, networks and training – have produced outputs. The impact of these outputs, however, remains to be assessed. The industrial cluster identified in the strategy has shown some development in that the synthesis of known and novel biomaterials has benefited the advanced manufacturing technology sector.<sup>7</sup> Impacts on other aspects of the industrial cluster and on the social cluster are more elusive. Conventional ways of assessing the impacts of a technology are less effective when applied to nanotechnology. For example, the traditional methods of cost–benefit analysis, life-cycle assessment, constructive technology assessment and real-time technology assessment are versatile tools for evaluating the impacts of a technology along the entire product value chain.<sup>9,10</sup> However, nanotechnology has unique attributes, and despite the progress made so far in implementing the nanotechnology strategy in South Africa, it is difficult to determine the impact of the technology on development.

## Challenges in assessing the impact of nanotechnology on development

Nanotechnology has been characterised as a general-purpose technology.<sup>11</sup> It is pervasive and has a propensity to spur complementary innovations that cut across many technological sectors.<sup>12</sup> Nanotechnology is becoming integral to many modern-day products, as a part of either the product or the manufacturing process, yet not always in a recognisable manner. The applicability of nanotechnology in virtually all manufacturing sectors means that its impacts become larger and harder to predict and measure. Nanotechnology is indeed being used widely by industries in South Africa, particularly in catalysis. The multi-purpose and enabling nature of nanotechnology makes it difficult to measure its impact using tools such as life-cycle assessment because the technology can be part of a product's key functionality, or just ancillary to the value chain and representing a small portion of the final product or process.

A second challenge is that nanotechnology is a misnomer as it is not just one, but multiple, technologies that involve manipulation of matter at the nanoscale. Sparrow<sup>13</sup> argues that we should be talking about 'nanotechnologies' instead of nanotechnology, as the technology is a microcosm of the whole innovation ecosystem. For example, the value chain of nanotechnology is incredibly long as it stretches from nanomaterials to nano intermediates to nano-enabled products.

Many different nanotechnologies have emerged, are emerging or are likely to emerge and it is hard to define where the technologies start or end. Thus having an umbrella term for technologies that have little in common other than the scale of the structures they produce or manipulate, makes it cumbersome to assess their impacts. The impacts of nanotechnology are often intermingled with that of many other interventions and technologies. This is further complicated by the fact that nanotechnology integrates multiple and overlapping scientific disciplines. As nanotechnology is not a discrete technology, it is difficult to use cost-benefit analysis and real-time technology assessment to establish its impacts.

Thirdly, nanotechnology embodies the three forms of a technology as defined by Wajcman<sup>14</sup>, as (1) sets of physical objects or artefacts, (2) human activities such as designing, making and handling of machines and (3) knowledge. Approaching nanotechnology using the lens of these layers means that when evaluating the impact of the technology, the focus should not be limited only to physical objects. Instead, it is important to incorporate the manufacturing processes as well as the knowledge generated. This inclusivity is challenging, as the latter forms of the technology tend to be invisible to ordinary consumers. While many forms of modern technology are invisible in that users generally do not know how they are produced, this phenomenon is likely to be more pronounced in relation to nanotechnology, thereby making the measurement of its impact by conventional methods problematic.

The futuristic cladding of nanotechnology is a fourth challenge, as it disguises the temporal aspect of the technology. For instance, the South African Nanotechnology Strategy stipulates the expected outcomes of the technology, but it is difficult to predict with certainty when an emerging technology will deliver. When the strategy was implemented, it was expected that by 2014, the projects would have matured and reached a stage of self-sustenance by generating their own income. However, by 2014, many projects were not ready to stand on their own, as their products were not yet fit for commercialisation. What is explicit from this is that nanotechnology is driven by future-oriented claims, which tend to enforce the legitimacy of the emerging technological sphere. The expectations of nanotechnology on the one hand and the realisation of its applications on the other, denote a problem of temporality as a result of discrepancies between time horizons. Constructive technology assessment, which is often used with emerging technologies, is less useful in this case because of a lack of clarity about when products might reach the market.

The final challenge of measuring the impact of nanotechnology on development emanates from the fact that the technology is characterised by complex and heterogeneous cycles of hope, expectation, hype and disappointment.<sup>15</sup> For instance, during the period when the South African Nanotechnology Strategy was published in 2005, 'nano' was a buzzword, and one could easily be tempted to add nano as prefix to a product or service to make it fashionable. It is not surprising that even products that did not embody nanotechnology per se could use the label strategically for marketing purposes. It was not until the unknown risks and uncertainties of the technology were raised that some nano-enabled products started to drop the label. As the discourse on nanotechnology increasingly includes concerns about its safety, products containing nanotechnology may no longer necessarily stand out, or be advertised.<sup>12</sup> Such a situation makes it problematic to identify applications of nanotechnology because unless a product is labelled as containing the technology, it is difficult to ascertain whether it does or does not. Thus, the fallout from overhyping nanotechnology brings complications such as failing to identify nanoproducts on the market, which poses further challenges in measuring its impact using conventional methods.

Thus, the generic but also heterogeneous nature of nanotechnology, its different technological manifestations, its status as an emerging area in South Africa, and the impact of its changing perceptions in the public mind, challenge the assessment of its developmental impact in South Africa. These challenges render conventional methods of technology assessment less effective. The unusual character of nanotechnology calls for unconventional and pluralistic approaches for the analysis of its impact on development.

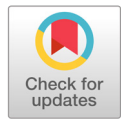
## The way forward

Although the impacts of nanotechnology are difficult to measure, that does not necessarily mean that the technology is not contributing to the development of the country. The challenges in assessing the impact of nanotechnology are compounded by the complexity of forces that drive economic growth and the long timescales from research-based discovery to commercialisation of technologies, often 20 years or more. However, such a disposition should not be used as an excuse for postponing investments in nanotechnology as it may result in South Africa missing opportunities for development. Instead there is need to devise mechanisms for measuring the impact of nanotechnology on development. This measurement may entail evaluating the economic impacts of investments in nanotechnology research and development in a rigorous fashion using a set of metrics and an aggregation of data on technology transfer and commercialisation.

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## The function of a university in South Africa: Part 2

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Social insurance institutions appeared after World War I, and were intended to provide safety nets for the income, health, education and pension levels of individual citizens. Later in the 20th century, enthusiasm for the concept of human rights generated a remarkable boost of research interest within universities in the aftermath of World War II. This war had witnessed an unprecedented catalogue of atrocities, most notably genocide, as well as human neglect on a mass scale, followed by the reaction against colonialism already on the brew.

One defining feature of what became the human rights movement has been a concern and set of state policies aiming to raise individual welfare, as well as the emerging conception of the well-being of *all* of a nation's citizens. Eloquent refugee experience in the aftermath of World War II illustrates this feature clearly:

*Hannah Arendt, exiled in 1933, stripped of her German citizenship in 1937,...also wondered how Europe had betrayed the stateless in her own time. In 1948, in The Origins of Totalitarianism, she observed that it was citizenship that gives human beings the 'right to have rights'. As for stateless persons, she concluded, they ought to have rights simply because they are human, but her own experience had taught her a different lesson.*<sup>1(p.2)</sup>

Thus the influence of human rights ideas in building firmer democracies, mostly emanating from university-based research, is ongoing despite strong differences of opinion amongst philosophers, lawyers and human rights advocates. These divisions show up prominently in the drafting of national constitutions in *emerging countries*. Bills of rights are embedded in these constitutions as normative aspirations that demand institutions and policies especially devised for the purpose of rights fulfilment. A troublesome idea in the logic of rights for instance, is that one individual's rights cannot be traded off or sacrificed for the benefit of the majority.

South Africa's 1996 constitution is an example of such conceptual conflicts. Human rights occupy an ambiguous position in the sphere of South African policy formation since the fall of apartheid. Controversy arises particularly regarding Clauses 26–29 that specify economic and social rights. When it suits politicians they appeal to rights-based ideas. But too often the constitutional commitment to rights fulfilment is simply ignored for political convenience by them as policymakers and by their advisers.<sup>2–6</sup>

The endurance of the institutions that emerged from university research, teaching and advocacy in the construction of welfare states, like those that exist today in Western Europe, is evidenced by their successful performance as stabilisers during recent crises. These institutional responses have been generated by the local conflicts emerging from ethnic differences, nationalism and religious divergence within numerous states, including welfare states. Most prominent are the anti-colonial struggles, the civil wars on Europe's periphery, as in the Balkans during the 1990s as well as during the Arab Spring in the last decade. Most recent are the multiple threats to stability posed by incoming floods of Middle Eastern and African refugees.

All these events have posed, and continue to pose, serious tests of welfare state institutions. Yet their stability has persisted. Numerous instances are discussed in an emerging literature; for example, Collini<sup>7</sup>, Algan et al.<sup>8</sup> and Stiglitz<sup>9</sup>. The relevant point here is simple. None of these successful institutions would have come into being without a great deal of university-based research in preceding decades, particularly so since the end of World War II.

Another cause of institutional disturbance and threat has been the international financial crisis since 2008. Viewed in the context constructed here, their success in stabilising the political and economic dimensions of nation states in Europe and North America make such welfare state institutions now even more widely admired.

Contrary to the conservative expectation that is sceptical of welfare states (often called *neo-liberalism* – a label purposely not used in this paper because of its imprecision and polemical character), the levels of social and economic disruption in the major welfare states have been consistently lower than the average scores worldwide.<sup>10–13</sup>

South African policymakers imbued with nationalist ambitions have to learn from precedents on every side. This lesson will not be easy. No linear progression is in evidence from developed countries' success to a set of policies suitable for an aspiring developing country like South Africa to copy. It is probable that in the longer run, in a troubling and confusing world, universities everywhere will provide research evidence that bears on the construction of the best institutions to embody the ideals of moral imagination and higher trust between people. At the same time, local universities must come to reflect more prominently the presence of black intellectual elites in teaching, research and administration.

Yet forcing the pace without knowing or heeding the consequences raises the likelihood that this anticipated evolution will take longer to achieve, and on the way impose painful costs on tertiary institutions. To make the universities in South Africa bear the burden of the other components of the education system's failures is illogical. The destined outcome is likely to be reached only some time in an indefinite future.

First, a tipping point is likely once larger and larger cohorts of inexperienced staff and under-prepared students enter existing universities, particularly those that aspire to be research universities on the international pattern. These institutions would then change their practice and culture in directions probably negative for the emergence of the highest quality talents and skills. Second, a proportion of existing academic staff will judge that the work environment for which they contracted originally no longer exists. It is likely they will depart for countries viewed as more promising for pursuing academic careers. Third, the international standing of South African research work and conferred degrees will not survive unaffected. As noted already, a simple test will be whether South African graduates continue to be readily accepted for postgraduate study in the world's major universities? Or instead will

South African applicants be put through rigorous testing procedures for admission there? This will remain the acid test of teaching and research quality for our existing universities.

Background information that can inform these challenging judgements must be treated with caution. Measured in various ways, at least since the early 1990s in the USA and elsewhere, international collaboration between academics in universities and research institutes set up for specific purposes (like environmental studies), has become strengthened and not weakened. This growing international collaboration is so despite the ongoing international conflicts that are driven by ethnic, religious and strategic differences. The evidence for this assertion is readily culled from publications like the *Times Higher Education Supplement*, the *Chronicle of Higher Education*, *World University News* and academic journals multiple in number. The isolation of Iranian and North Korean research bodies illustrates the rare national exceptions to closer research ties brought about by strategic and political conflicts at the present time.

In summary, if a university does not keep up its research output, its standing amongst its peers in the world inevitably declines. What does 'keeping up' mean? Einstein's<sup>14</sup> aphorism about research is a useful answer and reminder: 'Everything should be made as simple as possible, but not simpler.' It is the deepening international linkages that govern the progress of individual universities as well as the prestige accorded to national systems of universities.

*Why, then, has scientific research become increasingly collaborative? Viewing science as an aggregate process for producing new knowledge, the most plausible answer is that the knowledge base has become increasingly complex and specialised ... and thus requires that increased numbers of researchers combine their expertise to make advances. Consistent with this, our survey of corresponding authors shows that access to specialized human capital is the main driver of collaborations ... the growth of useful knowledge comes largely from combining the growing supply of past ideas and knowledge in new ways.*<sup>15(p.16,17)</sup>

Finally, the *economic role* played by universities is probably the most prominent of their activities, and the most unlikely to provoke contention. Contemporary economies that are successful combine private and public sectors that vary in relative size for reasons of history and informed belief. But all productive organisations, no matter their kind of output, require administrative, managerial and technical skills, growing ever larger in their variety because of ongoing specialisation trends.

Under this heading of an economic role fulfilled by universities, all that matters for the main theme of this essay is the truth behind the assertion that no national economy can function in the modern world without the skills produced through university study, teaching and research. A number of the necessary skills and aptitudes can be acquired outside formal tertiary study or be imported. Yet the vast bulk of the essential competencies cannot be acquired this way.

The interdependence of growth and diversification in economic activities, the expansion of scale economies, and the evolving knowledge incorporated into production, are the keys to progress that raises living standards. This fact has been known by scholars and policymakers since before the time of Adam Smith in the late 18th century. Increasing specialisation of tasks is entailed. This point can be illustrated using a simple example: bread can be produced most cheaply in large quantities if its production is confined to a source that does nothing else. But satisfying consumer wants for bread requires transport, a distribution network, multiple outlets, and a diversity of skills. To minimise the cost of a loaf of bread, these inputs too have to be specialised in their functions.

Why does this interaction of specialisation and economies of scale often fail? The administration of fragile states cannot deliver services in numerous spheres, most prominently in the conduct of their economic activities because of managerial incapacity, decision-taking based on the interests of the elite, corruption and, above all, the perpetual failure to

invest. For our purpose, investment is simply the use of resources *now* in order to obtain a larger output *later* greater in value.

In the economic sphere, the means of valuation – most importantly the indicators known in the discipline of economics as *relative prices* – have to be established by a combination of processes. These processes are free exchange between individuals and between organisations for which markets exist, as well as by the state's efficient pricing of *public goods*. Such goods cannot be produced and distributed through market processes alone for well-known and accepted reasons that need not detain the present discussion.

As already noted, the role played by universities in economic life is apparent with great clarity. Universities produce skills, aptitudes and knowledge with immediate economic application. In addition to this instrumentalist view, and at least equally important for stability and growth, are the effects on *values to live by* that university exposure embeds inside individuals. Certain effects have already been mentioned, although not their economic importance. For example, credibility is the ability of a person or institution to retain trust and legitimacy. In addition, there has to be recognition by legislators and policymakers that an individual's pursuit of maximum welfare, meaning the highest return that he or she wants from the possession of resources, does not get shaped and tamed sufficiently by the *invisible hand* of the market (Adam Smith's striking metaphor). An efficient regulatory state is essential.

For the insights that must govern economic alongside political institutions, university teaching has to steer between two 18th-century philosophers of the Scottish Enlightenment, Adam Smith and David Hume. A social contract has to underlie all nation states; that contract can be achieved through knowledge acquired and imparted by universities.

*Political writers have established it as a maxim that, in contriving any system of government, and fixing the several checks and controls of the constitution, every man ought to be supposed a knave, and to have no other end, in all his actions, than private interest.*<sup>16</sup>

One further illustration of the role played in economic life by universities concerns social and economic *equality* – a subject which is receiving a great deal of contemporary attention. Currently there is growing recognition that inside the world's major economies, the distribution of income and wealth, seemingly inexorably, moves in the direction of widening inequality, although this may not be true at the global scale because the available evidence cannot be unambiguously interpreted.<sup>17</sup>

Evidence on these trends widely cited is the research results for developed countries presented recently by prominent scholars.

*To sum up what has been said thus far: the process by which wealth is accumulated and distributed contains powerful forces pushing toward divergence, or at any rate toward an extremely high level of inequality. Forces of convergence also exist, and in certain countries at certain times, these may prevail, but the forces of divergence can at any point regain the upper hand, as seems to be happening now, at the beginning of the twenty-first century...historical experience suggests that the principal mechanism for convergence [on greater equality] at the international as well as the domestic level is the diffusion of knowledge. In other words, the poor catch up with the rich to the extent that they achieve the same level of technological know-how, skill, and education, not by becoming the property of the wealthy.*<sup>18(p.27,71)</sup>

Thus the role of universities in fostering *both* directions in the movements of inequality, towards higher as well as lower levels, is not complicated to understand. As we argued earlier, tertiary level institutions (universities being the most prominent) create knowledge, and they impart such knowledge through teaching within all societies in the contemporary

world. Knowledge is the key variable that determines and therefore explains the direction these inequality movements in the command over resources take at any point in historical time.

It is not just a matter of the demand and supply of university graduates that determines the value of the activities they produce. Low numbers and proportions of scientists, chartered accountants, medical specialists, lawyers, business entrepreneurs, and other categories of high earners in a national population do go a long way to explain their entrenched positions in the top percentiles of the income distribution of any country. South Africa occupies an intermediate position in the global scale of the rewards paid to professional skills.<sup>19</sup>

Yet universities determine equality and inequality in societies in multiple *other* ways too. For instance, technical progress in production has been shown to have major effects on the equality of income and wealth as well as on income growth. For decades it has been accepted that there is a bias favouring demand for higher skills in ever-changing technology. Ongoing technical progress has deepened inequality because it creates jobs for higher paid workers and inhibits job creation for lower paid workers who are offered deployment mainly of muscle power and extended time on the job.

The primary research behind new methods of production and organisation originates in universities, both in pure and applied sciences, so universities are the ultimate source of this bias. There appears to be no feasible counter strategy to limit these inequality deepening effects which are a byproduct of new technology.<sup>15,20</sup>

Skills bias is one idea underlying the interpretation of the 'laws of capitalism', as Piketty and his research group call them. Whether that claimed bias towards inequality can be offset by appropriate blocking institutions and policies is a separate question. It is also the key question that must be answered if human progress demands an inherent component of *rising* equality. This question is one that political philosophers have grappled to answer for centuries, most intensively in recent times since the 1971 appearance of Rawls' influential book, *A Theory of Justice*.

A literature sceptical about the structural nature of such *laws* is in the making. It claims that inequality can be countered by the right institutions and policies, given the necessary political willingness to do so.<sup>21-26</sup> For the purpose of the present argument, we do not need to pass judgement, but we must recognise the roles played by universities in the research on inequality and on potential countervailing policies and institutions.

## Nationalism and university destruction

An entire mythology is growing up around the subject of South African university 'transformation', and regrettably certain professional educationists are perpetuating these myths. The word 'transformation' needs quotation marks because it is used in ways that convey, at best, political intention. It is certainly *not* a word that adds insight and analytical value to discussion about the function of universities, nor about the criteria and decision processes essential to the search for the policies best able to regulate universities.

To summarise once more this Commentary's theme, if South African universities are damaged by ill-considered policies driven by ideology, then every group in the country will suffer the consequences. One cannot construct a set of national institutions that support democratic government; that sustain a lively and evolving cultural life; and that promote an economy that encourages individuals to pursue their own interests along with those of the entire community, without the high-level skills and personal values that must guide such conduct. These can be provided only by autonomous universities that pursue excellence as judged by international standards. No other institutions, least of all government decree, can provide these skills and values.

Numerous historical examples illustrate the vulnerability of universities to the pressure of nationalist aspirations. In the 18th and 19th centuries, German universities were admired above others for their teaching and research achievements. But they later fell prey to nationalism. Their activities became 'directed' in the service of German imperialism. Then again a century later, universities in countries newly independent

from colonialism were subjected to reform decisions by their new governments that led to their own destruction.

Pakistan is one example. Universities were seen as not meriting their resource allocations, as well as harbouring individuals and groups deemed unreliable in the task of nation-building. Existing universities were run down deliberately and quickly, so that by the time these policies came to be recognised as destructive of *nation-building* and so reversed, their rebuilding has proved costly in resources, lengthy in duration, and controversial to their citizens. '[In Pakistan] the science and education ministries were often afterthoughts. ... In the late 1970s, the [Peoples Party] founder Zulfikar Ali Bhutto diverted scarce resources and personnel into building the nuclear bomb.'<sup>27</sup> (See also Osama et al.<sup>28</sup> and Bennett-Jones<sup>29</sup>.)

At the present time, South Africa's higher education policies, particularly the pressures placed on the universities to conform to the dominant political ideologies, come mainly from groups who comprise the new black elite. The resulting policies look like a Trojan Horse. Racial identity alongside cultural identity are not self-evident goods to be fostered in the pursuit of democracy. Both concepts, treated as individual and communal values, are implausible and likely to be divisive. Further, if given priority as goals to be maximised, they threaten to be self-defeating.

*That cultural identity is 'a permanent feature of human life' is trivially true. We all come from somewhere ... But why must each of us be more than matter-of-fact in committing our lives to our history, our culture, our identity? They – culture, history, identity – have done many things for us and many things to us. What makes us affect gratitude instead of anger in return?<sup>30</sup>*

The pursuit of equity, when conceived to be simple numerical redress, no matter the possible damage to the characteristics that define and make any university a true university, is precisely such a device. It passes for an indicator of progress, but it is not so.

To recall the major proposition argued here, policies and remedial actions to make redress the dominating objective is to make it parasitic on the first-order functions of a good university. 'Redress' or 'transformation' demand much more nuanced understanding because they carry so much political baggage in South Africa.

The lack of any awareness of a historical perspective in the local policy arena is equally disturbing. Many international precedents in the past must be noticed. At least two should become common knowledge because they were policies that specifically excluded certain aspiring students from entry to universities on grounds that were openly prejudicial and decidedly *not* academic.

The first is the policy of *Numerus Clausus* (meaning 'closed number') in Tsarist Russia. This provision kept out of the universities a proportion of Jewish applicants just because they were Jewish. The second precedent relevant to us is the policy adopted by a number of East European states under communism this century. Their higher education authorities forbade the universities from admitting students from families considered to be bourgeois or dissident.<sup>31</sup>

These reminders must make all observers aware of what is at stake in using race to *admit* by privileging some students and thereby to *exclude* and penalise other students from access to university study. It is morally reprehensible, politically short-sighted, and highly probable to be destructive to the building of a viable democratic state. This tendency forms an integral part of the political baggage which burdens us in contemporary South Africa.

This is so because the first-order objectives of our universities described in this essay are likely to be severely compromised. This is additional to the damage inflicted on individual students aspiring to enter higher education. They will be denied a place in the queue by their race categorisation; others will be disappointed by the lowered quality of the learning and research skills they acquire.

At this stage, this judgement has to be tentative. It is not yet supported by research results from work dedicated to the purpose described here. But years of experience internationally as well as in South Africa should tell us that the right strategy for higher education researchers at every level is not the short-term political game in which policy decisions are made. The right game is the long-term one of building up the institutional capacity both within and outside universities (1) to formulate ideas that are judged relevant to change by university peers in the wider world; (2) to collect and analyse evidence with a bearing on change; and (3) to assess the effects of such changes that are made.

The research questions posed in this article have to be approached openly and *not* with any pre-commitment to answers deemed politically acceptable. To use the old metaphor, we in South Africa have to ask whether we are in danger of sawing off the tree branch on which we are now sitting. In addition, Warnock's<sup>32</sup> low-keyed definition of a good school summarises simply and clearly what is at issue for us when it is applied to a good university: 'A good school is a school where learning is possible.' In addition, a recent judgement about universities in the United Kingdom applies also to us in South Africa: '[The] big picture is even wider: if UK higher education is going to prosper in the contemporary world, it is going to have to become messier, less precious, more flexible, and significantly more co-operative.'<sup>33(p.561)</sup> This is a pithy summary of what we face here.

Will our South African universities continue to make learning possible for those who want it, into the indefinite future? This question concerns all the forms of university activity identified in this essay. So far though nobody is posing such a question. In *Pense'es* (1670), Blaise Pascal contributed an idea that must be pondered by every university reformer:

*The last step that Reason takes is to recognise that there is an infinity of things that lie beyond it. Reason is a poor thing indeed if it does not succeed in knowing that.*

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# The importance of monitoring the Greater Agulhas Current and its inter-ocean exchanges using large mooring arrays

The 2013 Intergovernmental Panel on Climate Change report, using CMIP5 and EMIC model outputs suggests that the Atlantic Meridional Overturning Circulation (MOC) is very likely to weaken by 11–34% over the next century, with consequences for global rainfall and temperature patterns. However, these coupled, global climate models cannot resolve important oceanic features such as the Agulhas Current and its leakage around South Africa, which a number of studies have suggested may act to balance MOC weakening in the future. To properly understand oceanic changes and feedbacks on anthropogenic climate change we need to substantially improve global ocean observations, particularly within boundary current regions such as the Agulhas Current, which represent the fastest warming regions across the world's oceans. The South African science community, in collaboration with governing bodies and international partners, has recently established one of the world's most comprehensive observational networks of a western boundary current system, measuring the Greater Agulhas Current System and its inter-ocean exchanges south of Africa. This observational network, through its design for long-term monitoring, collaborative coordination of resources and skills sharing, represents a model for the international community. We highlight progress of the new Agulhas System Climate Array, as well as the South African Meridional Overturning Circulation programme, which includes the Crossroads and GoodHope hydrographic transects, and the South Atlantic MOC Basin-wide Array. We also highlight some of the ongoing challenges that the programmes still face.

#### Significance:

- Large mooring arrays have been successfully deployed to monitor the Greater Agulhas Current system.
- Capacity development is ongoing, although established, in marine science around South Africa.
- Challenges exist with regard to retention of skilled staff, resources and funding.

## Introduction

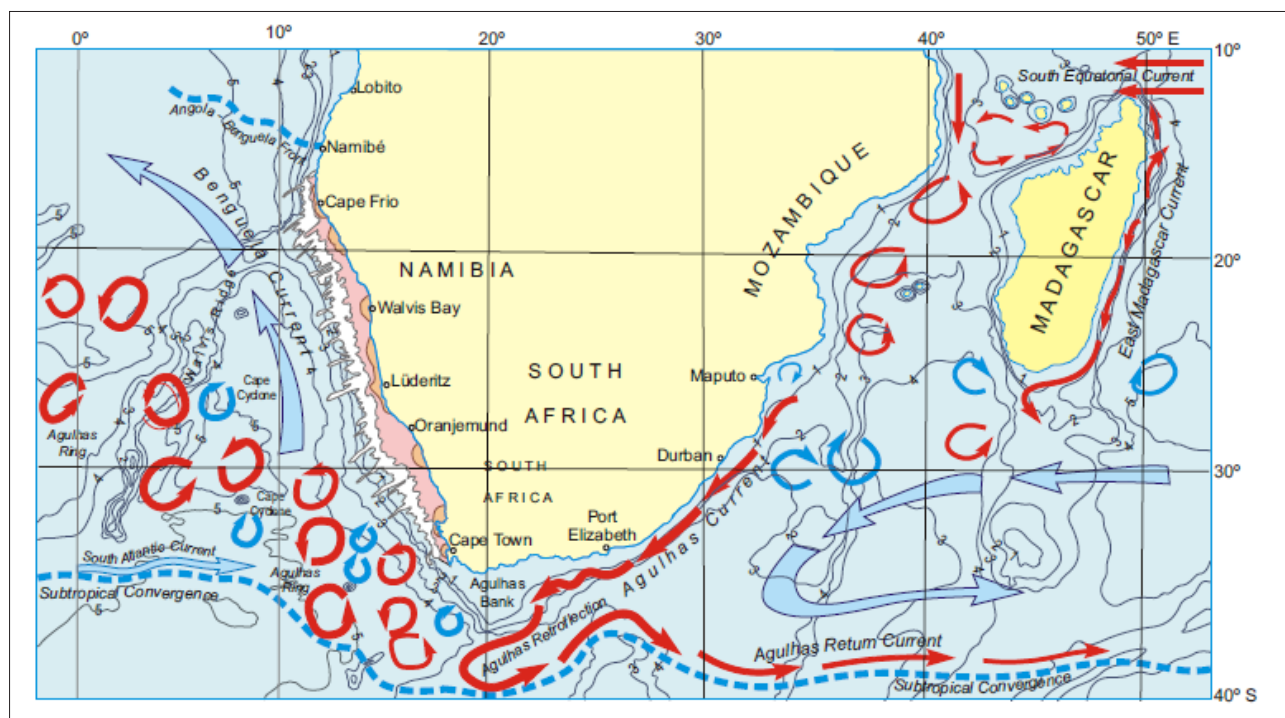
A bird's eye view of the ocean environment surrounding South Africa presents, to any oceanographer, a highly enviable snapshot of one of the most energetic ocean current systems in the world – the Greater Agulhas Current System (Figure 1).<sup>1</sup> Lying as close as 20 km to the South African east coast, the Greater Agulhas Current System consists of three main components: the Agulhas Current, the Agulhas Return Current, and the Agulhas Leakage that forms a conduit for inter-ocean exchanges of heat and fresh water between the Indian, Atlantic and Southern Oceans. Recently, this region has become the focus of a number of international research programmes.<sup>2,3</sup>

The Agulhas Current is a well-defined western boundary current, tightly coupled to the continental slope<sup>4</sup> with a volume transport over 75 Sv (1 Sv = 10<sup>6</sup> m<sup>3</sup>/s) and speeds exceeding 2 m/s. It originates near 26°S as a confluence of eddying flows from the Mozambique Channel and East Madagascar Current, as well as inflow from the subtropical Indian Ocean gyre.<sup>1</sup> Beyond the southern tip of the Agulhas Bank, the Agulhas Current retroflects<sup>5-7</sup> with most of its waters feeding back into the south Indian subtropical gyre as the Agulhas Return Current, and 10–20% leaking westward into the adjacent South Atlantic.<sup>2</sup> This leakage occurs through the generation of large warm Agulhas Rings, filaments, and sub-mesoscale processes and by a background flux component at the Agulhas Retroflexion.<sup>8,9</sup> The Agulhas Return Current extends from the Agulhas Retroflexion (~20°E) as far as 75°E,<sup>10</sup> approximately 3300 nautical miles. Its passage east remains largely zonal with meridional excursions related to meanders, some driven by bottom topography, especially in the vicinity of the Agulhas Plateau and South-West Indian Ridge.<sup>10</sup>

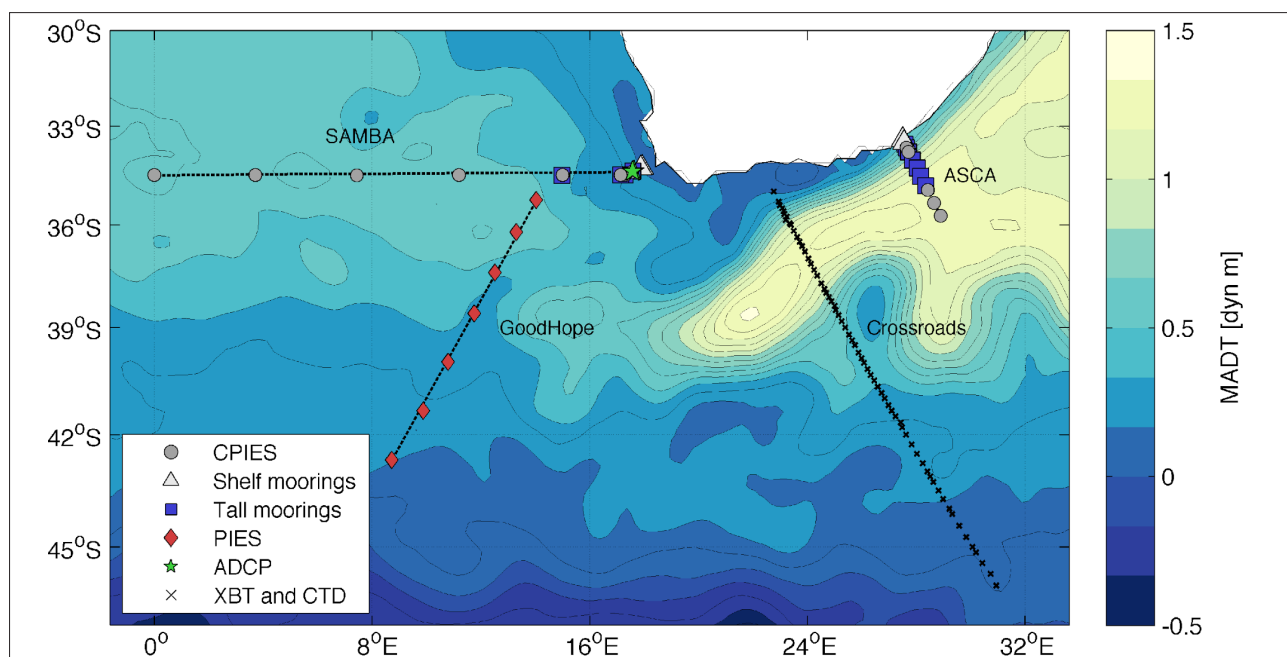
Surface-tracked satellite drifters, Argo floats, autonomous ocean gliders, and satellite remote sensing continue to revolutionise our ability to measure oceanic change. However, the features of the Greater Agulhas Current System are extremely energetic, narrow and deep. Satellite altimeter data are poor close to the coast, alias sub-seasonal signals,<sup>11</sup> and cannot resolve high-velocity shears. Drifters and Argo floats are quickly flushed out of the system into more quiescent waters, and gliders are challenging to control in currents that are ten times faster than their gliding speed. Hence, there is a critical need for long-term sustained measurements from moored instrumental arrays and repeat-hydrographic observations from ships to be able to study the Greater Agulhas Current System to its full depth and resolve subsequent changes over time.

Through the South African Meridional Overturning Circulation (SAMOC-SA) and Agulhas System Climate Array (ASCA) programmes, the South African oceanographic community is taking a global leadership role in such observations, improving our understanding of the oceans around South Africa and their role in future climate change (Figure 2). These programmes are supported locally by the Department of Science and Technology (DST), the Department of Environmental Affairs (DEA), the South African Environmental Observation Network (SAEON), the South African National Antarctic Programme (SANAP), the National Research Foundation and higher education institutions including the University of Cape Town, with international partners in France (the Laboratoire

d'Océanographie Physique et Spatiale (in collaboration with UBO and Ifremer, the French Agence Nationale de la Recherche, and the Ecole Normale Supérieure of Paris), the United States of America (University of Miami's Rosenstiel School of Marine and Atmospheric Sciences and the National Science Foundation) and the Netherlands (Netherlands Institute for Sea Research). Only when these arrays are fully in place and, more importantly, sustained over years to decades, can the scientific community begin to understand and predict changes in the Greater Agulhas Current System and its feedbacks on regional and global climate change, thus providing societal and economic benefits to the general public.



**Figure 1:** The Greater Agulhas Current System, showing the source regions of mesoscale eddies from the Mozambique Channel and East Madagascar Current and the recirculation of Agulhas Return Current, the Agulhas Retroflection and shedding of rings and filaments into the South Atlantic and the relative position of the Subtropical Convergence in the Southern Ocean (after Lutjeharms<sup>1</sup>)



**Figure 2:** The four monitoring arrays and their respective instrumentation – ASCA, Crossroads, GoodHope and SAMBA – plotted on the average absolute dynamic topography for 2015.



## Opportunities

### *ASCA: Volume, heat and salt transports of the Agulhas Current*

The Agulhas System Climate Array (ASCA) is a multi-institutional collaboration designed to provide the first long-term observations of Agulhas Current volume, heat and salt transport and its variability from seasonal to interannual timescales. These measurements will contribute to understanding the response of the Agulhas Current to climate change, as well as its impacts on regional and global climate variability. ASCA consists of nine full-depth moorings equipped with acoustic Doppler current profilers (ADCPs) (Figure 3), single-point current meters and microcats measuring velocity, temperature and salinity, as well as five bottom-mounted current and pressure-sensor equipped inverted echosounders (CPIES), measuring sound speed, pressure and bottom current velocity. Pairs of CPIES are able to estimate temperature, salinity and geostrophic velocity profiles when combined with regional Argo profiles. CPIES offshore of the tall moorings capture the Agulhas Current during offshore meanders, while those below tall moorings enhance water mass measurements over the upper water column where blowdown of the tall moorings is intense.

ASCA extends 300 km offshore along descending TOPEX/Jason satellite ground track #96 and across the core of the Agulhas Current. Six current meter moorings were initially deployed in April 2015 with a small inventory of microcats. In April 2016, these moorings were retrieved and the entire array – including an additional 52 microcats, three additional tall moorings and all five CPIES – was deployed. This work was complemented by 20 full-depth conductivity, temperature and depth casts along the ASCA line in July 2016 during a dedicated SEAmester/ASCA cruise. Other measurements collected during these cruises include vertical and oblique bongo tows, shipborne ADCP transects, surface-tracked satellite drifters, Argo float deployments and glider measurements.

A 34-month time series of moored velocity data, complemented by synoptic hydrographic and shipborne ADCP surveys, was collected along the same transect from April 2010 to February 2013 under the auspices of the US Agulhas Current Time Series Experiment (ACT),<sup>12-14</sup>

and forms the scientific basis of the ASCA project. ASCA, however, reflects an advancement over ACT, with the addition of two coastal moorings to capture shelf-slope exchanges, and microcat sensors to measure temperature and salt transport.

Results from the ACT project show the mean Eulerian current to be 219 km wide, 3000 m deep, with peak surface speeds of 1.8 m/s and a weak equatorward undercurrent at 1200 m along the continental slope.<sup>13</sup> Using a streamwise frame of reference for their calculation, Beal et al.<sup>13</sup> find a mean volume transport of  $84 \pm 2$  Sv ( $1 \text{ Sv} = 10^6 \text{ m}^3/\text{s}$ ), and suggest that the Agulhas Current appears stronger in the austral summer months (December–February). A sustained ASCA array over a period greater than 5 years is needed to provide a robust seasonal cycle, with interannual variability needing a data set greater than 10 years, and decadal variability and climate trends needing 20+ years.

Meander events are found to impact the Agulhas Current less than previously understood<sup>12,14,15</sup> with events occurring less often and having only a small impact on transport. Mesoscale meanders propagate downstream and are robustly linked to eddies from the Mozambique Channel and East Madagascar Current, which impact on the Agulhas Current in its northern reaches.<sup>14</sup> Meanders can cause the core of the Agulhas Current to weaken by  $\sim 70$  cm/s and widen by  $\sim 40$  km, with these two effects offsetting one another so that the southwestward volume transport of the Agulhas Current remains largely unchanged.<sup>12</sup> At the same time, the net Eulerian transport weakens by about 20 Sv as a result of a strong inshore countercurrent during meander events.<sup>12</sup> During meanders, coupling between the Agulhas Current and the atmosphere, together with strong upwelling, acts to cool coastal waters by over 4 °C at the surface.<sup>16</sup> On average, only 1.6 mesoscale meanders propagate through 34°S per year,<sup>15</sup> with two per year measured at 32°S, showing a 20% dissipation of meanders prior to reaching the Agulhas Retroflection.<sup>14,15,17</sup> Approximately 80% of meanders are temporally consistent (within 3–6 months) with ring-shedding events into the South Atlantic Ocean, but cannot be reliably correlated because of the high eddy kinetic energies throughout the retroflection region.<sup>14</sup> With six ring-shedding events per year and only 1.6 meanders, other influences on ring shedding must be considered.



Photo: Jarred Voorneveld

**Figure 3:** Top float deployment, showing the elliptical float and acoustic Doppler current profiler of a tall mooring.

Combining measurements from the ASCA moorings with those from the Crossroads, GoodHope and South Atlantic MOC Basin-wide Array (SAMBA) lines (discussed further below) will shed light on the links between the dynamics of the Agulhas Current and Return Current, and Agulhas Ring shedding and Leakage. Furthermore, the interplay between the Greater Agulhas Current System, regional winds, ocean sea surface temperatures, and coastal upwelling can be explored to advance understanding of their influence on South African rainfall and climate. Preliminary results suggest that ASCA captured a large meander event in 2015, which merged with the Agulhas Return Current, resulting in a suspected early retroflexion of the Agulhas Current. Model studies have suggested that such an event will reduce sea surface temperatures south and west of Africa, which could, in turn, increase rainfall over the continent.

### *Crossroads: The Agulhas Current and its return path*

Current understanding of the co-variability of the southwestward flowing Agulhas Current and the eastward Agulhas Return Current, particularly the difference in fluxes between them, remains incomplete, with knowledge largely based on remote sensing or model outputs.<sup>18</sup> A dedicated monitoring line, critical to studying the long-term trend in the Agulhas Return Current, the nature of its warming, and its impact on local climate south of Africa, began in 2013. This transect, comprising full-depth conductivity, temperature and depth and expendable bathythermograph casts, follows directly under the altimetry track N198 and is currently in its fifth year of data acquisition.

The transect was first initiated as a seismic oceanography study in 2012, north of the Agulhas Plateau, where the Agulhas Return Current meanders around a large anticyclonic eddy. The objective of the work was to establish the origins and pathways of cold water intrusions within strong frontal regions, with results showing the interleaving of warmer, saltier south Indian subtropical waters with colder subpolar waters subducted underneath.<sup>19</sup>

An analysis of the carbonate system of the Agulhas and Agulhas Return Currents<sup>20</sup> shows that the solubility and biological pumps play a minimal role in the drawdown of carbon from the subtropical zone (i.e. Agulhas Current); however, the solubility pump functions for CO<sub>2</sub> drawdown within the sub-Antarctic zone. The most effective CO<sub>2</sub> sink, using both the solubility and biological pumps, occurred within the Agulhas Plateau eddy during an initial CO<sub>2</sub> study in 2013,<sup>20</sup> thus providing a baseline for subsequent long-term measurements.

Given the relatively short data set (2013 to present), the Crossroads transect has already yielded interesting and useful results. The value, however, will lie in determining changes to the established baseline data, and investigating anomalies recorded. One limitation to the long-term study of fluxes and anomalies across this transect is that Crossroads is occupied once yearly on the return passage of the Marion Island Relief Voyage, thus providing only year-on-year changes and no seasonal data. Nevertheless, results from the GoodHope transect, discussed next, have shown the value of data acquired annually in helping to separate natural decadal variability from anthropogenic-induced changes in the region south of Africa.<sup>21</sup>

### *GoodHope: Agulhas Leakage and its influence on the region south of Africa*

The GoodHope transect is an intensive oceanographic monitoring line extending from South Africa to Antarctica, initiated in 2004 and entering its 14th year in 2017. GoodHope was established to study the importance of this region as a conduit for subtropical water masses, which exchange heat and salt between the Indian, Atlantic and Southern Oceans, particularly associated with Agulhas Rings entering the sub-Antarctic zone.<sup>22</sup> The strengths of the GoodHope line are threefold. Firstly, it follows the TOPEX/Jason altimetry track, providing ground-truth measurements for altimetry-derived sea height anomaly data. Secondly, the southern part of this line (south of 50°S) is monitored by a mooring array to investigate the formation of deep and bottom water in the Weddell Sea.<sup>23</sup> Thirdly, the northern section of the GoodHope line is positioned to the west of the Agulhas Retroflexion where it is able to capture rings and leakage transport between the Indian and Atlantic basins.<sup>24,25</sup>

Since the inception of the GoodHope project, over 25 high-resolution repeat expendable bathythermograph transects (two per year), seven full-depth hydrographic transects (five Russian, one French-International Polar Year Bonus GoodHope, and one South African in winter) have been undertaken.<sup>24</sup> Approximately 200 Argo and Bio-Argo floats have been deployed along the GoodHope transect over these last 14 years, that together with satellite data, contribute to the understanding of basin-wide dynamics in the South Atlantic, South Indian and Southern Oceans. These data are improving our knowledge of regional mesoscale dynamics, the ventilation of intermediate water masses, and heat and saltwater exchange south of Africa.<sup>26-28</sup> In addition, the pathways of Indian Ocean waters, advected within Agulhas Rings into the South Atlantic, have been redefined.<sup>25,27-35</sup> These pathways are influenced by topographical features, dividing Agulhas Leakage into northern, central and southern routes. Dencausse et al.<sup>25</sup> show that approximately 23% of Agulhas Rings advect along the southern corridor, across the subtropical front and into the sub-Antarctic zone, undergoing substantial hydrological modifications through increased mixing and high air-sea fluxes as a consequence of the cooler and fresher surroundings.<sup>25,36,37</sup>

An array of ADCPs, PIES and CPIES was deployed along the northern section of the GoodHope transect in December 2014 (Figure 2) to link the GoodHope measurements to the SAMBA (discussed further below). With SAMBA and GoodHope, Agulhas Leakage into the Atlantic Ocean via all three pathways can be monitored.

### *SAMBA: Investigating Agulhas Leakage and its influence on the MOC*

The large meridional gap separating the southern tip of the African continent and the Agulhas Return Current, flowing along the subtropical front, is a crossroads for water mass exchange between the subtropical Indian and South Atlantic gyres. Variations in this exchange, Agulhas Leakage, have been linked to the strength and position of the westerly winds.<sup>38,39</sup> Modelling and palaeoceanographic studies<sup>2</sup> suggest that the Agulhas Leakage is of critical influence on the upper limb of the MOC, with increased leakage bringing more heat and salt into the Atlantic. Observations of rising sea surface temperatures and intensifying westerly winds, together with 20th-century simulations, point to an ongoing increase in Agulhas Leakage in response to anthropogenic forcing.<sup>40,41</sup> This increase may be strengthening the MOC<sup>42</sup> and Atlantic Ocean heat content<sup>43</sup>, at a time when Northern Hemisphere ice melt is predicted to weaken it.<sup>2</sup>

Observing arrays are needed to monitor changes in the Atlantic MOC and improve our understanding of the influence of Agulhas Leakage on climate and climate change. The Atlantic MOC observing system consists of three arrays – two in the North Atlantic monitoring the subpolar and subtropical gyres, and one in the South Atlantic subtropical gyre between Brazil and South Africa.<sup>44</sup> This last array, the South Atlantic MOC Basin-wide Array (SAMBA), is a collaborative initiative between South African, Brazilian, French and US oceanographers.

In September 2013, a network of eight CPIES was deployed in the ocean off Cape Town, initiating the French–South African component of SAMBA. A further eight moorings – two bottom-mounted ADCPs on the shelf edge, two more on the continental slope and four ‘tall’ current meter moorings extending over the deeper continental slope – were deployed in September 2014. The array currently extends from South Africa across the deep abyssal plain to 0°E.<sup>3</sup> Additional ‘tall’ moorings are envisaged at the mid-Atlantic Ridge, contingent upon funding. In the meantime, repeat oceanographic surveys are planned between the African continental shelf and the Greenwich Meridian during each DST/DEA SANAP logistic voyage to Gough Island and annual or semi-annual surveys are planned for the eastern end of the SAMBA line when possible. These observing components complete the basin-wide SAMOC and will provide observations with high temporal sampling to enable estimates of Agulhas Leakage and its long-term contribution to the MOC.<sup>3</sup>

Additionally, the shelf edge and continental slope moorings will contribute knowledge to the limited understanding of the Benguela Jet, critical to fish egg and larval transport between the Agulhas Bank and west coast of South Africa.

### *Dynamics of the Greater Agulhas System through numerical modelling*

Numerical models are a key tool for understanding in-situ observations in a broader dynamical context and there have been many studies attempting to understand the physical controls on the Agulhas Current, its leakage, and its impact on the Atlantic MOC.<sup>9,38,39,45-50</sup>

Studies linking the southern hemisphere westerlies with Agulhas Leakage demonstrate the complexities of the system, with several studies suggesting that a southward shift of the westerlies, and hence the subtropical front, results in an increase in leakage<sup>2,40,41</sup>, whereas more recent studies suggest that intensifying westerlies relate to an increase in leakage<sup>38,51</sup>. It has been further suggested that the leakage is both inversely proportional to Agulhas Current transport<sup>52</sup> and proportional to Agulhas Current transport<sup>41</sup> and that it is decoupled from its transport<sup>39</sup>. Only observations such as ASCA and SAMBA can determine in what dynamical regime the Agulhas system currently resides.

More recently, climate models and ocean reanalysis products have been used to show that subtropical western boundary currents, including the Agulhas Current, may be intensifying and shifting polewards as a result of the long-term effects of global warming. However, these currents are not yet resolved in state-of-the-art climate models, such as those used by the Intergovernmental Panel on Climate Change. Low resolution, lack of ocean measurements, and uncertainties in wind products make these results irresolute.<sup>53</sup> Again, in-situ observations of the real ocean are vital to constrain models and to give a true understanding of oceanic change around South Africa, bringing us full circle to the importance of the SAMOC-SA and ASCA programmes.

Within the South African marine science community, proficiency has been developed with numerical model based coastal and regional oceanographic studies. Coupled with this is the growth of skilled users of satellite-derived marine data and products and algorithm development. It is essential that the standards of physical observational science are maintained at the same skilled level, to enhance our understanding of the Greater Agulhas Current System using all the tools available to us.

### *A call for sustained observations*

South Africa is uniquely positioned globally, between three diverse oceans linked together by the Greater Agulhas Current System and its leakage. Despite the significance of the Agulhas Current regionally and globally, the state of observations and modelling of the oceans south of Africa is not as developed as that of other regions, such as the North Atlantic (Gulf Stream) and North Pacific (Kuroshio Current) western boundary current systems. This underdevelopment can be linked to limited ship availability and on-board equipment, insufficient resources, scarcity of qualified and employed seagoing technical and scientific personnel, and lack of technological innovation for buoys and sensor prototypes suitable for the uniquely energetic conditions of the Agulhas.

Large, natural variability within dynamic western boundary currents, such as the Greater Agulhas Current, obscure longer-term signals such as climate change. Only through sustained in-situ measurements can these signals be untangled. Currently, we have an incomplete picture of the mean state and variability of our sector and surrounds, of its coupling with the atmosphere, and of the exchange between the zonal and meridional fluxes across neighbouring basins. Our observations are limited in space and time and our models do not confidently simulate the complex processes within the Greater Agulhas Current System. For instance, recent observations have shown that the annual cycle of the Agulhas Current is not captured realistically by simulations.<sup>54</sup>

The SAMOC-SA and ASCA projects have begun to fill in these gaps and have the potential to place South Africa as a leader in the international oceanographic research. However, these observations will need to be sustained over decades to fulfil their true potential as 'fingers on the pulse' of South Africa's oceans and their influence on regional and global climates. These observing systems are the key to quantification, physical understanding and long-term monitoring of the Greater Agulhas Current System as the connection between the Indian, Atlantic and

Southern Oceans, and to understanding the importance of our oceans as a potential driver of climate change. Furthermore, SAMOC-SA and ASCA are providing a platform for international collaborations and capacity building which, if sustained, will help train the next generation of South African oceanographers and technicians. For example, in a recent initiative, the SEAmester Floating University programme partnered with ASCA to train students aboard the MV SA *Agulhas II*.<sup>55</sup> Most importantly, these arrays place South Africa at the heart of the international community's Global Ocean Observing System (GOOS), to become a major contributor to future understanding and predictions of climate change.

One of the greatest challenges for researchers in South Africa is the need for strategic organisational integration and cooperation across relevant governmental departments, so that the ambitions of these large mooring arrays can be realised. Both the ASCA and SAMOC-SA programmes are funded in South Africa primarily through DST, with reliance on DEA for ship time, equipment and technical support. The successful operation of these programmes would additionally benefit from efficient consultation, communication and collaboration at the management levels of these government departments. Researchers struggle to understand the complexities of management level procedures needed to raise funds and would benefit from support in this regard. Although it is recognised that there are many unique South African socio-economic challenges (health, poverty, safety, etc.) that compete towards the shrinking fiscus, it is important to recognise that the results emanating from this research provide science-based management advice including information products towards mitigating against natural seaborne disasters. A great effort is thus required to demonstrate the importance and benefits of these observation arrays to the general public in a bid to get full support of management from the government departments currently involved, and where possible, obtain the endorsement from government departments which could benefit from the work, such as the Departments of Agriculture, Forestry and Fisheries, of Energy and of Mineral Resources. Different funding streams must be sought and matched with priority areas to achieve the basic scientific operations on which currently funded research relies, thus demonstrating the usefulness of the results achieved thus far. What is needed are clear and well-structured agreements (MoAs, MoUs and contracts) between the departments and various agencies, characterising the respective commitments and responsibilities to these large programmes as regards personnel, instrumentation, ship time, data processing and management, and the costs thereof.

There are other significant challenges in sustaining these important observational systems for South Africa and for GOOS. Obtaining commitments to the necessary long-term funding is problematic, given the constraint of three-year government funding cycles. The scientific equipment aboard South African research vessels must be more regularly calibrated and better configured in order to attain international standards. To be a partner in GOOS, and to detect the small yet important signals of oceanic variability and change, precision and accuracy are paramount. Finally, technical and scientific staff need to be given long-term roles, responsibilities and dedicated time in these programmes so that they can leverage available international training and collaboration towards building future autonomous capacity for South Africa, thus benefiting South Africa's societal needs. Overcommitment of current technical staff and lack of career opportunities within marine research leads to lack of retention of knowledge and skills for the relevant institutions and organisations and jeopardises the future of these ambitious programmes.

The DST has identified the understanding of ocean dynamics as a key research theme in its 10-year Global Change Research Plan for South Africa. Furthermore, the South African government's National Development Plan and the objectives behind Operation Phakisa (Oceans Economy) identify these very real issues at the heart of South Africa's success in achieving its long-term development goals in the marine sciences and its sustained growth within South Africa and beyond. There is no lack of acknowledgement of the importance and priority at a high level, so the challenge lies in realising this into substantial commitments in terms of funding and institutional cooperation.

The various programmes highlighted in this article have already demonstrated great success in their contributions towards putting in place infrastructure, and more importantly towards training and developing skills and capacity. These programmes have established scientific baselines as well as some initial understanding of the dynamics of the oceans around South Africa. The next level of engagement and commitment, which has been inadequate in previous programmes, is to convert the data and information emanating from such initiatives into knowledge products that are readily available to the general public of South Africa, and the region, thus giving the programmes even more prominence and in turn attracting new and continued funding from private and public entities. With formal integration and cooperation of all partners involved, the work can be amplified significantly and make South African marine science a force to be reckoned with.

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## Authors' contributions

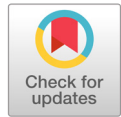
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# Wind speed characteristics and implications for wind power generation: Cape regions, South Africa

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Spatio-temporal dynamics of near-surface wind speeds were examined across the Northern, Western and Eastern Cape regions of South Africa. The regions assessed were geographically subdivided into three zones: coastal, coastal hinterland and inland. Wind speed data (10 m) were evaluated at monthly, seasonal, annual and zonal resolutions, with the aim to establish wind speed attributes and trends. Data from 19 weather stations with high-resolution wind records between 1995 and 2014 were evaluated. The majority of stations (79%) recorded a decrease in mean annual wind speed over the study period. The mean rate of decrease across all stations over the 20-year period equates to -1.25%, quantifying to an annual decrease of -0.002 m/s/year (-0.06% pa). The largest seasonal decline of -0.006 m/s/year (-0.15% pa) was recorded in summer. Statistically significant declines in mean annual wind speed are somewhat more pronounced for the coastal zone (-0.003 m/s/year, -0.08% pa) than over interior regions (-0.002 m/s/year, -0.06% pa) for the study period. The largest decrease (-0.08% pa) was recorded for the coastal zone, followed by the inland zone (-0.06% pa), equating to an annual reduction in available energy of 0.18% pa and 0.09% pa, respectively. When considering all stations over the study period, the mean inter-annual variability is 3.11%. Despite such decreases in wind speed, the variance identified in this study would not have posed any risk to power generation from wind across the assessed stations, based on the period 1995 to 2014.

## Significance:

- Mean recorded wind speed decreases have been marginal under recent (last 20 years) climatic conditions and change, thus adding confidence to the justification by the South African government to procure additional wind-generated electricity capacity.
- Wind speed trends and variance measured over the research period (1995–2014) for the Cape stations in this study, would not have posed any risk to power generation from wind.
- Only four stations (28.6%) recorded statistically significant trends at the 0.05% level; of these 75% were decreasing trends.
- Coastal zones recorded a statistically larger decrease in mean wind speed compared to inland regions.
- When considering all stations over the period 1995–2014, the mean inter-annual variability is 3.11%.

## Introduction

Despite uncertainty in forecasting wind speed and variance over time, wind power generation is the fastest growing form of renewable energy, and thus such forecasts are important considerations for the renewable energy sector. Globally, wind energy generation has been growing at a rapid rate over the past few years, with ~370 GW of installed capacity, and growth rates in excess of 15% per annum.<sup>1</sup> It is thus pertinent to evaluate recent South African surface wind trends in the context of wind energy generation. To this end, information relating to recent near-surface wind trends can be applied in various fields of interest, such as pollen dispersal alerts, wind erosion in agricultural settings, building engineering, and the design of wind farms. South Africa is a developing country with limited capacity to generate sufficient energy, thus the importance of establishing renewable energy sectors (solar and wind in particular). Given the global uptake of alternative energy generation, such as wind power generation, the South African government initiated the procurement of wind power in 2011 from independent power producers, aimed at diversifying and expanding South Africa's electricity generation.<sup>2,3</sup> South Africa recorded its first wind-generated electricity from independent power producers incorporated into the national grid at the end of 2013. This generation had reached 1212 MW by the end of 2015, which equates to 2.66% of the national installed power capacity.<sup>4</sup> The projected outlook would see up to 4360 MW (approximately 5% of national power capacity) of wind generation installed by 2030.<sup>5</sup> This substantial uptake in energy generation from wind requires some understanding of wind variability and trends in the South African context, so as to quantify the potential impact of wind variability and/or change over a 20-year power purchase agreement term.

The most remarkable characteristic of wind is its inherent variability, both geographically and temporally. Wind speed is a function of the atmospheric pressure gradient, with the ultimate driver being the sun. Varied heating of the earth results in global circulation patterns with Coriolis forces fundamentally driving large-scale motion of the air. Wind variability at a regional scale is strongly influenced by micro-scale, meso-scale and synoptic-scale factors such as topography, water bodies (e.g. oceans, lakes) and land use. Wind variability is thus an essential indicator of atmospheric circulation. As part of an international effort to quantify climate and related circulation changes, several studies have focused specifically on wind speed variance.<sup>6-9</sup>

Studies from around the world have found variable trends in mean wind speeds over the last few decades. For instance, studies in Turkey (1975 to 2006), Brazil (1986 to 2011), China (1969 to 2005) and Canada (1940 to 2006) found that most stations were experiencing a decrease in seasonal and annual mean wind speed.<sup>10-13</sup> In

contrast, wind speed trends have increased in several other regions such as over the global oceans and the Baltic region.<sup>11,14</sup> Most such changes were strongly linked to fluctuations in synoptic-scale circulation.<sup>15</sup> Several studies in South Africa have evaluated and quantified wind distribution and frequency.<sup>16-19</sup> A recent study statistically assessed wind speed distribution and power density in Port Elizabeth and concluded that average wind power density is highest during spring (September–October) and lowest during autumn (April–May).<sup>20</sup> Kruger<sup>21</sup> considered the impact of wind power on the South African built environment and suggested that the strong wind climate of South Africa is similar to that of southern South America and Australia, with the primary, strong wind-producing mechanisms being thunderstorms and extratropical cyclones. However, there is still a research gap with respect to identifying wind speed trends and associated impacts on wind energy generation in southern Africa, and the Cape region in particular. We thus aimed to address this gap by analysing recent (1995–2014) South African wind speed data in the Cape regions, with the intention to establish recent spatio-temporal trends and variability.

### Data and methods

Wind speed data from 19 stations across the Western, Eastern and Northern Cape Provinces of South Africa, covering the years 1995–2014, were obtained from the South African Weather Service. The research period was limited to years for which data were available across all stations. Stations are distributed across the study region, as indicated in Figure 1. Wind speed measurements were taken 10 m above ground surface, at 5-min intervals. The quality control procedure evaluated data continuity to determine potential external effects on station data.

Data uniformity checks were undertaken to minimise potential data errors. Given that considerable inhomogeneity was detected, 5 of the 19 data sets were completely disregarded, thereby reducing the number of

stations considered to 14. External factors identified to have influenced such station records include station relocation, tree growth or removal, and urbanisation. The data recovery rate was 98.06% for the 14 stations, with a standard deviation of 1.7%; imputed values replaced missing records. Given that it is near impossible to obtain homogeneous wind records, several previous studies have used a similar quality control approach to assess wind speed data, as that applied in our study.<sup>22-24</sup>

### Statistical evaluation

Descriptive statistics calculated for wind speed data include standard deviation ( $SD = \sqrt{\frac{\sum(x-\bar{x})^2}{N-1}}$ ), mean, minimum and maximum values to provide a range of wind speeds over the 20-year period. Daily mean wind speed data were consolidated into monthly, seasonal and annual means, thereby permitting trend analyses and the proportional variance to be ascertained over the study period. The locality of each station is placed within one of three geographic zones, namely coastal zone (0–10 km from shoreline), coastal hinterland zone (10–60 km from shoreline) and inland zone (> 60 km from shoreline). The proportional variation of the mean wind speed for each station was calculated at monthly, seasonal and annual zonal resolutions (for the period 1995–2014), and linear regression methods were applied to the data. The least squares approach was applied to fit the linear regression, as is widely applied.<sup>25-27</sup> The regression analyses indicate that four of the stations (EC3, NC6, WC3 and WC4) record statistically significant trends, with only EC3 recording an increasing trend, while the remaining stations record an insignificant trend at a 5% significance level.

### Results

Although a 20-year period is insufficient to establish conclusive changes in wind associated with climate change, the record is nevertheless able to provide tentative comparison of the data sets and indicate mean wind speed variance and trends over the last 20 years for the Cape regions.

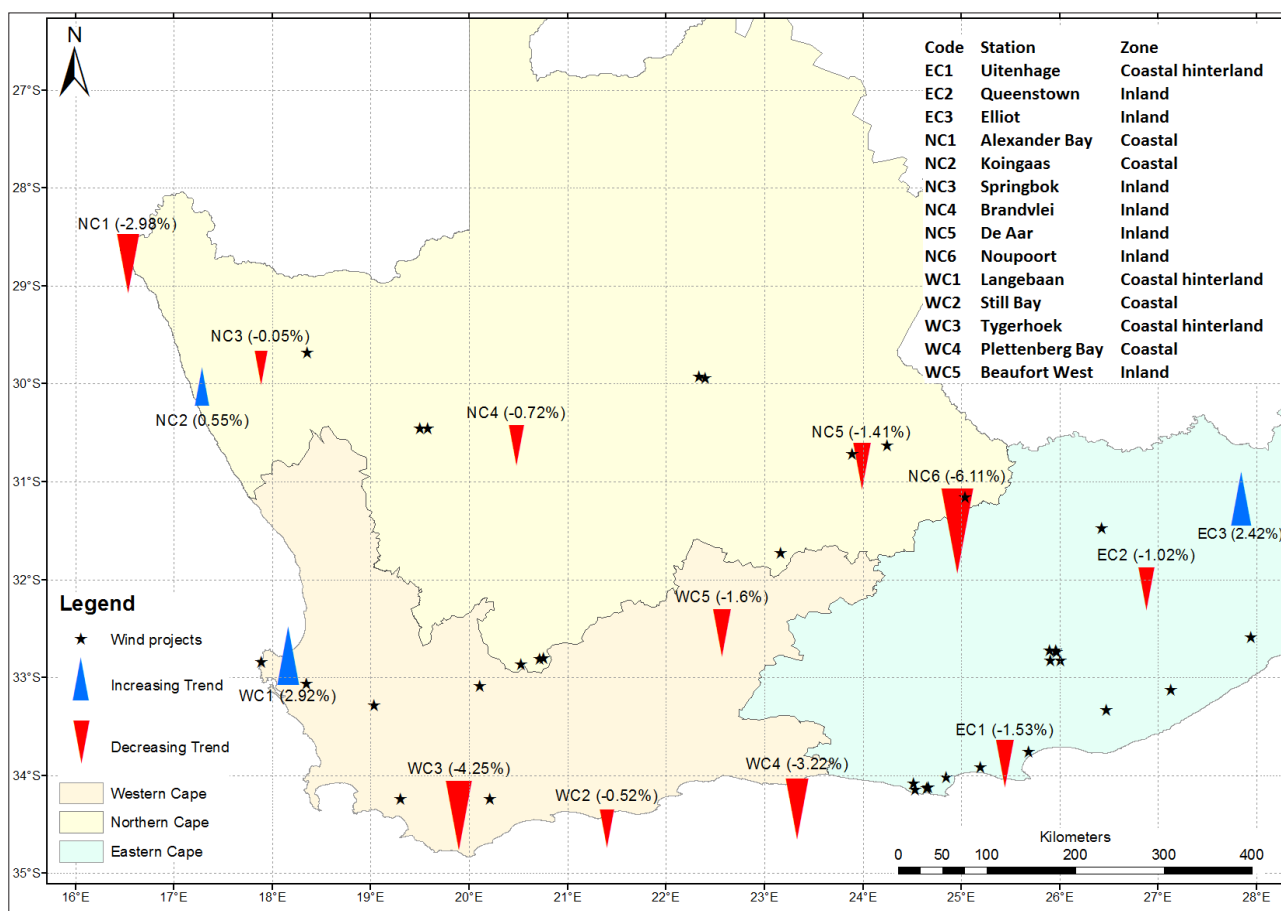


Figure 1: Mean short-term wind speed trends (1995–2014) mapped for the Northern, Western and Eastern Cape regions of South Africa.

Given that the standard term of a wind power purchase agreement is 20 years, this period will allow a better understanding of potential wind speed variance and change over such a period of time for the stations concerned.

**Statistical characteristics**

When considering the Beaufort wind scale which is an empirical measure of observed wind speed, all 14 wind stations fall into one of two categories: 'light breeze' or 'gentle breeze'. Five (36%) stations had mean conditions constituting a 'light breeze' (1.6–3.3 m/s), while the remaining nine (64%) stations had mean conditions constituting a 'gentle breeze' (3.4–5.4 m/s) (Table 1). Thus, stations overall fall within the 'moderate' wind range, with highest speeds in the Northern Cape and 'light breeze' conditions being more typical to the Western and Eastern Cape regions.

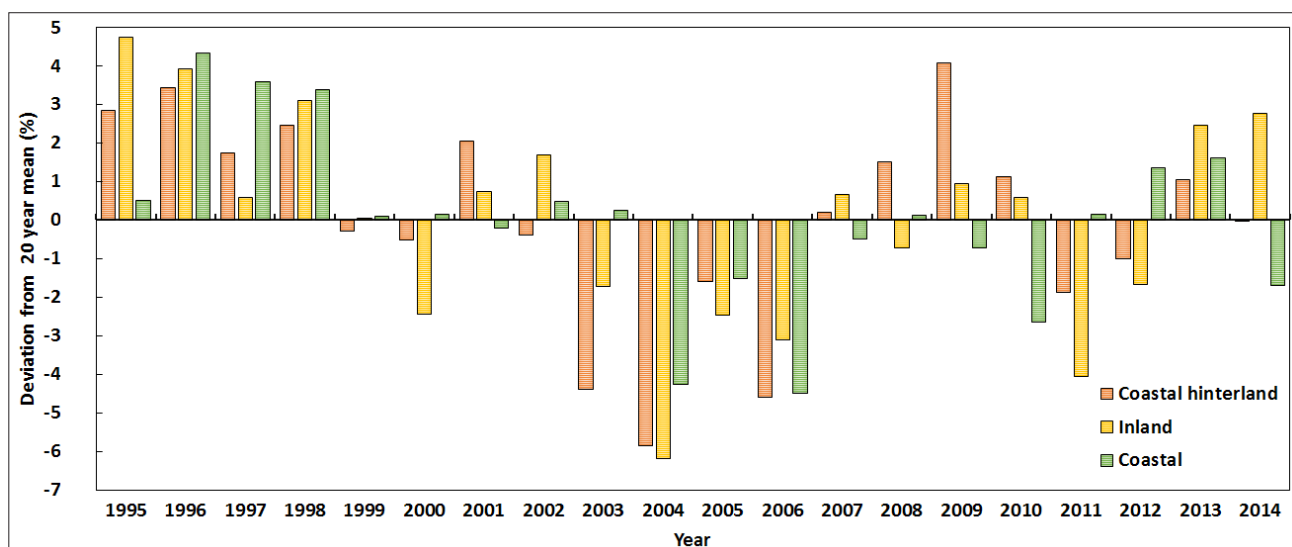
For the study period (1995–2014), mean annual wind speed across the 14 stations was 3.79 m/s, but varied considerably from 5.13 m/s

at Koiingaas (coastal zone; Northern Cape) to 2.51 m/s at Tygerhoek (coastal hinterland; Western Cape). Alexander Bay (coastal zone; Northern Cape) has the highest inter-annual standard deviation of 0.91 m/s, while Plettenberg Bay (coastal zone; Western Cape) has the lowest at 0.33 m/s. The highest average monthly wind speed (7.53 m/s) was recorded at Koiingaas for December 2005, while the lowest (1.62 m/s) was recorded at Tygerhoek for June 2003 (Table 1).

Notably, all three zones (coastal, coastal hinterland and inland) recorded decreasing mean annual wind speeds over the observation period. The coastal zone recorded the largest decrease (-0.06 m/s, -1.54%), followed by the inland zone (-0.05 m/s, -1.21%) and finally the coastal hinterland zone (-0.03 m/s, -0.95%). The Eastern Cape inland zone is the only region which recorded an increasing mean annual wind speed over the observation period (0.02 m/s, 0.7%), but this increase is statistically insignificant at the 0.05% level (Figures 2 and 3).

**Table 1:** Wind speed statistics for various Cape stations (1995–2014)

Code	Station	Zone	Mean monthly (m/s)	Max monthly (m/s)	Min monthly (m/s)	Standard deviation (m/s)	p-value	Statistically significant trends
EC1	Uitenhage	Coastal hinterland	3.14	4.22	2.10	0.42	0.39	No
EC2	Queenstown	Inland	3.24	4.52	2.09	0.50	0.62	No
EC3	Elliot	Inland	3.12	5.08	1.97	0.50	0.03	Yes
NC1	Alexander Bay	Coastal	4.36	6.63	2.55	0.91	0.25	No
NC2	Koiingaas	Coastal	5.13	7.53	2.56	0.70	0.60	No
NC3	Springbok	Inland	4.48	6.73	3.51	0.49	0.88	No
NC4	Brandvlei	Inland	3.62	4.76	2.34	0.56	0.72	No
NC5	De Aar	Inland	4.66	6.29	3.28	0.68	0.51	No
NC6	Noupoort	Inland	3.88	5.50	2.25	0.73	0.01	Yes
WC1	Langebaan	Coastal hinterland	3.89	5.70	2.33	0.73	0.17	No
WC2	Still Bay	Coastal	3.67	4.56	2.85	0.38	0.97	No
WC3	Tygerhoek	Coastal hinterland	2.51	3.53	1.62	0.40	0.02	Yes
WC4	Plettenberg Bay	Coastal	3.23	4.11	2.10	0.33	0.01	Yes
WC5	Beaufort West	Inland	4.14	5.47	2.87	0.47	0.36	No



**Figure 2:** Mean annual wind speed variance per zone, based on mean annual short-term trends between 1995 and 2014.



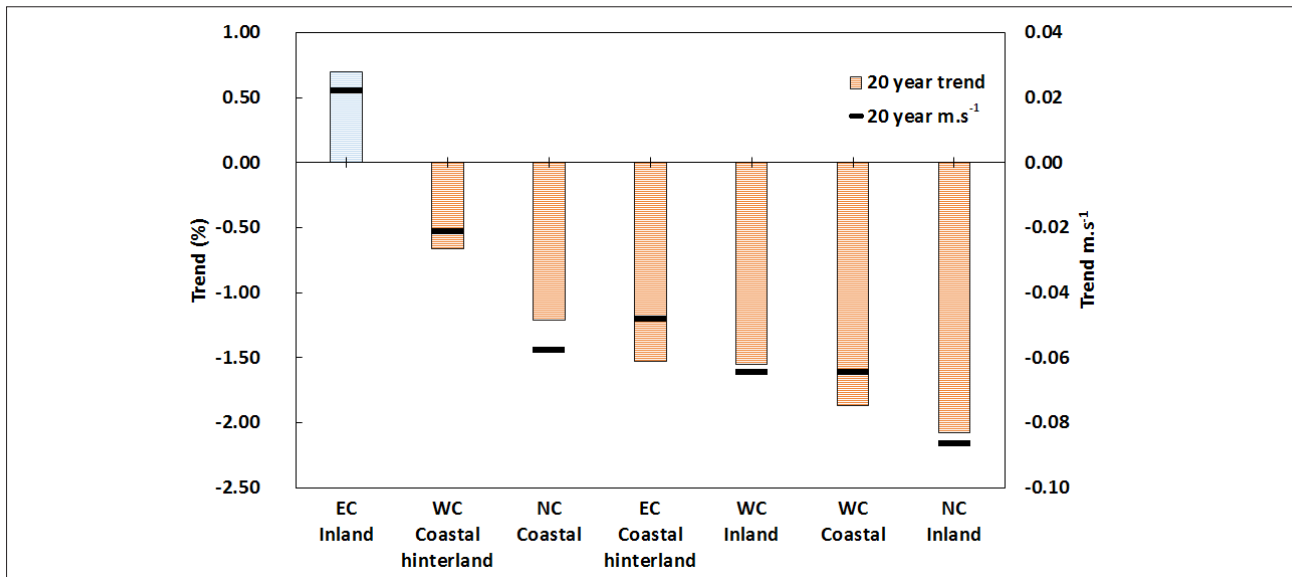


Figure 3: Mean wind speed trends per zone, based on mean short-term trends between 1995 and 2014.

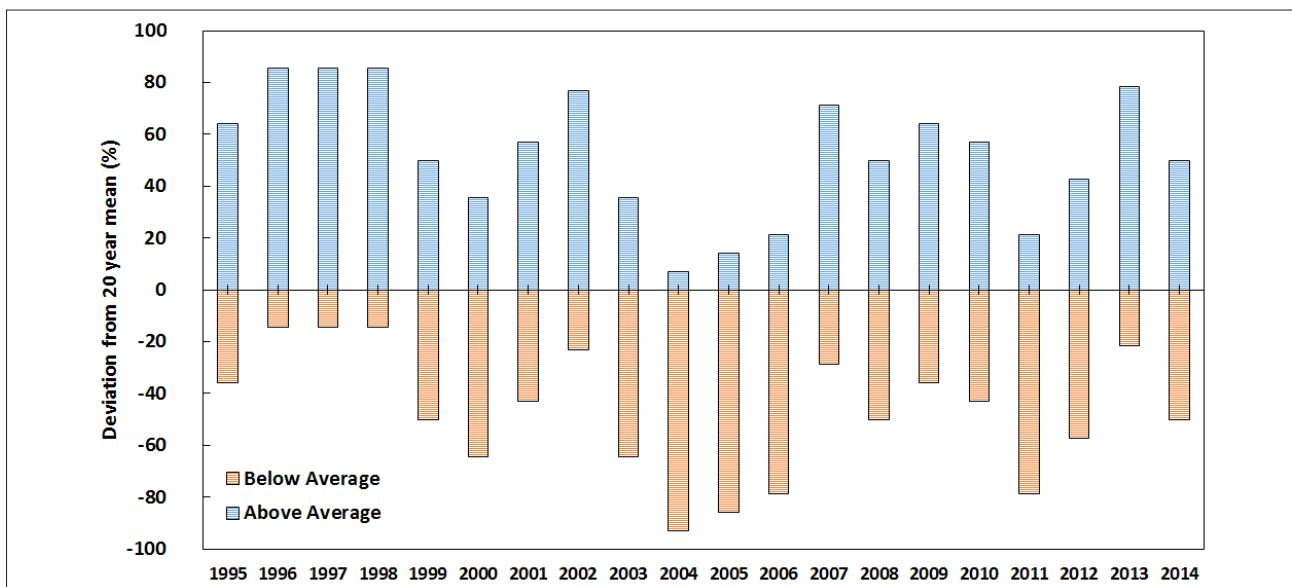


Figure 4: Deviation from mean wind speeds for the period 1995–2014.

### Monthly, seasonal and annual trends

Mean annual wind speed generally decreased for the 14 stations over the period 1995–2014. Although a mean loss of  $-0.05$  m/s ( $-1.25\%$ ) in annual wind speed is evident over the 20-year period, some stations (e.g. WC1, NC2 and EC3) experienced increasing trends (Figure 4). For the stations included in this study, both decreasing (79%) and increasing (21%) trends were recorded (Figure 1). Langebaan recorded the highest increasing trend of  $0.12$  m/s ( $2.9\%$ ), while Noupooort recorded the highest decreasing trend of  $-0.24$  m/s ( $-6.1\%$ ). Decreasing trends (11 stations) average  $-0.08$  m/s ( $-2.1\%$ ), while the increasing trends (3 stations) average  $0.07$  m/s ( $2\%$ ).

Over the 20-year period, mean increasing seasonal wind speeds were recorded for autumn ( $0.11$  m/s,  $2.87\%$ ) and winter ( $0.06$  m/s,  $1.49\%$ ). In contrast, mean decreasing wind speed trends were recorded for summer ( $-0.11$  m/s,  $-2.93\%$ ) and spring ( $-0.09$  m/s,  $-2.27\%$ ). The inland zone recorded the highest mean seasonal increase ( $0.12$  m/s,  $3.1\%$ ) during autumn, while the coastal hinterland zone recorded the highest mean decrease ( $-0.13$  m/s,  $-4.0\%$ ) during summer. Regionally, inland areas of the Eastern Cape recorded the highest increase ( $0.16$  m/s,  $4.9\%$ ) during autumn, while the Northern Cape coastal region recorded the largest decrease ( $-0.23$  m/s,  $-4.9\%$ ) during summer (Figures 5 and 6).

Over the 20-year period, mean annual wind speed trends were between  $-0.012$  m/s/year ( $-0.31\%$  pa) for Noupooort and  $0.006$  m/s/year ( $0.15\%$  pa) for Langebaan, with a mean decrease across all stations of  $-0.002$  m/s/year ( $-0.06\%$ ). The seasonal mean wind speed trends ranged from  $-0.016$  m/s/year ( $-0.36\%$  pa) recorded in summer, to  $0.011$  m/s/year ( $0.26\%$  pa) recorded in winter, both at Alexander Bay. Across all stations, mean seasonal wind speeds decreased by the highest margin ( $-0.006$  m/s/year;  $-0.15\%$  pa) during summer.

For the 20 years assessed, 71% of stations recorded a decreasing mean wind speed trend ( $-0.004$  m/s/year,  $-0.1\%$  pa), while 29% recorded increasing mean trends ( $0.004$  m/s/year,  $0.1\%$  pa). At a monthly scale, stations recorded a mean decrease of  $-0.0016$  m/s/year ( $-0.043\%$  pa) for September through February, and a mean increase of  $0.001$  m/s/year ( $0.035\%$  pa) for March through August. The strongest mean decreasing trend of  $-0.0023$  m/s/year ( $-0.06\%$  pa) was recorded in January, while the strongest mean increasing trend of  $0.002$  m/s/year ( $0.06\%$  pa) was recorded in May. A high percentage (86%) of stations recorded increasing wind speed trends during the autumn and winter months of March to August, while most stations (93%) recorded decreasing trends during the spring and summer months of September to February (Figure 7).

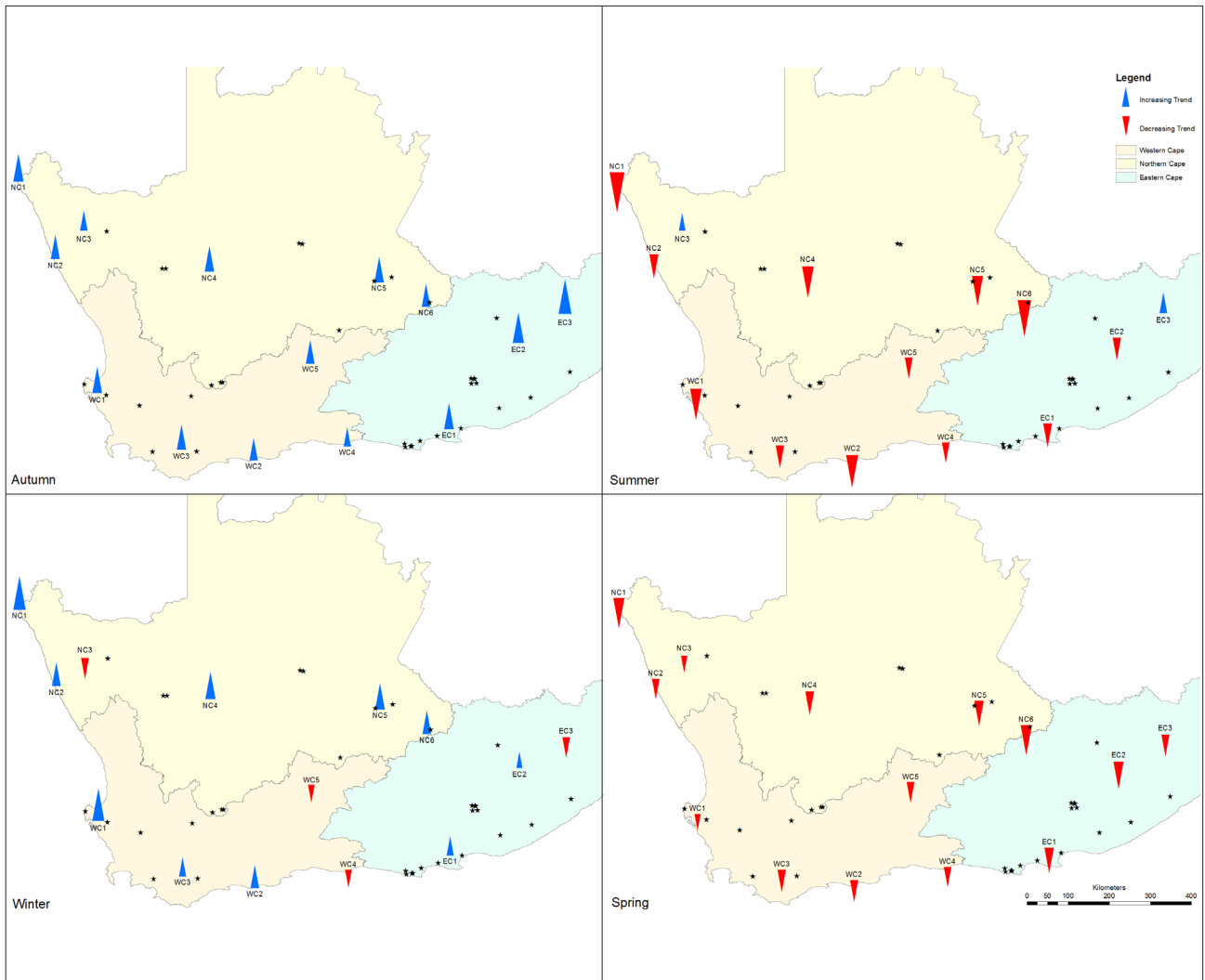


Figure 5: Map of seasonal wind speed trends for the period 1995–2014.

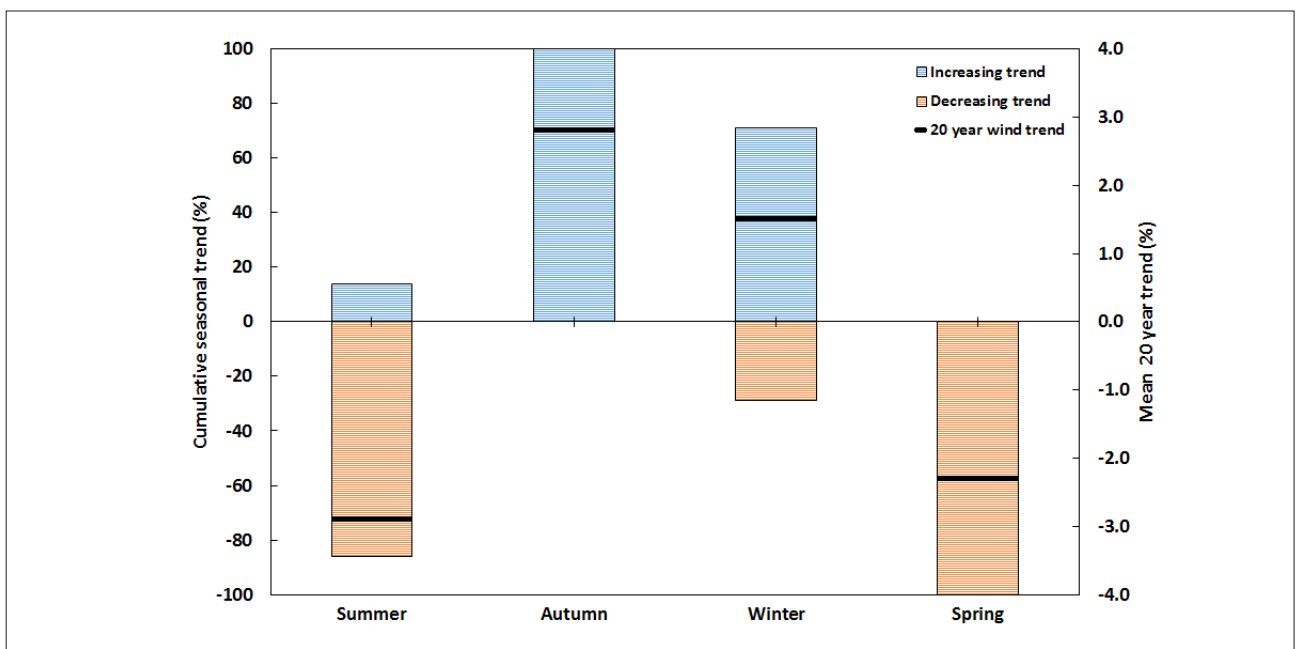


Figure 6: Mean seasonal wind speed trends for the period 1995–2014.

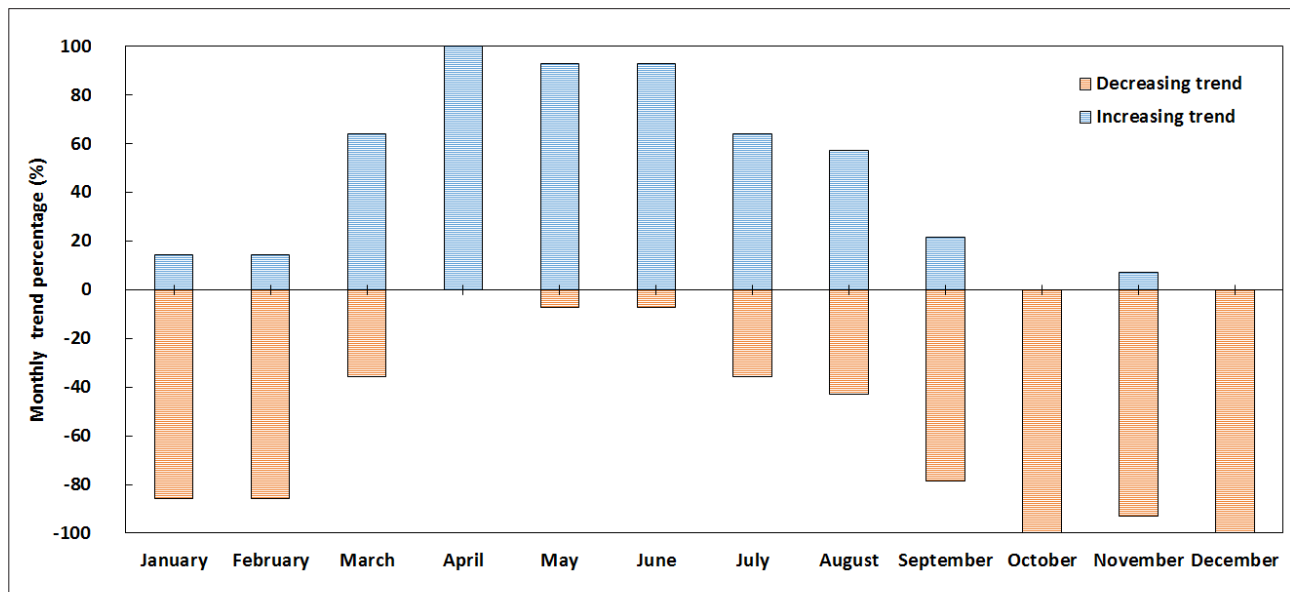


Figure 7: Mean monthly wind speed trend for the period 1995–2014.

All three geographic zones recorded mean decreasing wind speed trends; the coastal zone recorded the largest mean decrease (-0.06 m/s, -1.54%) followed by the inland zone (-0.05 m/s, -1.21%) and finally the coastal hinterland zone (-0.03 m/s, -0.95%). The Northern Cape inland region recorded the largest decrease (-0.09 m/s, -2.07%) of all the study regions over the study period, which equates to an annual decrease of -0.004 m/s/year (-0.10% pa). In contrast, the Eastern Cape inland region is the only region that recorded increases in mean wind speed (-0.001 m/s/year, -0.04% pa), but these increases are statistically insignificant at the 0.05% level (Figures 2 and 3).

A key aspect to consider for wind power is inter-annual variability in wind speed. The Eastern Cape stations recorded the highest mean inter-annual variance (4.3%), followed by the Western Cape (3%) and finally the Northern Cape (2.7%). When considering all stations over the study period, the mean inter-annual variability is 3.11%; the Northern Cape inland region of Brandvlei recorded the lowest inter-annual variability of 1.79%, while the Eastern Cape coastal hinterland region of Queenstown recorded the highest at 4.72%. Across all stations, the lowest mean inter-annual variability (1.93%) was recorded between 2001 and 2002, while the highest (4.31%) was recorded between 2006 and 2007. The largest inter-annual variability (12.64%) was recorded between 2003 and 2004 at the Northern Cape inland region of Noupoort.

## Discussion

Changes in near-surface wind speed at various temporal scales may have several implications. A key impact in the South African context includes energy generation. Electricity generated from wind is derived from a well-known scientific mathematical expression ( $P = \frac{1}{2} \rho C_{dp} A V^3$ ), which implies that when wind speed is doubled or halved, available energy respectively increases or decreases eight-fold.<sup>28</sup> Over the 20-year period, all three zones recorded a decrease in mean wind speed, with the coastal zone recording the largest decrease (-0.06 m/s, -1.54%), followed by the inland zone (-0.05 m/s, -1.21%) and coastal hinterland (-0.03 m/s, -0.95%) (Figure 2). These decreases equate to a reduction in available energy of 3.7%, 1.8% and 0.9%, respectively. According to McVicar et al.<sup>29</sup>, studies with more than 30 stations and in excess of 30 years of data have recorded a mean wind speed decrease of -0.001 m/s pa, which equates to a decrease of -0.028 m/s over a 20-year period.

Between 1979 and 2008, several regions globally recorded average decreasing wind speed trends, including Europe (-0.01 m/s/year),

North America (-0.007 m/s/year), Central Asia (-0.016 m/s/year), South Asia (-0.008 m/s/year) and East Asia (-0.012 m/s/year).<sup>30</sup> In Africa, both increasing and decreasing wind speed trends have been recorded over the last 65 years (Table 2). For instance, Niger records the largest increasing trend of 0.065 m/s/year (one station, 11 years data), while Cameroon records the largest decreasing trend of -0.2 m/s/year (one station, 5 years data). The results of this study place the Cape regions of South Africa within a marginally decreasing wind speed trend of -0.002 m/s/year (-0.06% pa) over the past 20 years (equating to a mean decrease of -0.5 m/s, -1.25%), quantifying to a decrease in available energy of 1.95%. This decreasing trend does not pose any immediate risk to wind power projects in the Cape regions of South Africa. The allowance for inter-annual variability in a forecast energy yield model would account for any potential decrease of this nature.

## Summary

This assessment confirms that mean regional near-surface wind speeds are insignificantly declining at 10 Cape stations at an average rate of -0.002 m/s/year (or -0.05 m/s over the 20-year study period from 1995 to 2014). Only four stations (28.6%) recorded statistically significant trends at the 0.05% level; of these 75% were decreasing trends. Coastal zones recorded a statistically larger decrease in mean wind speed compared to inland regions. When considering seasonal wind speed trends over the study period, decreasing trends were recorded in summer and spring and increasing trends were recorded in winter and autumn. Wind speed trends and variance measured over the research period (1995–2014) for the Cape stations in this study, would not have posed any risk to power generation from wind. As has been quantified, mean recorded wind speed decreases have been marginal under recent (last 20 years) climatic conditions and change, thus adding confidence to the justification by the South African government to procure additional wind-generated electricity capacity.

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## Authors' contributions

M.W. performed the research, analysed the data and wrote the paper; S.G. performed key editorial reviews and provided research guidance.

**Table 2:** Recent wind speed trends for various African sub-regions

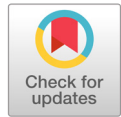
Country	Number of sites	Coordinates	Period	Trend (m/s/year)	Reference
Niger	1 site	13°N, 2°E	1984–1994	0.064	31
Tanzania	1 site	9°S, 35°E	2001–2005	0.063	32
Nigeria	2 sites	11–12°N, 11–13°E	1969–1982	0.046	33
Egypt	1 site	24°N, 33°E	1995–2003	0.043	34
Algeria	22 sites	28–37°N, 2–15°E	1973–2003	0.005	35
Atlantic Coast	24 sites	15°S–21°N, 23°W–14°E	1955–1985	0.005	36
Mauritania and Senegal	4 sites	14– 21°N, 15–17°W	1951–1994	0.001	37
Kenya	1 site	1°S, 37°E	1979–2008	-0.002	30
South Africa	19 sites	28–35°S, 16–28°E	1995–2014	-0.002	This study
North Africa	150 sites	10–37°N, 15°W–55°E	1973–2003	-0.014	38
Ethiopia	1 site	7°N, 39°E	1973–2003	-0.022	39
Cameroon	2 sites	7–9°N, 13°E	1990–1999	-0.029	40
Libya	1 site	33°N, 13°E	1993–2002	-0.087	41
Algeria	8 sites	24–37°N, 0–8°E	2002–2006	-0.091	42
Libya	1 site	33°N, 12°E	1979–1988	-0.116	43
Ghana	1 site	11°N, 0°E	2001–2005	-0.200	44
Cameroon	1 site	10°N, 14°E	1991–1995	-0.200	45
Cameroon	1 site	10°N, 14°E	1991–1995	-0.240	46

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# Extreme 1-day rainfall distributions: Analysing change in the Western Cape

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Severe floods in the Western Cape Province of South Africa have caused significant damage to property and infrastructure over the past decade (2003–2014). The hydrological design criteria for exposed structures and design flood calculations are based mostly on the implicit assumption of stationarity, which holds that natural systems vary within an envelope of variability that does not change with time. This assumption was tested by examining the changes in extreme 1-day rainfall high percentiles (95th and 98th) and both the 20- and 50-year return period rainfall, comparing the period 1950–1979 against that of 1980–2009 across the province. A generalised Pareto distribution and a peaks-over-threshold sampling approach was applied to 76 rainfall stations across the province. Of these stations, 48 (63%) showed an increase in the 50-year return period 1-day rainfall and 28 (37%) showed a decrease in the 1980–2009 period at the 95th percentile peaks-over-threshold. At the 98th percentile peaks-over-threshold, 49 stations (64%) observed an increase and 27 (36%) a decrease for the later period. The change in the number of 3-day storms from the first to the second period is negligible, evaluated at 0.9% and 0.5% at the 95th and 98th percentile peaks-over-threshold levels, using cluster analysis. While there is no clear spatial coherency to the results, the general trend indicates an increase in frequency of intense rainfalls in the latter half of the 20th and early 21st centuries. These results bring into question assumptions of stationarity commonly used in design rainfall.

## Significance:

- 63% of analysed rainfall stations in the Western Cape display an increase in 20- and 50-year 1-day rainfall extremes.
- The results challenge the current assumptions of climate stationarity made in design rainfall estimations.
- We propose an alternative methodology to rainfall extremes analysis for design flood estimation.
- The methods employed can be replicated by future studies in other regions.

## Introduction

Katz et al.<sup>1</sup> state that ‘it is the unusual disturbances that have disproportionate effects on ecosystems’. This view can be extended to economic infrastructure. From 2003 to 2014, the Western Cape Province of South Africa (Figure 1) has been affected by severe storms occurring almost annually, which cause substantial damage to economic infrastructure and farmlands.<sup>2,3</sup> These severe floods, caused mostly by intense rainfall resulting from cut-off low weather systems, resulted in damage equating to at least ZAR4.9 billion (Table 1).<sup>2,3</sup>

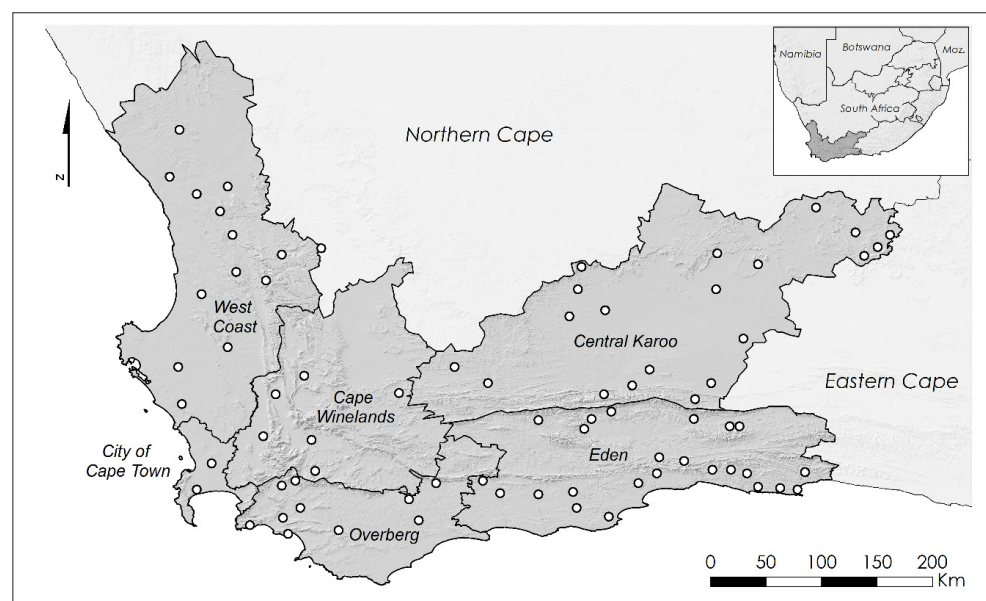


Figure 1: The Western Cape Province of South Africa showing the location of the 76 rainfall stations included in the study.

**Table 1:** Financial and human losses as a result of extreme flood events in the Western Cape (2003–2014)

Date	Location: Municipalities and districts	Deaths	Displaced people	Financial losses (–ZAR million; 2010 ZAR)
2003 March	Montagu (town)	3	>3000	343
2004 December	Eden			83
2005 April	Overberg and Karoo	5	1600	13
2006 August	Southern Cape			691
2007 June	West Coast	2	2400	160
2007 November	Overberg, Eden and Cape Winelands			1192
2008 July	West Coast			82
2008 November	Cape Winelands, Overberg, Eden and Langeberg	2		1139
2011 June	Cape Winelands, Central Karoo, Eden and Overberg	1	>1400	348
2012 July–August	Eden, Central Karoo and Cape Winelands	6	>2000	378
2013 November	Cape Winelands, Eden and Overberg	2	>19 000	168
2014 January	Central Karoo, Eden and Overberg	7		466

Sources: Holloway et al.<sup>2</sup> and Pharoah et al.<sup>3</sup>

Whether this damage arises as a result of changes in the frequency and intensity of extreme rainfall, or of human intrusion into hazardous areas and land-use change is unknown. Unfortunately, financial loss records are sparse prior to the initial analysis done by Holloway et al.<sup>2</sup>, making analysis of prior losses difficult. However, extreme rainfalls are the predominant drivers of flood risk and concerns of increases in the frequency and/or intensity of extremes have been raised across the world.<sup>4</sup>

Although national and provincial roads as well as hydraulic structures are designed for appropriate design lives,<sup>5</sup> the probabilistic estimation methods (through the use of the annual maximum series) of these design floods are based on the assumption of stationarity of the rainfall regime. Stationarity is a theory that natural systems vary within an envelope of variability that does not change with time. This is a foundational concept that is prevalent throughout hydrological engineering practice.<sup>6</sup> However, flood levels for given return periods are known to be increasing in some places in the world<sup>7</sup>, and are possibly decreasing in other parts, which may be a result of changing rainfalls in these regions<sup>8</sup>. A limitation to the estimation of reasonably accurate return period rainfalls is that it requires long records (multi-decadal) of high-quality data.<sup>7</sup> Unfortunately, in many areas, the length of the data record is limited and the possibility of a non-stationary climate is largely ignored.<sup>6</sup> The design of hydraulic structures and determination of design flood-levels therefore assumes that weather events are independent outcomes of a stationary climate.<sup>6</sup> It is, however, evident that the climate is changing in some places<sup>9</sup> and that the concept of stationarity is no longer an appropriate assumption, which potentially renders the design capacity of hydraulic structures inappropriate for the evolving conditions. We examined the stationarity of rainfall extremes for the historical rainfall record of 76 rainfall stations in the Western Cape Province (Figure 1) and, using appropriate statistical analytical processes, tested whether change is indeed occurring.

## Previous studies examining changes in South African rainfall

Various previous studies have been undertaken to investigate the changing frequency and intensity of extreme rainfalls in South Africa. Mason et al.<sup>10</sup> found significant changes in rainfall over 70% of South Africa, except in parts of the winter rainfall region (the Western Cape) for two periods: 1931–1960 and 1961–1990. According to their analysis, the intensity of the 10-year rainfall events had increased by

10% over much of the country except in the northeast (Limpopo and Mpumalanga Lowveld and the eastern Highveld), northwest and the winter rainfall region (Western Cape). However, the density of the rain gauge network used in the study was low for those areas, indicating declines in maximum rainfall intensity.

Easterling et al.<sup>11</sup> found significant increases in heavy rainfall frequency over the thresholds of 25.4 mm and 50.8 mm for southwestern South Africa (the Western Cape) and parts of KwaZulu–Natal, respectively. The frequencies of these events were estimated to increase at 5.5% and 4.1% per decade, respectively. Richard et al.<sup>12</sup> discovered an increase in rainfall in the southeastern part of the country in a review of time series rainfall data, while Groisman et al.<sup>13</sup> showed an increase in frequency of very heavy rainfalls between the periods 1901–1910 and 1931–1997 for most of South Africa for those rainfalls equal to or above the 99.7 percentile (the upper 0.3%). Their data set was spatially differentiated by blocks of about 50 km on a side with six or more rain gauges per block. Kruger<sup>14</sup> found that changes in annual maximum 1-day rainfalls for the Western Cape above the 99th percentile are inconclusive for records ending in 2002. New et al.<sup>15</sup>, using similar methods, showed that there was a ‘statistically significant increase in regionally averaged daily rainfall intensity and dry spell duration’ from 1961 to 2000 across the southern African region, but that few trends at individual stations were statistically significant.

## Methods and data

One of the most important tasks in analysing extremes is to choose the statistical basis for the calculation.<sup>16</sup> There are two fundamental approaches used in extreme value theory: the ‘block maxima’ approach, used in the annual maximum series and the ‘peaks-over-threshold’ (POT) approach.<sup>16</sup> The traditional approach to extreme value analysis in South African rainfall analyses has been to use the annual maximum series.<sup>5,17,18</sup> The block maxima approach relies on identifying the highest value for each year and fitting a distribution to the data, while the POT approach fits a distribution to all data points that exceed a defined threshold.<sup>16</sup>

The advantage of the block maxima approach is its relative simple application; however, this method results in a substantial loss of information resulting from discarding values that are less than but close to the maximum in each year. As Katz<sup>16</sup> argues, this modelling approach may result in poorer return level estimates and the POT may be considered a more appropriate alternative.

In this study, we therefore used the POT approach to analyse the changes in extreme return period rainfalls for 76 rainfall stations across the Western Cape and compare two equal periods: 1950–1979 and 1980–2009. The periods were chosen to split the record into two equal lengths and incorporate the most recent data that the South African Weather Service (SAWS) would supply.

### Peaks-over-threshold

The POT approach is based on the same principle as that of the partial duration series, which was developed as a way of avoiding problems associated with the block maxima approach.<sup>19</sup> The POT approach is predicated on fitting any suitable probability distribution, such as a generalised Pareto distribution (GPD), to all data points exceeding a defined extreme threshold.<sup>20</sup> The benefit of this approach is the inclusion of more data, but it does have the drawback that the events being observed may not be fully independent, which is a requirement for modelling.<sup>16</sup>

The POT approach obtains extreme values of a data set  $X_1, X_2, \dots, X_n$  by considering the exceedances  $Y = X - t$  over a sufficiently high threshold  $t$ . According to extreme value theory, the distribution of the exceedances  $Y_1, Y_2, \dots, Y_{N_t}$ , where  $N_t$  is the number of exceedances above the threshold  $t$ , can be reasonably approximated by a GPD.<sup>21</sup> The distribution function of the GPD is given by Equation 1:

$$G(y, \sigma, \gamma) = \begin{cases} 1 - (1 + \frac{\gamma y}{\sigma})^{-\frac{1}{\gamma}} & \text{for } \gamma \neq 0 \\ 1 - \exp(-\frac{y}{\sigma}) & \text{for } \gamma = 0 \end{cases}, \quad \text{Equation 1}$$

where  $\sigma$  and  $\gamma$  are the respective scale and shape parameters of the distribution. The shape parameter, which is known as the extreme value index in the generalised extreme value distribution, is considered the most important parameter in determining the tail behaviour of a distribution. The procedure of fitting the GPD to the exceedances above the threshold requires the estimation of the two unknown parameters  $\sigma$  and  $\gamma$ . Their maximum likelihood estimates can be obtained through maximisation of the log-likelihood function corresponding to the GPD,

$$\log L(\sigma, \gamma) = \begin{cases} -N_t \log \sigma - (\frac{1}{\gamma} + 1) \sum_{i=1}^{N_t} \log (1 + \frac{\gamma Y_i}{\sigma}) & \text{for } \gamma \neq 0 \\ -N_t \log \sigma - \sum_{i=1}^{N_t} \frac{Y_i}{\sigma} & \text{for } \gamma = 0 \end{cases} \quad \text{Equation 2}$$

with respect to  $\sigma$  and  $\gamma$ .

This estimation task can be relatively easily executed using the function *gpd.fit()* available in the package *ismev* called by the statistical language *R*.<sup>22</sup> The GPD is described as a heavy-tailed distribution, which is appropriate for rainfall analyses because extreme precipitation distributions largely exhibit heavy-tailed characteristics.<sup>23-25</sup>

Use of the GPD requires a high threshold and the choice of threshold must be such that the excess over the threshold should have a nearly exponential distribution – to fit with the requirements of the GPD theorem.<sup>26</sup> A threshold value that is too large, however, will result in few data points (exceedances) from which the parameters of the GPD are estimated, with the consequence of possibly high variance of parameter and return level estimates. However, because the exceedances correspond to data points that lie far in the tail of the distribution of the original data, the limiting results on which the GPD is based are valid and the estimates are likely to exhibit low bias.<sup>21</sup> In contrast, estimates that result from thresholds set too low will exhibit low variance as more data points (exceedances) are available for use in the estimation. However, data points that lie more towards the centre of the distribution of the original data, rather than in the tail, translate to estimates with higher degrees of bias.<sup>21</sup> The choice of threshold is often made subjectively, keeping the above-mentioned bias–variance trade-off in mind.<sup>21</sup> A statistical compromise needs to be achieved between setting the POT threshold high enough so that the

excess distribution (above the threshold) converges to that of the GPD but low enough to have a sample of sufficient size so that the location, size and scale parameters can be estimated efficiently.<sup>24</sup>

Setting the threshold high does not imply an exact value – the outcome is somewhat subjective. ‘*ismev*’ – an add-on package to the *R* statistical language – provides a technique of fitting a range of thresholds, in which the scale and shape parameters gradually change over the fitted range.<sup>27</sup> When setting the threshold, the scale and shape parameters should not end up diverging to such an extent as to imply increasing uncertainty in those parameters. While this is a useful process when applied as an intensive examination of an individual record, it is an overly time-consuming method when applied to many stations (as in this study). A more direct approach which could give sufficiently robust results is required. In similar extreme rainfall studies which evaluate many stations, two approaches are commonly adopted: (1) the use of relative thresholds or percentiles as thresholds (commonly the 95th and 98th percentiles) or (2) absolute thresholds.<sup>4,28</sup> We thus took two useful thresholds to be located at the 95th and 98th percentiles for each rainfall station. Separate thresholds at the 95th and 98th percentiles were estimated for each time period (1950–1979 and 1980–2009) as the two periods need to be viewed as separate data sets.

### Cluster analysis

Rainfall exceedances over thresholds often occur in groups, with one extreme closely following another (because they may be caused by the same event) and this clustering produces dependence in the observations.<sup>21</sup>

In utilising the GPD function for deriving the probability distribution of rainfall events, it is assumed that rainfall extremes fit the Poisson process – a stochastic process in which events occur continuously (as opposed to discrete occurrences) and, importantly, independently of one another.<sup>16</sup> The Poisson process has a long history of use in rainfall modelling.<sup>29</sup> It is therefore crucial to determine whether the data points that exceed the threshold value (threshold exceedances) are independent of each other when fitting a GPD.<sup>24</sup> This problem is addressed by making use of a process known as (de)clustering. Once a definition of cluster length of exceedances has been specified, only the maximum value in each cluster is retained and the remainder of the exceedances are discarded. This process then results in a ‘new’ set of exceedances that are approximately independent and the GPD can then be applied.

In the case of large storm systems such as cut-off low pressure systems, mid-latitude cyclones and cold fronts prevalent in the Western Cape, heavy rainfall can last for 3 days and more per storm. As a result, the observed rainfall may exceed the threshold value every day over a sequence of days for the same event and thus the individual daily observations may not be independent. These data points need to be ‘declustered’ in order to remove such related threshold exceedances.<sup>21</sup> The process of declustering groups is done as another step with the ‘*evd*’ package, which has a specific function serving that purpose. In this study, a value of  $r=3$  in the declustering process was considered reasonable. The value of the parameter implies that three consecutive threshold deficits following exceedances above the threshold indicate the end of a cluster. Further, in order to investigate the influence of cluster length on the results,  $r=2$  and  $r=4$  were also considered but showed very little variation in the outputs.

Following this definition of clusters of exceedances, a cluster can be interpreted as a single extreme 1-day rainfall event (the highest value).

Where:

$n_t$  = the number of exceedances over the threshold  $t$ , and

$n_c$  = the effective number of clusters.

The number of storms resulting in heavy rainfall lasting longer than a single day can be obtained by computing  $n_t - n_c$ . Here,  $n_c$  is referred to as the number of effective clusters rather than just the number of clusters, to emphasise that any cluster may consist of only a single exceedance above the threshold  $t$ . A GPD was then fitted to the new ‘declustered’ data set using the ‘*ismev*’ package in *R*.



### Rainfall data

Rainfall stations used in this analysis were initially identified using the database compiled by Lynch<sup>30</sup>. Suitably long (60 years – divided into two 30-year periods) records of daily rainfall data of SAWS stations were selected. The Lynch<sup>30</sup> data set terminates in 2001. SAWS supplied the remaining data to extend the records to 2009.

Long data records are required in order to divide the rainfall record into equal time periods and to have sufficient data points for the fitting of a distribution. Therefore, use was made of patched (infilled) data provided by the Lynch<sup>30</sup> data set.

The use of patched data for extreme value analysis has precedents in the literature<sup>31,32</sup> and we believe that it provides, in this research, an acceptable means for overcoming gaps in data and extending records where necessary, especially in the early parts of the records. The possible errors that could be introduced into the analysis using this method are low as the rainfall events have already been observed at nearby rain gauges. Although rainfall records extend further back than 1950 for all of the stations used, the quantity of infilled data in these records increases substantially for earlier patched data sets. Thus, rainfall stations were chosen based not only on data length, but also on the low totals of infilled data. The quantum of all exceedances greater than the 95th percentile of the data used in this study that are infilled is 1.4%.

### Rainfall catch anomalies and inhomogeneities

Mason et al.<sup>10</sup> and Zang et al.<sup>33</sup> mention the problem of inhomogeneities in the data. These inhomogeneities arise when a rain gauge is moved or instrumentation is changed, or as a result of other environmental factors that may influence rainfall catch. These authors caution against use of data containing inhomogeneities, noting that testing of long-term change requires quality-controlled data. Indeed, Mason et al.<sup>10</sup> left out many gauges for potential analysis because of these perceptions.

We take a different view. Our approach is that the quantum of individual extreme 1-day rainfalls overwhelms subtle changes within a station time series, and that removing such data from the study implies an a priori understanding of the impacts of the inhomogeneities in the data on extreme values. Inhomogeneities in the extremes of temperature data, by contrast and comparison, are of real concern,<sup>34</sup> but are likely because temperature extremes – both maxima and minima – are far more strongly bounded in nature than precipitation extremes. Thus, measuring an extreme temperature of 51 °C is very unlikely under natural

conditions (i.e. above a vegetated surface) and the probability of an extreme temperature of 52 °C above the same surface would decrease by an order of magnitude or more. Measuring a temperature of 60 °C is almost impossible under current circumstances (an increase from 51 °C of 17.6%). However, a comparison of two extremes of rainfall – e.g. 150 mm and 200 mm in 24 h, an increase of 33% – is quite plausible and the upper limit of rainfall is very poorly defined, for example 597 mm in one day was recorded at St Lucia during Cyclone Domoina on 31 January 1984.<sup>35</sup> Further, much of the data utilised in this study have already been checked and corrected for errors by Lynch<sup>30</sup>.

## Results and discussion

Two key results based on the 95th and 98th percentile POT sampling are presented here, in which there is a strong change to more frequent extreme 1-day rainfalls in the later part of the rainfall record. Both results are considered in more detail below in separate sections. However, a spatial representation of these results reveals that these changes do not provide a clear spatial pattern of change. A pattern may be evident but is difficult to determine because of the low station density across the province.

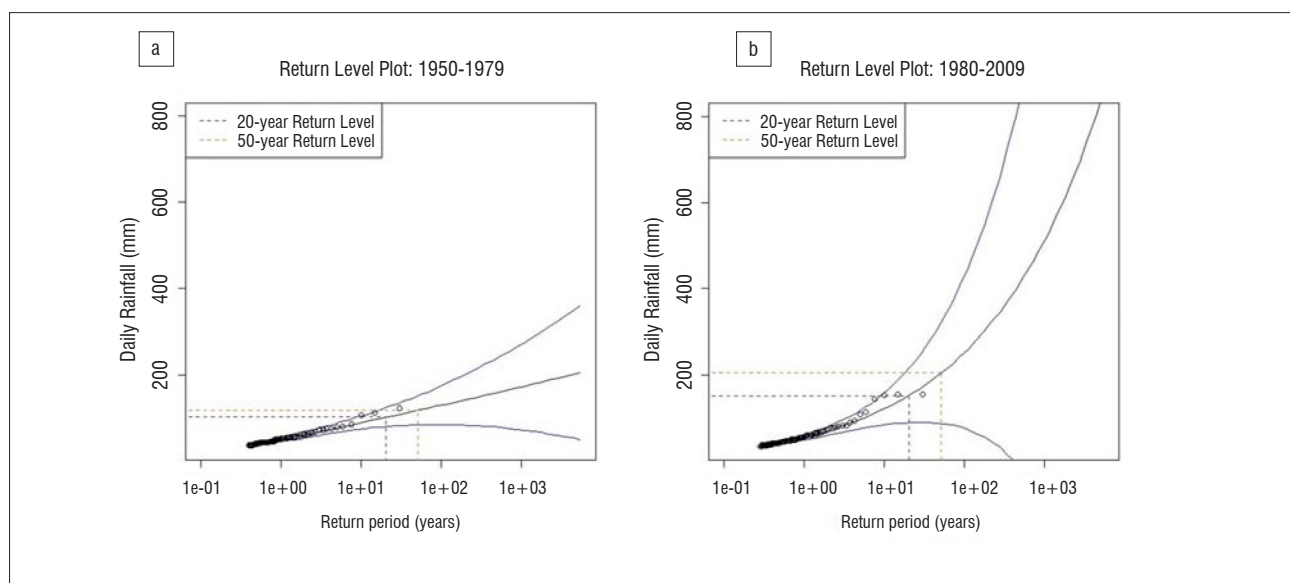
### Changes in design rainfalls

Table 2 presents a summary of the changes in the 50-year return period rainfalls.

**Table 2:** A summary of the change in rainfall intensity at the 50-year return period for rain stations analysed at the 95th and 98th percentile peaks-over-threshold for the 1980–2009 period compared with the 1950–1979 period ( $n=76$ )

	95th percentile		98th percentile	
	Number	%	Number	%
Increase	48	63	49	64
Decrease	28	37	27	36

The GPD output is displayed in the return period rainfall plots in Figure 2 as examples. For the study, similar graphs were produced for each of the 76 rainfall stations. These graphs display the return period rainfalls (on the linear y-axis) against the return period (on the logarithmic x-axis) for both time periods.



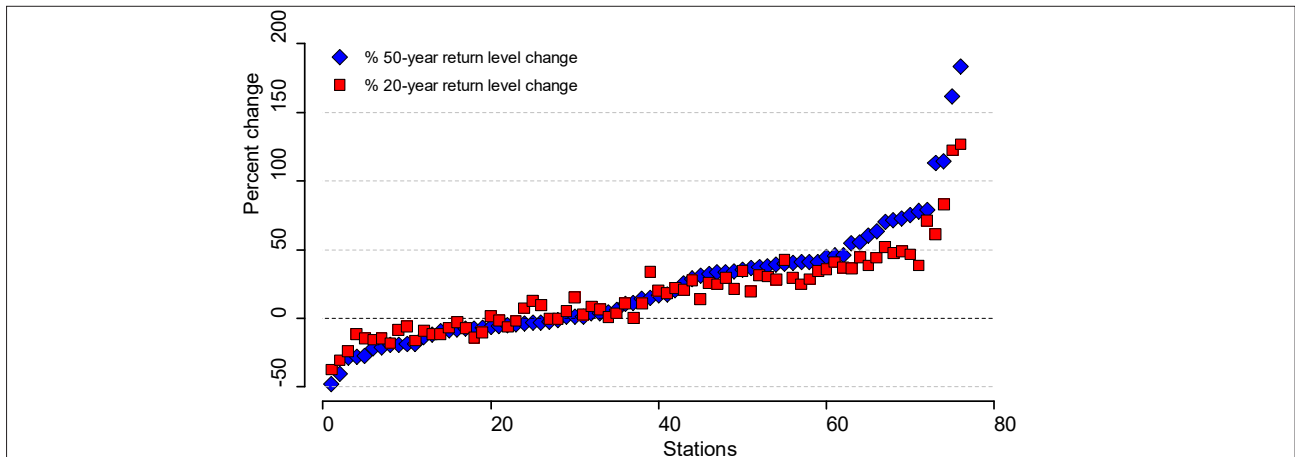
**Figure 2:** Return level plots based on  $r=3$  (consecutive non-exceedances) of the 95th percentile threshold for the rain station 0022539 W Villiersdorp for (a) 1950–1979 and (b) 1980–2009.

The blue response functions (continuous curves) in Figure 2 indicate 95% confidence intervals, while the black response function is the curve indicating estimated return period rainfalls for the same periods. Figure 2 displays results for a rainfall station at Villiersdorp that had an increase in the 50-year return period rainfall magnitude from 118.2 mm for the period 1950–1979 to 202.6 mm for the period 1980–2009 – an increase of 71%.

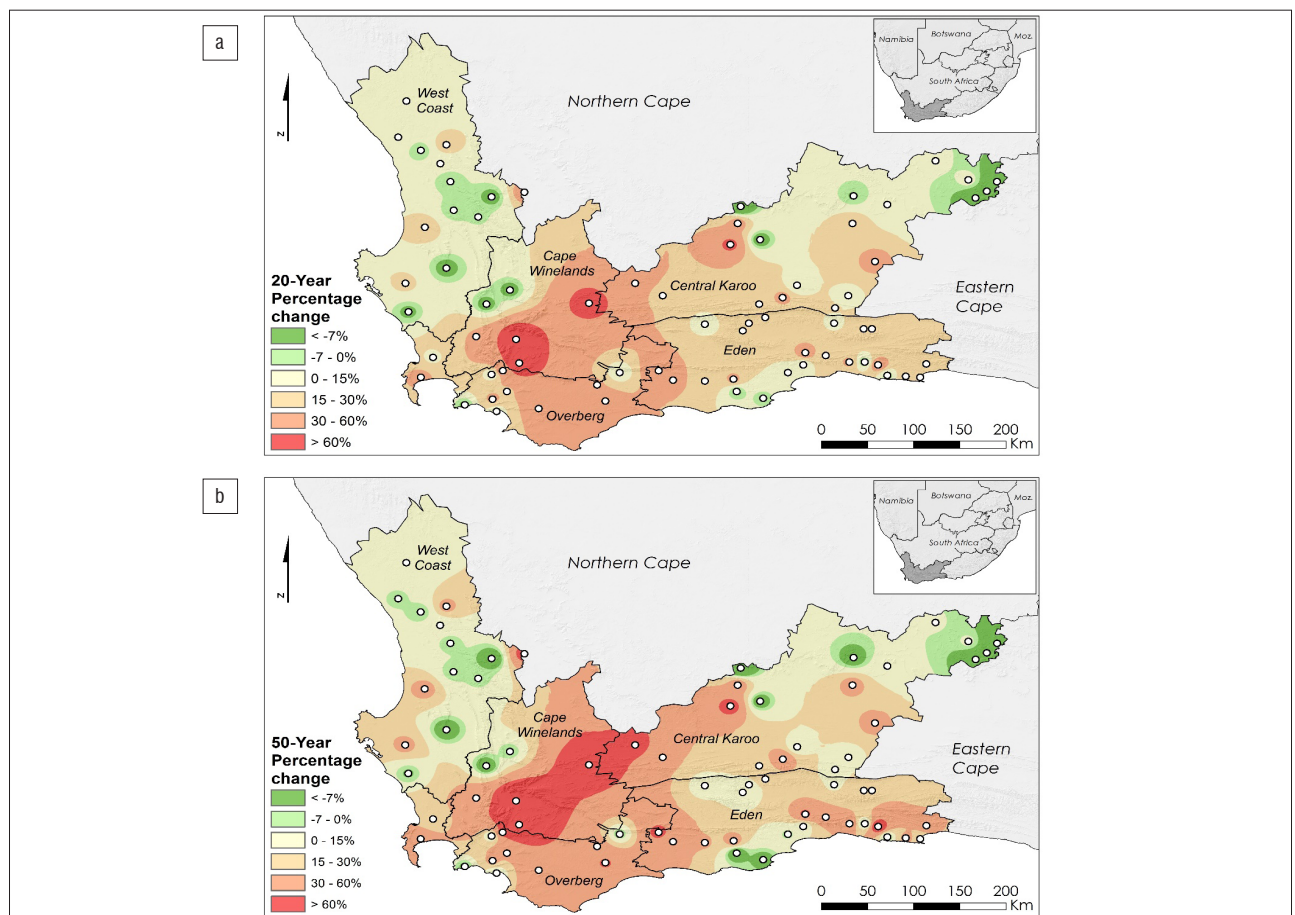
It should be noted that the confidence intervals expand rapidly as a consequence of the logarithmic scale used on the x-axis, and that, if both return period plots were displayed on the same set of axes, their confidence levels would overlap. The differences between the return period for individual stations are therefore not statistically significant. However, it can be expected that the differences for all 76 stations should be randomly and normally distributed. A following section addressed

this assertion. However, the overall pattern of all gauges suggests that substantial changes in rainfall extremes have occurred in the Western Cape over the 60-year period studied.

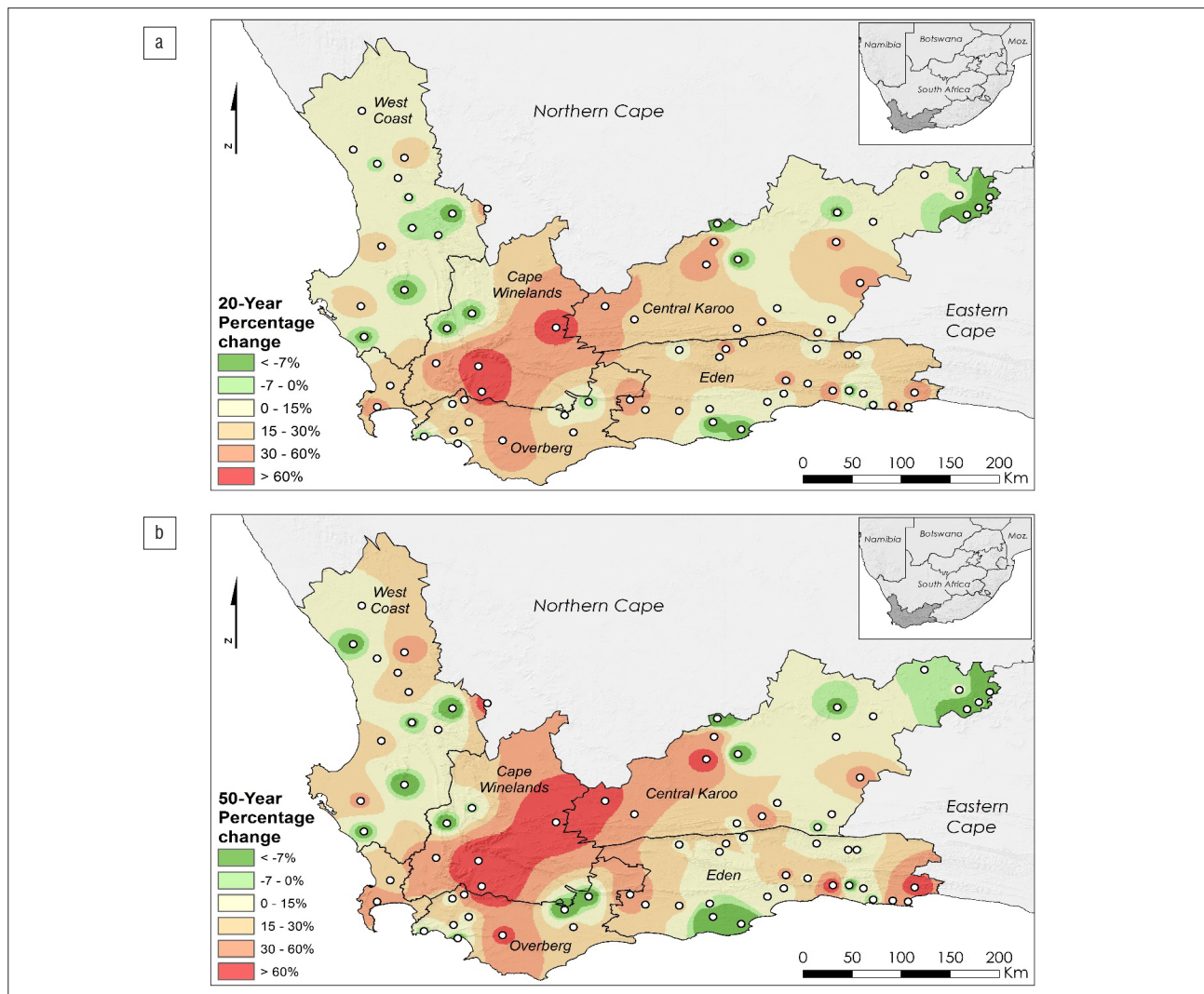
Figure 3 represents the changes in both 20- and 50-year return period rainfall from the initial return level calculated in period 1 (1950–1979) for each individual rainfall station based on the 95th percentile POT data series. A majority of rainfall stations show an increase (>0) in return period rainfalls in the second period (63% for 50-year return period rainfalls), in comparison with the number of rainfall stations that display a decrease (<0) in the magnitude of 50-year storms (37%). We also looked for spatial coherency in the signal by spatially interpolating between stations using ArcGIS (Figures 4 and 5).



**Figure 3:** 20- and 50-year return period rainfall changes by rainfall station as a percentage of change in the 1980–2009 period from the 1950–1979 period (peaks-over-threshold data series: 95th percentile threshold).



**Figure 4:** Inverse-distance-weighted interpolations of the (a) 20-year and (b) 50-year 1-day return period rainfall changes (%) above the 95th percentile threshold for the Western Cape from 1950–1979 to 1980–2009.



**Figure 5:** Inverse-distance-weighted interpolations of (a) 20-year and (b) 50-year 1-day return period rainfall changes (%) above the 98th percentile threshold for the Western Cape from 1950–1979 to 1980–2009.

The green areas in Figure 4 represent areas of coherent decreases in 20- and 50-year return period rainfalls, while other areas (beige to red) are areas of coherent increases. Two separate regions stand out as areas of coherent decreases: the western mountain escarpment of the West Coast District Municipality (Cederberg to Kouebokkeveld Local Municipalities) and the Central Karoo District Municipality. Most of the remaining parts of the province show increases in the 20- and 50-year rainfalls in the second period, particularly in the mountainous regions of the southern Cape Winelands District Municipality (Drakenstein to Breede Valley local municipalities), and suggest a strong increase in the intensity of extreme return period rainfalls, which potentially enhances their flood risk substantially. There are three pairs of rainfall stations close together in which the pairs show opposing signs of change. Either the data quality of these stations should be questioned, or they are subject to more local-scale influences on rainfall intensity than are the others. Spatial techniques (such as interpolation) are therefore possibly useful for assessing the data quality of these stations by highlighting stations that are different from the general local trend of other nearby gauges.

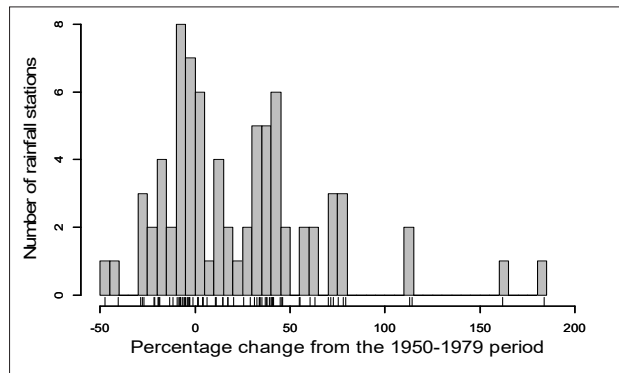
The results produced using the 98th percentile as the GPD threshold show an expectedly similar pattern to that of the 95th percentile. Increases in 50-year return period rainfall intensity range up to 219% (0022803W Bellevue – between Villiersdorp and Worcester in the Cape Winelands). Using a higher threshold (98th percentile) also increases the proportion of rainfall stations that indicate a rise in the number of 50-year return period rainfalls to 64% – up from 63% using a 95th percentile threshold (Table 2).

### Percentile analysis

The use of the GPD method requires a setting of the threshold value to extract the data series. For this study, the 95th and 98th percentiles were accepted as useful estimates of rainfall extremes, as discussed earlier. As the periods 1950–1979 and 1980–2009 need to be viewed as separate data sets for each station, the method entailed calculating separate percentile values for each time period across all rainfall stations. The changes in these percentiles represent changes in the tails of these data distributions, illustrated by the histogram in Figure 6, which represents the percentage of change from the earlier period at the 95th percentile for the given number of stations. The substantial weight of change lies in an increase for the later 1980–2009 period, represented statistically as a positive skewness of 1.32 and the station records are highly skewed to increases in 1-day extreme rainfall. A skewness close to zero should be expected for a comparison in which there is no change between periods.

These changes are represented spatially in Figure 7. Here, light areas represent a decrease in 95th percentile between the two periods, while increasingly darker areas represent regions showing 0–10%, 10–20% and >20% increases in the 95th percentile. The Swartland region up the West Coast, as well as a few isolated stations, display a decrease in 95th percentile between the two time periods, while the Kannaland, Oudtshoorn, Laingsburg and Prince Albert Local Municipalities of the Central Karoo and Eden Districts show a marked increase in 95th percentile, which indicates a substantial change in the tails of these

distributions. Figure 7 indicates that, in some areas, the threshold value (95th percentile) for the latter period has changed when compared with the original 1950–1979 period. In general, these results show that rainfalls have become more extreme.



**Figure 6:** A histogram of the percentage of change return periods at the 95th percentile from the 1950–1979 period for all rainfall stations.

## Conclusions

Our results indicate that the intensity of extreme 1-day rainfalls have shown both increases and decreases across the Western Cape Province in the previous 30 years in comparison to an earlier period. The results are positively skewed towards increases in intensity in the later period across the distribution of the rainfall stations included in this study. The results indicate that the general assumption of stationarity in design rainfall assessments should be strongly questioned. This study provides robust results because the two different methods used provide broadly similar results. These methods can be replicated by future studies in

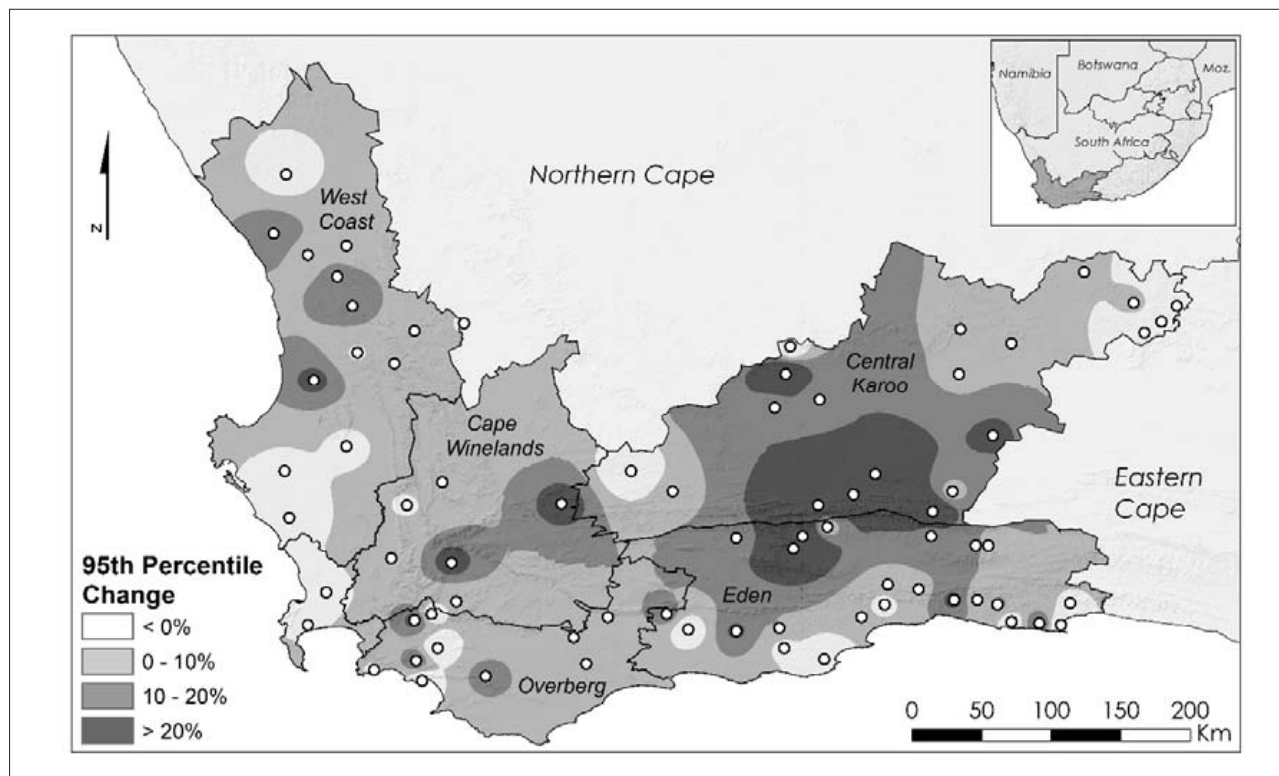
other regions across South Africa and elsewhere and should use the latest rainfall values so as to incorporate more data. The incorporation of additional (more recent) data for the later period to the present in an analysis may change the evaluation further still, as cut-off low weather systems have produced extreme rainfalls in the Western Cape each year from 2010 to 2014 which were not incorporated in this analysis.<sup>3</sup>

As the magnitude and probabilities of extreme 1-day rainfalls appears to be changing, we also suggest a need for a review of estimation methods and what these mean for design calculations. Our results have implications for the future design and maintenance of infrastructure, as well as water resources management. The statistical methods of evaluating the extreme rainfalls are evolving and it is important that new studies consider these methodological changes. They can add value to the design and decision-making process, and account for changing flood risks, which will benefit society by ultimately reducing deaths, injury and socio-economic losses. Further study is also needed on the changing seasonality of extreme events, which we did not address herein.

We also recommend further investigations into the methods of evaluation, for example including the full rainfall data sequences and using parametric non-stationary approaches by considering changes in the  $\sigma$  and  $\gamma$  parameters of the extreme value distributions with time.<sup>21</sup> Du Plessis and Burger<sup>36</sup> have applied this approach in a limited way to short-duration (<24 h) rainfall intensities for a small number of rainfall stations across South Africa. Such potential future studies would represent analyses of continuous change over time, rather than the comparison of two periods presented here.

## Acknowledgements

We gratefully acknowledge the South African Weather Service for providing the rainfall data for 2001–2009 for all 76 rainfall stations used in this analysis. We also thank Chané Orsmond for her assistance in data analysis as well as the anonymous reviewers for their valuable insights and recommendations.



**Figure 7:** Spatial changes in 95th percentile between 1950–1979 and 1980–2009 periods in the Western Cape Province interpolated between rainfall stations using inverse-distance weighting.

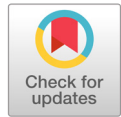
## Authors' contributions

J.H.d.W. wrote significant sections of the paper and undertook the data analysis; he also conceptualised parts of the analysis method. A.C. conceptualised the original approach of using GDP and wrote sections of the paper. J.K. developed the spatial analysis and created the maps.

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# Conservation implications of avian malaria exposure for African penguins during rehabilitation

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The African penguin (*Spheniscus demersus*) is the only penguin species that breeds on the African continent and it is currently classified as endangered. Its conservation is assisted by the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) which is a seabird rehabilitation facility based at the Rietvlei Wetland Reserve in Tableview, Cape Town. Despite the success of SANCCOB in rehabilitating diseased, injured or oiled penguins, significant mortalities have occurred at the facility as a result of avian malaria. Avian malaria can be contracted during rehabilitation during which penguins are inadvertently exposed to additional threats. An enzyme-linked immunosorbent assay (ELISA) was used to assess the anti-*Plasmodium* antibody levels of penguins to avian malaria on entry into the SANCCOB facility from 2001 to 2004 and during their rehabilitation process. Using blood smear data, avian malaria prevalence and malaria-related deaths were also monitored from 2002 to 2013. Significant increases in anti-*Plasmodium* antibody levels after admission were found during summer months. New infection and not parasite recrudescence was concluded to be the cause of this increase. This source was confirmed by a dramatic drop in penguin mortalities upon exclusion of mosquito vectors in 2008. Mortalities did not depend on the birds' abilities to produce an anti-*Plasmodium* antibody response and oiling had no influence on immunity or prevalence of avian malaria infections. This study highlights the importance of mosquito vector control to control pathogen exposure in wild bird rehabilitation centres.

## Significance:

- Efforts to assist with the conservation of endangered species can unintentionally add to the conservation burden.
- Rehabilitation influences exposure of African penguins to avian malaria.
- Avian malaria prevalence and mortality are not influenced by oiling or anti-*Plasmodium* antibody responses.
- Vector control can limit avian malaria exposure in wild bird rehabilitation centres.

## Introduction

The African penguin (*Spheniscus demersus*) is the only penguin species that breeds on the African continent. Their numbers have decreased from an estimated 1.5–3 million before 1900 to fewer than 26 000 breeding pairs in 2009<sup>1,2</sup> – a decline which has resulted in their conservation status being changed from vulnerable to endangered<sup>2</sup>. Since the late 1800s, a sequence of threats has led to their decline. Breeding habitats were reduced through guano collection, followed by egg collection for human consumption, overexploitation of prey species and, recently, oiling events caused by oil spills.<sup>1</sup> Furthermore, blood parasites such as *Plasmodium*, which causes avian malaria, are ongoing threats leading to further mortalities.<sup>3,4</sup>

The Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) maintains a seabird rehabilitation facility based at the Rietvlei Wetland Reserve in Tableview, Cape Town. They rehabilitate diseased, injured or oiled seabirds, of which most are African penguins. Through SANCCOB's efforts, African penguins have been able to survive in the wild after release and have successfully returned to breeding.<sup>5</sup> Unfortunately, avian malaria infections and associated mortalities in African penguins do occur at the facility.<sup>3,4</sup>

Internationally, avian malaria is a known cause of mortality in captive penguins kept in outdoor displays or zoos with *P. relictum* and *P. elongatum* being the associated parasites.<sup>6–10</sup> In the case of wild birds, *P. tejerai*, *P. cathemerium*, *P. nucleophilum* and *P. unalis* could be identified in Magellanic penguins (*S. magellanicus*) undergoing rehabilitation along the coast of Brazil.<sup>11</sup> The first report of a *Plasmodium* infection in an African penguin in the wild was from Saldanha Bay, described as *P. relictum* subsp. *spheniscidae*.<sup>12</sup> Brossy et al.<sup>4</sup> identified *P. relictum* in wild African penguins being rehabilitated at SANCCOB, but rarely found parasitaemia in penguins at their breeding colonies. These findings were based on blood smear analysis; when using anti-*Plasmodium* antibody levels as an indicator of avian malaria exposure, both wild and captive African penguins were found to be exposed to avian malaria.<sup>4,13</sup> In addition, about 30% of penguins admitted to SANCCOB were already malaria positive based on blood smear analysis, on entry into the facility, indicating exposure of the wild population to the pathogen.<sup>3</sup> It was subsequently suggested that wild and captive penguins were being exposed to different *Plasmodium* species<sup>4</sup> which could explain the higher levels of infection and mortality experienced during rehabilitation.<sup>3,13</sup> In captivity, there is an increased chance of being exposed to mosquito vectors that could act as a reservoir for land bird avian malaria parasites.<sup>14,15</sup>

The impact of avian malaria on the decline of wild avian populations is best illustrated by the history of native Hawaiian bird species. Examples are the the Hawaiian crow, or Alalā (*Corvus hawaiiensis*), which is now extinct in the wild<sup>16</sup>, and the Hawaiian honeycreepers (Drepanidinae) of which most species are either extinct or critically endangered<sup>17</sup>. In the case of the Galápagos penguin (*S. mendiculus*), the introduction of *Plasmodium* to the Galápagos Islands is causing concern about the effect this introduction will have on the survival of this endangered species.<sup>18</sup> Because seabirds breed in relatively small geographical areas, they are sensitive to environmental changes, with

population declines as a possible consequence.<sup>19</sup> Population declines in turn increase the vulnerability to diseases.<sup>20</sup> As a result, there is a need for dedicated rescue and rehabilitation centres that play a significant role in ensuring the conservation of species, but they could inadvertently be exposing animals to new threats.<sup>21</sup> The possibility of introducing a foreign avian malaria parasite into African penguins during rehabilitation is therefore a major concern, as subsequent introduction into wild breeding populations could cause a further decline in an already endangered seabird population.

During rehabilitation at SANCCOB, efficient treatment of avian malaria requires early diagnosis, because it is often too late for treatment once clinical signs appear. Screening for blood parasites is therefore conducted through routine blood smear evaluation, but serious pathological effects and even death can occur prior to the appearance of parasites in circulating erythrocytes.<sup>22</sup> The lack of parasites in erythrocytes also does not exclude their possible presence in the endothelium or haemopoietic tissue.<sup>6,7,23</sup> Furthermore, *Babesia* infections cannot easily be distinguished from *Plasmodium* infections by blood smear.<sup>24</sup> The polymerase chain reaction (PCR) can be used as an alternative diagnostic technique as it is viewed to be more sensitive and highly specific and does not rely on visualisation of the parasite.<sup>25</sup> Unfortunately, similarly to blood smears, the method relies on the presence of circulating blood parasites<sup>26</sup> and therefore these methods are not always a true reflection of parasite exposure<sup>13,26</sup>.

On the basis of cross-reactivity between anti-*Plasmodium* antibodies, Graczyk et al.<sup>23</sup> developed an enzyme-linked immunosorbent assay (ELISA) for the detection of anti-*P. relictum* and anti-*P. elongatum* antibodies. It was found to be an effective tool for diagnosing exposure to avian malaria in penguins.<sup>27</sup> The ELISA made use of a recombinant polypeptide (R32tet<sub>32</sub>) as capture antigen, which consisted of 32 tetrapeptides – 31 with the sequence NANP and 1 with the sequence NVDP followed by a 32 amino acid hydrophobic tail.<sup>28</sup> The sequence was derived from the highly immunogenic repeat region of the circumsporozoite (CS) protein of *P. falciparum*. CS-proteins are uniformly distributed over the entire membrane surface of sporozoites, which is the first stage of the parasite in the avian host after being infected. Immunological cross-reactivity is known to exist against the CS-proteins of unrelated species and this may be as a result of structural and functional similarities of the secondary and tertiary structures resulting in common epitopes.<sup>23,29-31</sup>

The objectives of this study were, firstly, to evaluate the exposure of wild African penguins to avian malaria during rehabilitation at SANCCOB by measuring anti-*Plasmodium* antibody levels using an ELISA similar to that of Graczyk et al.<sup>23</sup>; secondly, to determine the influence of these antibody levels on survival during rehabilitation and the effect of oiling on antibody levels and, finally, to show the effect of vector exclusion on the incidence of malaria-related deaths at SANCCOB.

## Materials and methods

### Sample collection and processing

Anti-*Plasmodium* antibody levels of African penguins upon entry to the SANCCOB facility, and for up to 3 weeks after admission, were assessed in birds admitted from October 2001 to January 2004. Penguins were admitted for various reasons such as oiling, poor condition, injury, abandonment or arrested moulting. No specific age group was targeted.

As part of SANCCOB's health monitoring procedures,<sup>3</sup> weekly blood samples were routinely taken from all penguins present in the rehabilitation facility for blood smear analysis. Sampling of blood entailed insertion of a 23-gauge needle into the intradigital foot vein of a penguin and collection into a heparinised capillary tube. Thin blood smears were prepared immediately after blood collection and slides were fixed with methanol and stained with a modified Wright-Giemsa stain (Kyron Laboratories, Johannesburg, South Africa). For antibody analysis, a single 50 mL blood volume, as measured by calibrated heparinised

capillary tubes, was deposited on filter paper (Immunovet Services, Johannesburg, South Africa) and air dried.<sup>27</sup> Prior to ELISA testing, blood was eluted overnight at 4 °C from each of the filter papers with 333.33 mL Millipore water containing 0.4% Tween 20.<sup>23</sup>

Birds were rehabilitated and released as soon as deemed fit to survive in the wild.<sup>3</sup> Consequently, there was a difference in the number of data points collected for each bird. The aim was to obtain at least 30 samples per week and therefore released birds were replaced with newly admitted birds, unless fewer birds were actually being rehabilitated, at any given time.

Positive and low or negative control sera were obtained from the routine blood samples. The positive control was from a penguin that tested malaria positive on blood smear and had a high anti-*Plasmodium* antibody titre in our ELISA. The negative control was from a penguin chick that was artificially hatched and raised in a vector-free environment before being admitted to SANCCOB for rehabilitation.

### ELISA capture antigen

Ballou et al.<sup>32</sup> synthesised peptides containing 8–16 residues of the CS-protein repeat region of *P. falciparum* containing the sequence NANP. Antibodies against these peptides were able to recognise native CS-protein and therefore a peptide with the sequence (NANP)<sub>4</sub> was used as capture antigen in this study. To allow for conjugation to bovine serum albumin (BSA) the peptide was synthesised containing a S-acetylmethylmercaptosuccinic anhydride (SAMSA) group coupled to its N-terminal side. Synthesising the SAMSA-peptide (Biopep Laboratories, Stellenbosch University, Stellenbosch, South Africa) allowed the preparation of a capture antigen free of contaminating serum proteins that could cause cross-reactions in the ELISA. The purity of the peptide was confirmed by electrospray mass spectrometry analysis.

Prior to use, the peptide was conjugated to BSA in a 3:1 ratio to allow for a more rigid attachment of the peptide to the polystyrene surface of the microtitre plate.<sup>33</sup> This step prevents desorption of antigen during ELISA incubation and wash steps. Conjugation consisted of three reaction steps: the introduction of maleimide groups into BSA, introduction of a sulfhydryl group into the malaria peptide and conjugation of the malaria peptide to the activated BSA.<sup>34-38</sup> To ensure that the peptide-BSA conjugate solution was not contaminated with smaller or larger complexes, it was subjected to gel filtration chromatography using a G-25 Sephadex column.

### Penguin anti-*Plasmodium* antibody ELISA

Microtitre plates (96 well, MediSorp™, Thermo Scientific™, Nunc™, Roskilde, Denmark) were coated overnight at 4 °C with 0.5 mg/mL (100 mL/well) of the 3:1 peptide-BSA conjugate in carbonate buffer (50 mM, pH 9.6). The coating solution was decanted and the plate blocked (1 h, 37 °C) with casein buffer (0.5% casein, 0.15 M NaCl, 0.01 M Tris-HCl, 0.02% thiomersal, pH 7.6, 200 mL/well). Filter paper eluates were diluted 1/50 and serum 1/200 in casein buffer containing 0.1% Tween 20 (casein-Tween), added to wells in triplicate (100 mL/well) and incubated (3 h, 37 °C). Biotinylated rabbit anti-penguin Ig antibody was prepared as described<sup>33</sup> and added (100 mL/well) after being diluted 1/100 in casein-Tween. After incubation (1 h, 37 °C), avidin-horseradish-peroxidase conjugate (Zymed®, San Francisco, CA, USA) diluted 1/100 in casein-Tween was added (100 mL/well) and the plates were further incubated (1 h, 37 °C). Finally, the substrate solution (ABTS, 0.015% H<sub>2</sub>O<sub>2</sub> in 0.1 M citrate buffer, pH 5, 100 mL/well) was added and the absorbance measured after 30 min at 37 °C on a Labsystems Multiskan MS spectrophotometer at 405 nm. Between all steps, the plates were washed three times, except after coating, with phosphate-buffered saline (PBS; 200 mL/well) containing 0.1% Tween 20. Negative and positive control sera were included on each plate to monitor inter-assay variation. The ability of the capture antigen to distinguish between malaria positive and negative sera as well as non-specific reactions towards activated BSA were also evaluated.

### Data analysis

ELISA data from October 2001 to January 2004 were grouped together into 2-month periods. Because penguins were being admitted continuously within a specific 2-month period, the week of entry for all penguins in that period was taken as Week 0 and subsequent weeks of sampling as Weeks 1 and 2.

The absorbance values measured during ELISA analysis are referred to as ELISA titres which represent anti-*Plasmodium* antibody levels. The change in antibody levels, one and two weeks after admission, were calculated for each 2-month period. This calculation was done by subtracting the average titre value obtained at Week 0 from that obtained at Week 1 and again at Week 2. The resulting two values were plotted graphically for each 2-month period.

Most penguins were rehabilitated for no longer than 2–3 weeks after admission and therefore only the data for Weeks 0, 1 and 2 were used for statistical analysis using the general linear models procedure in the Statistical Analysis System (SAS) Enterprise Guide (version 1.3.0.161). Weather data were obtained from Weather Underground and Harris et al.<sup>39</sup>

### Monitoring the prevalence of avian malaria

The prevalence of avian malaria (number of samples positive during rehabilitation divided by the number of individual bleeds) was also determined for the facility as a whole. This determination was based on blood smear analysis which is routinely performed and therefore allowed for long-term monitoring (2002–2013). *Plasmodium* diagnosis was based on identification of trophozoites and gametocytes in the erythrocytes with the latter used to distinguish from *Babesia* infections. Meronts were rarely identified. Deaths that occurred as a result of avian malaria were confirmed during post-mortem examinations as described.<sup>40</sup>

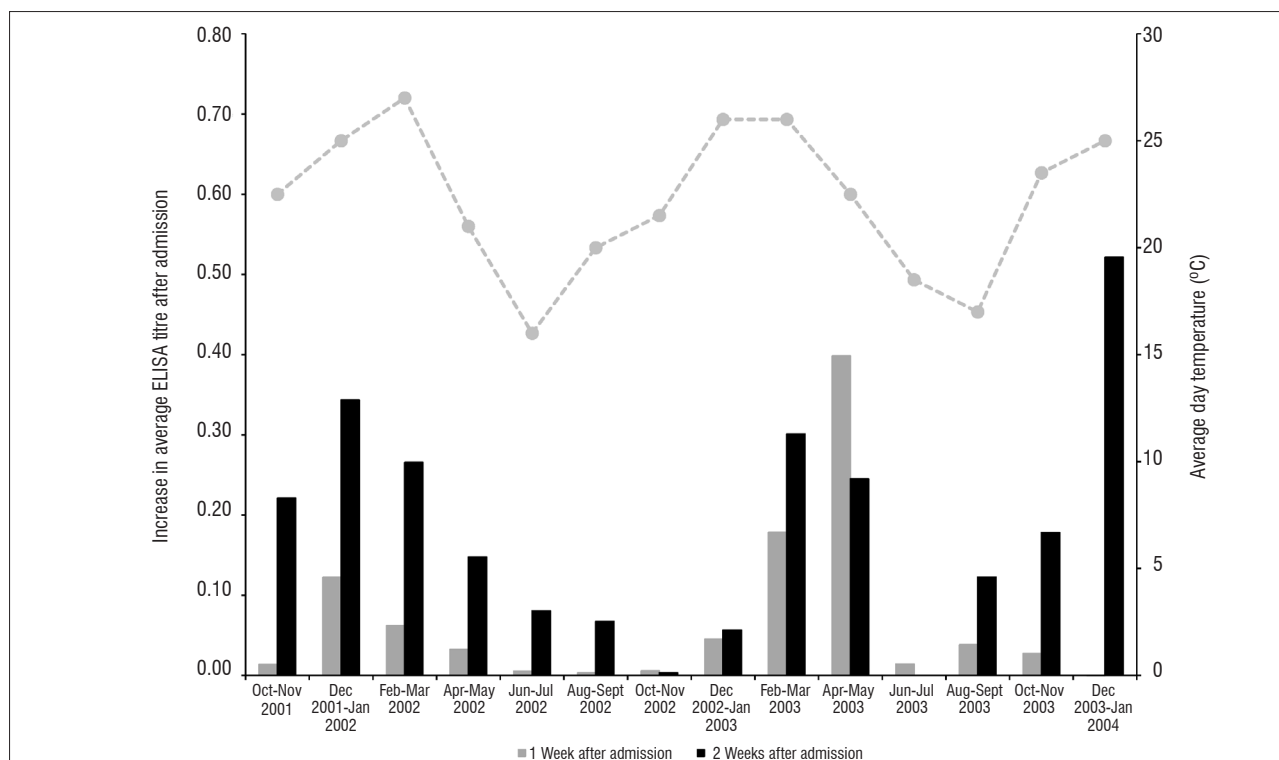
## Results

### Penguin anti-*Plasmodium* antibody ELISA

Gel filtration chromatography produced a single peak indicating that the conjugate consisted of a single complex (Supplementary figure 1). ELISA titres of positive and negative penguin serum samples indicated that anti-*Plasmodium* antibodies were able to cross-react with the peptide–BSA conjugate (Supplementary figure 2) and this interaction was primarily aimed at the peptide.

### Anti-*Plasmodium* antibody response

The increase in anti-*Plasmodium* antibody levels after admission to the SANCCOB facility is shown in Figure 1. In penguins admitted from October to November 2001, an increase in antibody levels could only be observed by Week 2. In penguins admitted from December 2001 to January 2002, there was an earlier increase in antibody levels one week after entering the facility and this pattern continued for penguins admitted during the warmer months until March 2002. This period coincided with an increase in the number of birds that tested positive for malaria by blood smear during rehabilitation (Table 1). As ambient temperatures started to drop, so did the increase in antibody responses one week after admission as well as the percentage of penguins that tested blood smear positive (BS+). Antibody levels started to increase again after admission during October–November 2002, but at much lower levels than those during 2001. A more pronounced increase in antibody levels, however, followed during February–May 2003 compared to the same period in 2002, but this increase did not coincide with an increase in BS+ penguins (Table 1). The elevation in antibody levels in 2003 again decreased as temperatures dropped (June–July), and then increased slightly as temperatures started to increase (August–September), but BS+ cases during rehabilitation only started to increase after the August–September 2003 period. Analysis indicated a significant association between the average increase in ELISA titre values 2 weeks after admission and average day ( $p=0.028$ ) and night ( $p=0.008$ ) temperatures (see the supplementary material).



**Figure 1:** Increases in anti-*Plasmodium* antibody levels in the weeks after entry into the SANCCOB facility: ‘1 Week after admission’ represents the difference in average ELISA titre values from Week 0 to Week 1; ‘2 Weeks after admission’ represents the difference in average ELISA titre values from Week 0 to Week 2. The temperature is the average maximum values for a given 2-month period.

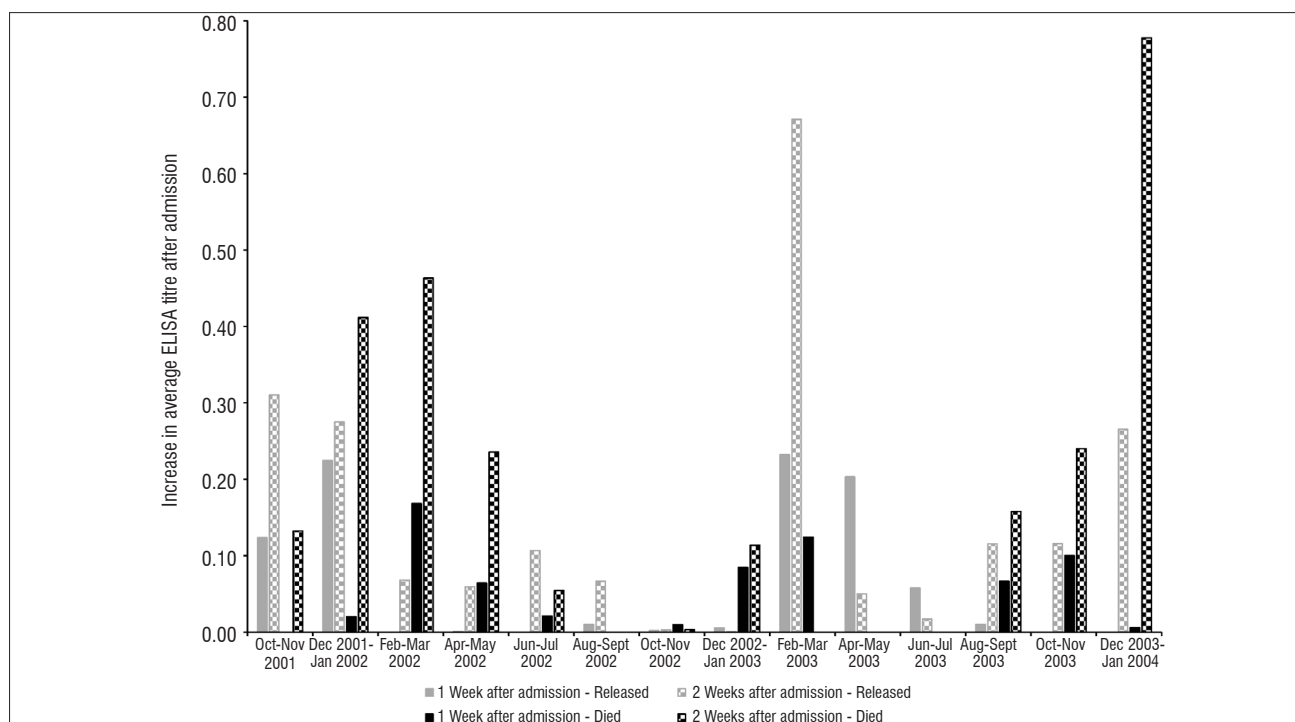


**Table 1:** Avian malaria blood smear data for African penguins that were eventually released and for those that died during rehabilitation at SANCCOB

		October – November 2001	December 2001 – January 2002	February – March 2002	April – May 2002	June – July 2002	August – September 2002	October – November 2002	December 2002 – January 2003	February – March 2003	April – May 2003	June – July 2003	August – September 2003	October – November 2003	December 2003 – January 2004
<b>All</b>	<i>n</i>	52	48	10	66	51	61	42	32	37	53	70	82	64	54
	BS+	59%	70%	50%	16%	9%	14%	21%	38%	18%	13%	8%	6%	26%	22%
<b>Released after rehabilitation</b>	<i>n</i>	36	25	6	59	46	59	35	24	27	50	68	80	53	42
	BS+	53%	48%	50%	12%	9%	15%	14%	38%	11%	12%	9%	6%	21%	14%
<b>Died during rehabilitation</b>	<i>n</i>	16	23	4	7	5	2	7	8	10	3	2	2	11	12
	BS+	75%	96%	50%	57%	20%	0%	57%	38%	40%	33%	0%	0%	55%	50%
	Malaria-specific death*	75%	96%	50%	57%	20%	0%	57%	38%	20%	33%	0%	0%	55%	50%

BS+, blood smear positive

\*percentage of total number that died during rehabilitation



**Figure 2:** Increases in anti-*Plasmodium* antibody levels of penguins that were released compared with those that died after entry into the SANCCOB facility: ‘1 Week after admission’ represents the difference in average ELISA titre values from Week 0 to Week 1; ‘2 Weeks after admission’ represents the difference in average ELISA titre values from Week 0 to Week 2. No deaths were recorded during April–May 2003. Missing data points for other months reflect no increases in titre values.

**Influence of anti-*Plasmodium* antibody response on survival**

The increase in anti-*Plasmodium* antibody levels in penguins that were released and those that died during rehabilitation are shown in Figure 2. Although these data indicated that the penguins were responding to *Plasmodium* infections by producing an antibody response, the difference in response between the released and deceased penguins was not statistically significant.

Malaria blood smear data for the penguins that were released vs those that died for each of the respective 2-month periods are shown in Table 1 along with the percentage of deaths as a result of malaria as confirmed by post-mortem examination. All penguins that died during rehabilitation as a result of malaria were also those that tested BS+ for malaria resulting in the percentage BS+ cases and malaria deaths being the same. The only exception was the birds sampled in February–March 2003, for which not all deaths were as a result of malaria – only 20% were malaria-related deaths.

### Influence of oiling on the anti-Plasmodium antibody response

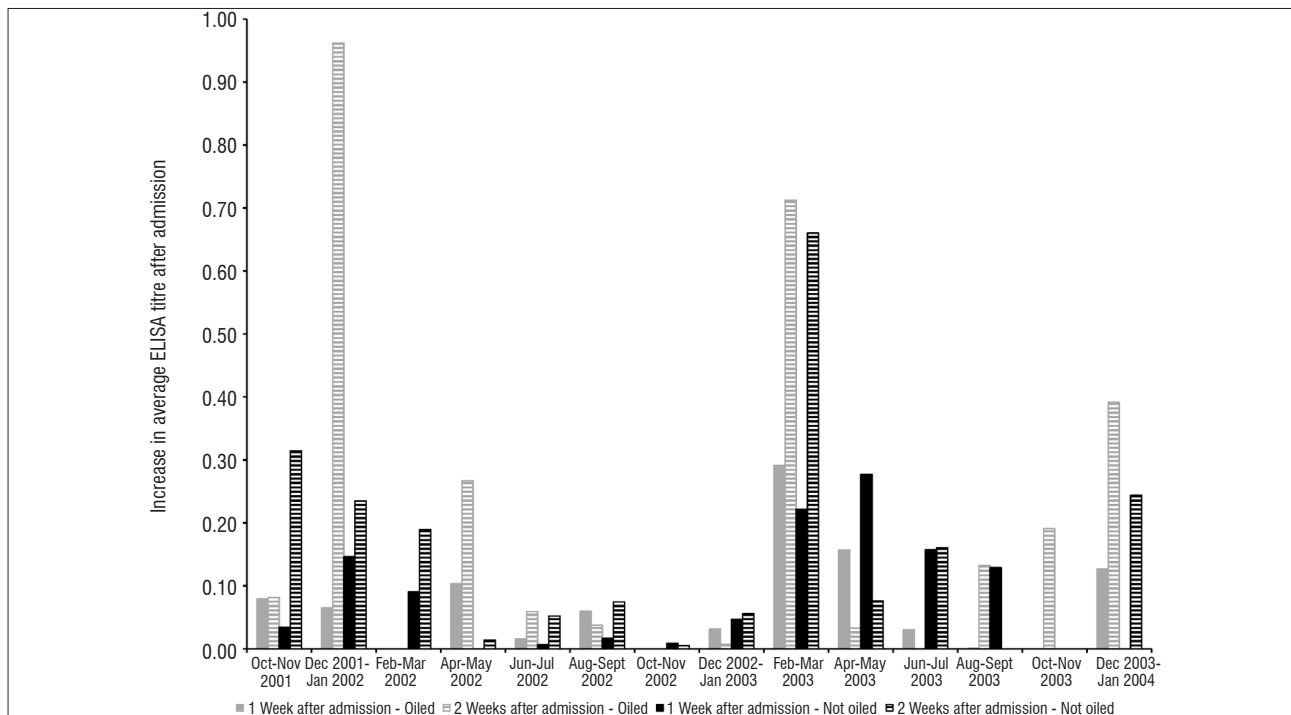
The effect of oiling on the increase in anti-*Plasmodium* antibody levels is shown in Figure 3. No statistically significant difference was found between oiled and not oiled penguins except for the period December 2001 to January 2002. The significant difference ( $p=0.0136$ ) is, however, questionable as there were only four oiled penguins during this period and the difference was caused by the high titre of a single penguin that was oiled and that died during rehabilitation.

Malaria blood smear results of the oiled versus not oiled penguins during rehabilitation and the number of penguins that died as a result of malaria are shown in Table 2. The number of birds that tested positive for malaria

by blood smear and that died as a result of malaria during rehabilitation were on average higher in the not oiled group.

### Monitoring the prevalence of avian malaria

The prevalence of avian malaria and the deaths specifically related to avian malaria at SANCCOB in the period from 2002 to 2013 are shown in Table 3. These data show a persistent level of avian malaria infection in penguins being rehabilitated during the period from 2001 to 2008. There is, however, not always a good correlation between avian malaria prevalence and malaria-specific deaths, which indicates the inefficiency of blood smear analysis as a diagnostic tool. A mosquito-proof net was installed over the open-air part of the facility in October 2008, after which there was a sharp decrease in the prevalence of and deaths as a result of avian malaria.



**Figure 3:** Increases in anti-*Plasmodium* antibody levels of penguins that were oiled compared with those that were not oiled upon entry into the SANCCOB facility: '1 Week after admission' represents the difference in average ELISA titre values from Week 0 to Week 1; '2 Weeks after admission' represents the difference in average ELISA titre values from Week 0 to Week 2. There were no oiled penguins during February–March 2002. Missing data points for other months reflect no increases in titre values.

**Table 2:** Avian malaria blood smear data during rehabilitation for African penguins that were oiled and not oiled on admission

		October – November 2001	December 2001 – January 2002	February – March 2002	April – May 2002	June – July 2002	August – September 2002	October – November 2002	Dec 2002 – January 2003	February – March 2003	April – May 2003	June – July 2003	August – September 2003	October – November 2003	December 2003 – January 2004
All	<i>n</i>	52	48	10	66	51	61	42	32	37	53	70	82	64	54
	<i>n</i>	20	7	0	41	43	46	19	4	5	35	55	70	40	28
	BS+	45%	71%	0%	12%	7%	9%	11%	75%	20%	6%	4%	6%	18%	21%
	Malaria-specific death*	10%	43%	0%	7%	0%	0%	0%	25%	20%	0%	0%	0%	5%	14%
Not oiled	<i>n</i>	32	41	10	25	8	15	23	28	32	18	15	12	24	26
	BS+	69%	71%	50%	24%	25%	33%	30%	32%	19%	28%	27%	8%	42%	23%
	Malaria-specific death*	31%	46%	20%	4%	13%	0%	17%	7%	3%	6%	0%	0%	25%	8%

BS+, blood smear positive

\* percentage of total number that were oiled/ not oiled, respectively

**Table 3:** Prevalence of avian malaria in African penguins admitted to SANCCOB for rehabilitation

Year	Total admitted	Total released	Individual bleeds	Average bleeds per bird	Malaria positive	Apparent prevalence	Total deaths	Malaria deaths	% Malaria deaths
2002	977	721	890	4	175	19.7%	256	46	18%
2003	1052	873	994	5	187	18.8%	179	43	24%
2004	655	444	587	5	101	17.2%	211	20	9%
2005	952	778	900	4	94	10.4%	174	33	19%
2006	1299	1118	1236	5	126	10.2%	181	39	22%
2007	896	628	825	5	131	15.9%	268	108	40%
2008*	499	363	426	5	20	4.7%	136	3	2%
2009*	769	648	703	5	2	0.3%	121	1	1%
2010*	905	686	839	4	11	1.3%	219	11	5%
2011*	519	319	500	5	4	0.8%	200	0	0%
2012*	955	650	904	3	5	0.6%	304	3	1%
2013*	1021	687	895	3	20	2.2%	309	10	3%

\* Mosquito-proof netting installed over the open-air part of the facility.

## Discussion

In previous studies, penguins were reported to harbour *Plasmodium* (in the erythrocytic stages of infection) upon admission,<sup>3</sup> which implied that they had already been infected in the wild. In this study, *Plasmodium* could be detected in some penguins during rehabilitation when using blood smear analysis, which may indicate prior exposure in the wild. As observed in other studies, the BS+ cases increased in the warmer months and decreased in the colder months<sup>3</sup>, which can be attributed to the negative influence of cooler temperatures on the distribution of mosquito vectors, with a subsequent decrease in malaria infections<sup>22,41</sup>. Prior exposure to *Plasmodium* does not preclude the possibility of penguins being confronted with a different *Plasmodium* species in captivity<sup>4</sup>, given that co-infections are possible<sup>42</sup> and that as expected<sup>25,26</sup>, the changes in anti-*Plasmodium* antibody levels did not always coincide with increases in malaria BS+ cases.

If penguins survive their first infection of avian malaria, their immune system appears to be capable of reducing the number of parasites with a resulting low-level infection (premunition) resulting from survival of latent parasites.<sup>43</sup> This premunition allows penguins to control a new infection with a rapid and intensified antibody response. Recrudescence, which is an increase in the number of latent parasites in the blood and therefore the development of symptoms, can be induced in birds with premunition by stress factors such as nutritional, environmental or migration stress.<sup>7</sup> The rehabilitation process itself stresses penguins, which could lead to recrudescence in penguins that enter the SANCCOB facility with an existing low-level infection.<sup>4</sup> However, if existing infections, and therefore recrudescence, were the main cause of antibody responses seen in penguins being rehabilitated, then the same increase in antibody levels should be seen throughout the year, irrespective of season. An increase in the anti-*Plasmodium* antibody response was, however, only observed during the warmer spring and summer months (October–March); a reduced response was observed during the colder autumn and winter months (April–September). The pattern of antibody increase and decrease did, however, shift from one year to the next because of differences in weather patterns between years. The climate along the South African west and south coasts exhibits variable temperatures and rainfall conditions (Supplementary table 1) that in turn can influence vector and parasite abundance and host exposure.<sup>44</sup> November 2002 experienced a higher than normal rainfall which could have caused a hatch delay with an increase in mosquito populations in subsequent

months,<sup>45</sup> causing a larger increase in anti-*Plasmodium* antibodies measured during February–May 2003 as well as an increase in malaria-specific deaths in 2003 compared to 2002 (Table 3).

In an attempt to reduce malaria infections in the facility, mosquito-proof netting was installed at the facility in 2008. A significant decrease in the prevalence of avian malaria after the installation provided conclusive evidence that avian malaria infections in the SANCCOB facility were primarily a result of new infections and not recrudescence. However, the very low numbers of penguins that contracted avian malaria in the facility after 2008 can probably be ascribed to existing infections upon admission and therefore parasite recrudescence.

New infections rely on the presence of a vector as well as a suitable avian reservoir host. It is therefore unlikely that natural infections in penguins will occur in the absence of infected wild birds.<sup>14</sup> If African penguins are naturally infected with *P. relictum* or a subspecies thereof<sup>12,24</sup> and have developed resistance against this species, it might be that they are exposed to possible infection by other malaria species during rehabilitation. The SANCCOB rehabilitation facility is adjacent to a large shallow freshwater lake (Rietvlei) with abundant bird life as well as large numbers of culicine mosquitoes. This scenario could facilitate host switching with resulting *Plasmodium* infections to which penguins are not exposed in their natural environment.<sup>46</sup> *Plasmodium* spp. are known for their low specificity and broad host range which allows for host switching between different mosquito vectors as well as avian hosts.<sup>47</sup> Host switching could also cause a parasite to undergo a change in virulence<sup>48</sup> which could translate into an acute infection. Even if penguins survive these new infections during rehabilitation, they could become carriers and introduce this *Plasmodium* species into breeding colonies, thereby exposing the population to a new hitherto unknown *Plasmodium*. In future studies, it would be worthwhile to confirm, using molecular methods,<sup>49</sup> the identity of the *Plasmodium* species that infect penguins during rehabilitation in comparison to those infecting breeding colonies, as well as relevant reservoir hosts.

If penguins are infected during rehabilitation, their survival may be influenced by their physical condition upon admission and thus their ability to produce an anti-*Plasmodium* antibody response. If the response is too low or delayed, the bird is likely to succumb.<sup>43</sup> We found no difference in the antibody responses between penguins that survived and were released after rehabilitation versus those that died as a result

of malaria during rehabilitation. Survival therefore did not depend on antibody response alone. The mortality results can, however, be viewed as being biased because all penguins diagnosed as malaria BS+ were treated against malaria.

Apart from large oiling events, penguins are admitted to SANCCOB as a result of chronic oiling throughout the year.<sup>3,50</sup> Oiling is one of the major human threats to penguin conservation worldwide. Oiling causes the feathers to lose their natural insulative and waterproofing properties and ingested oil can lead to internal organ damage as well as anaemia and a depression of immune function.<sup>50,51</sup> An altered immune function could make them more susceptible to malaria infection during rehabilitation. In this study, oiling was found not to influence the ability of penguins to produce an anti-*Plasmodium* antibody response. A possible explanation for this finding may be that, because of the presence of conservation staff monitoring most of the African penguin breeding colonies and public awareness, penguins are brought to SANCCOB soon after oiling, and are generally strong on arrival.<sup>3</sup> Furthermore, not oiled penguins were admitted throughout the year whilst the majority of oiled penguins were seen in winter months when there are fewer malaria infections, as diagnosed by blood smear, as well as fewer malaria-specific deaths. From this observation it can be concluded that oiling had no effect on the prevalence of malaria in African penguins that were being rehabilitated.

## Conclusion

This research highlights the importance of mosquito vector control in order to control avian malaria in wild bird rehabilitation centres. Blood smear results indicated that birds are being exposed to avian malaria in the wild, but anti-*Plasmodium* antibody responses indicated that penguins were in all likelihood being newly infected by mosquitoes during rehabilitation. This was further confirmed by a sharp decline in malaria prevalence after vector control measures were implemented at SANCCOB in the form of mosquito netting. Further studies are needed to confirm whether penguins are confronted with a different *Plasmodium* species during rehabilitation than in the wild. Also, determining the source of infections will allow effective management of the disease by establishing conservation strategies to either control or prevent future infections during rehabilitation.

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## Authors' contributions

A.B. was responsible for methodology development, antibody analysis, curation of ELISA data, data collection, writing the initial draft and manuscript revision. H.T. was responsible for antibody analysis, curation of ELISA data and data collection. N.J.P. was responsible for blood and serum collection, data collection, curation of blood smear and malaria data, and manuscript revision. D.U.B. was responsible for conceptualisation of the project, acquisition of funding, methodology development and manuscript revision.

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# A simulation study on the effect of climate change on crop water use and chill unit accumulation

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Climate change and its impact on already scarce water resources are of global importance, but even more so for water scarce countries. Apart from the effect of climate change on water supply, the chill unit requirement of deciduous fruit crops is also expected to be affected. Although research on crop water use has been undertaken, researchers have not taken the future climate into consideration. They also have focused on increasing temperatures but failed to relate temperature to chill unit accumulation, especially in South Africa. With a view of helping farmers to adapt to climate change, in this study we provide information that will assist farmers in their decision-making process for adaptation and in the selection of appropriate cultivars of deciduous fruits. Crop water use and chill unit requirements are modelled for the present and future climate. Results show that, irrespective of the irrigation system employed, climate change has led to increases in crop water use. Water use with the drip irrigation system was lower than with sprinkler irrigation as a result of efficiency differences in the irrigation technologies. It was also confirmed that the accumulated chill units will decrease in the future as a consequence of climate change. In order to remain in production, farmers need to adapt to climate change stress by putting in place water resources and crop management plans. Thus, producers must be furnished with a variety of adaptation or management strategies to overcome the impact of climate change.

### Significance:

- Producers must closely monitor the usage of efficient irrigation technology.
- Climate adaptation needs to be anticipated years in advance and will require a transition to different crop species or cultivars or the development of management practices.
- The results of this study will guide producers in the selection of cultivars when re-establishing their orchards.

## Introduction

Climate change and its impact on already scarce water resources are of global importance, but even more so for water scarce countries. The projected increase in temperature in certain regions of the world is anticipated to have an inevitable influence on water availability.<sup>1</sup> Changes in the supply of water will inevitably affect the availability of water for domestic use, agricultural production, and industrial use. The water demand pressure, driven by global temperature surges, population growth, degradation of water quality, lack of efficient water management and the like, accentuates water scarcity.<sup>2</sup> According to the Intergovernmental Panel on Climate Change, by 2020, it is anticipated that about 250 million people will be exposed to water stress because of the changing climate. Combined with an increase in demand, the adverse effect on livelihoods and the aggravation of already existing population shifts, uneven wealth distribution and related problems can lead to a more complicated system.

The unprecedented levels of climate change predicted will have repercussions for climate-sensitive systems (forestry, natural resources and agriculture) around the world. Projected changes in temperature, solar radiation and precipitation could impact on the productivity of both crop and livestock farming. Such changes also have economic impacts on agriculture leading to changes in prices, farm profitability, trade and regional comparative advantage. For an arid and water scarce country such as South Africa, the effects would be more noticeable. In addition, the competitiveness of agriculture may be at risk. Changes in hydrological regimes will also affect the availability of water for irrigation purposes. In addition, future competition for water by non-agricultural users will increase because of population and economic growth.

Climate change is also expected to have an impact on future winter chill, which could potentially have a major impact on fruit species with chilling requirements.<sup>3</sup> Fruit trees, such as apricots, apples, pears and nectarines, need to achieve a chilling requirement in order to break dormancy in winter and recommence growth in spring. If the winter chill is not sufficient or fulfilled, dormancy is not broken (which occurs in extreme situations) and fruit yields and fruit quality can be severely affected.<sup>4</sup> If winter chill reduction occurs because of the changing climate, production restraints are expected to set in, because fruit trees might not even undergo or experience their minimum chilling requirement to break dormancy.<sup>5</sup> This leads to trees developing some physiological symptoms relating to insufficient chill: (1) reduced fruit set and enlarged buttoning, (2) delayed foliation and (3) reduced fruit quality.<sup>6</sup> It also disrupts spring growth, leading to inconsistent bud break and leaf development, and non-consistent fruit growth.<sup>7</sup> These physiological symptoms subsequently affect the yield and quality of the fruit. Thus, failure to accumulate the required chill units may have a significant effect on the productivity of such trees as well as the economy of the production region, and even the country.

Research on water use of crops has received much attention in the recent past,<sup>8-10</sup> but very few studies have considered future climate. Attention has been paid to increased temperature, but most studies in the field<sup>11,12</sup> to date have failed to relate temperature to chill unit accumulation. The aim of this study was to estimate the changes in crop water requirements as well as chill unit accumulation of deciduous fruit crops in a changing climate. The findings will assist in the decision-making process for adaptation and in the selection of appropriate future cultivars of crops

and deciduous fruits under the predicted climate change scenarios. After orchards are established, they remain in production for years; therefore the consideration of future expected winter chill is indispensable in times of looming climate change. The accurate quantification of the ‘coldness’ of winter using phenological models can therefore assist farmers with a relatively complete assessment of how particular cultivars fare under the current conditions, which facilitates cultivar choice. Accurate models can also help researchers measure the impact of various climate change possibilities on fruit production in the fruit producing areas in order to adapt orchard practices accordingly.

Crop water requirement was modelled for current and future climate for two irrigation systems (sprinkler and drip) to establish how climate change will influence water use of fruit crops. Similarly, chill unit accumulation was modelled using the dynamic model for both the present and future climate. The application of the models was demonstrated in an important fruit producing area. In this study, we consider Ceres – an important fruit and crop producing area in South Africa. Fruits and fruit concentrates produced in Ceres are exported to more than 84 countries in Africa, North America, Europe, the Far East, the Middle East and Asia. The production of crops, vegetables and fruits vital for healthier global diets is being threatened by climate change and any changes in the status quo because of projected climate change will destabilise global supply (trade) with an inevitable impact on the production economy. Maintaining and increasing an exporting nation portion of global fruit markets is vital for long-term economic relevance in providing jobs and a reliable source of income for the producers.

## Study area and methodology

### Study area

The Western Cape of South Africa is traditionally the major fruit production province. The province also has the largest concentration of fruit growers with more than 74% of the total area planted to deciduous fruit. Ceres is an important fruit production region in the Western Cape and has 46 251 inhabitants. Ceres is an important agricultural area bounded by fruit exporting farmers. Of all the pear producing regions in the country, the Ceres region has the highest potential. The fact that Ceres produces almost half of the total pear production in South Africa reflects its favourable conditions. Ceres is thus important to the Western Cape economy and the country as a whole because of the strong agriculture-based industry and services. The climate in Ceres is characterised by a major temperature variation between the summer maximums and the winter minimums.

### Downscaling of global climate models

The empirically downscaled data from various global climate models (GCMs) include daily minimum and maximum temperature and rainfall. Agricultural impacts occur at more local scales; outputs from the global scale GCMs have to be downscaled to a suitable finer-scale resolution. The empirical downscaling of values to climate station level used in this study, was undertaken by the University of Cape Town’s Climate System Analysis Group. The climate change scenarios were developed for the ‘present’ (1971–1990) and ‘intermediate future’ (2046–2065). The period 2046–2065 was chosen because the hydrological impacts of climate change are more evident in the intermediate future (mid-century). Various methods have been developed, including the SOMD (self-organising map-based downscaling) developed at the University of

Cape Town which was used in this study. Details of the method can be found in the study by Hewitson and Crane<sup>13</sup>.

### Ceres deciduous fruits and chill units requirements

Fruit and nut tree species cultivated in South Africa which originated from the cool subtropical and temperate regions require winter chill to ensure homogeneous flowering, satisfactory fruit setting, and economically satisfactory yields.<sup>5</sup> Table 1 presents four main cultivars of deciduous fruit typically planted in the Ceres region, with their associated winter chill requirement to break dormancy. The chill units are available in Richardson unit because most of the farmers and industry experts in this region record in Richardson unit. These chill requirements are location specific and in this case the ones for the study area are presented. The selection of these four cultivars was based on a 2012 tree census.

In Table 1, the Richardson chill unit requirements for apple cultivars Golden Delicious and Top Red are 1400 Richardson chill unit (RCU). Apples require a higher chill unit than do the other deciduous fruit types presented in Table 1. The chill unit requirement for pears ranges between 850 RCU and 1200 RCU. The Williams Bon Chretien pears cultivar has the highest chill unit requirement of 1200 RCU. Other deciduous fruits such as nectarines, apricots and plums have relatively moderate chill unit requirements. Considering the long life span of deciduous fruit in comparison with annual crops and the huge investment required for their establishment, growers of deciduous fruit crops are particularly vulnerable to changes or the absence of the required chill unit.

### Impact of climate change on crop water requirement

The development of water balance and crop models and the impact of these models on production have been reviewed.<sup>14</sup> Models such as Agricultural Catchment Research Unit (ACRU), CANE-GRO, CERES, PUTU, SAPWAT and SWB were considered in the review. Of all the models considered, SWB<sup>15</sup> and SAPWAT<sup>16</sup> are easily assessable. SWB is a crop growth simulation model that was specifically developed to improve real-time irrigation scheduling.<sup>17</sup> SWB adoption has been relatively slow and the user base is still very small because it is cumbersome to set up the model and to simulate predefined irrigation schedules.

SAPWAT<sup>16</sup> was used to estimate crop water requirements for the base or observed climate (1971–1990) and for the intermediate future climate (2046–2065). It is a further development of CROPWAT and is used to estimate irrigation requirements of crops under varying crop production approaches and climates. The present and future periods are of the same duration for easy comparison. SAPWAT was developed as a planning and management tool for the estimation of crop water requirements by irrigation engineers, agriculturists, managers and farmers in South Africa.<sup>16</sup>

SAPWAT is founded on internationally acknowledged principles of estimating crop water requirements; as a result, the user base is large. Furthermore, government considers it a tool to benchmark lawful water use under the *National Water Act (Act 56 of 1998)*. It is easy to use the model because it is supplied with weather data and a unique set of crop parameters specific to South Africa.<sup>17</sup> In addition, the crop varieties database in SAPWAT is extensive and it has provision for tree and deciduous crops which is not common in other models. SAPWAT uses the Koppen climate system<sup>18</sup> for calculating crop coefficients and will therefore make it widely acceptable<sup>14</sup>.

**Table 1:** Selected fruit types in Ceres and Richardson chill unit (RCU) requirements

Apples	RCU	Pears	RCU	Apricots	RCU	Nectarines	RCU	Plums	RCU
Golden Delicious	1400	Forelle	850	Soldonne	650	August Red	650	Angelino	400
Top Red/ Starking	1400	Williams Bon Chrétien	1200	Bebeco	700	Fantasia	600	Southern Belle	600
Royal Gala	1200	Packham’s Triumph	900	Ladisun	500	Flamekist	700	Fortune	400
Granny Smith	NA	Abate Fetel	850	Suaprieight	450	Summer Bright	550	African Delight	250

An artificial weather station (i.e. a subset of the original weather station that was reparametrised based on future climate projection) was built into SAPWAT to calculate crop water requirements for the intermediate future in the absence of any information to that effect. It is hypothesised that with climate change, crop water requirements will increase. Two different types of irrigation technologies – drip and sprinkler irrigation systems – were considered and analysed. These are the most common types used in the Ceres region.

SAPWAT uses the basic methodology proposed in FAO-56<sup>19</sup> in its calculation of crop water requirements utilising the reference evapotranspiration rate ( $ET_0$ ) and the crop coefficient ( $K_c$ ). In order to get the crop water requirement, the calculated reference evapotranspiration ( $ET_0$ ) needs to be linked to the crop for which a water requirement is to be determined.<sup>16</sup> This is achieved through the use of a crop coefficient ( $K_c$ ) that is defined for each of the four growth stages of the crop, then the sum gives an estimated crop water requirement or crop evapotranspiration ( $ET_{crop}$ ).<sup>16,19</sup>  $K_c$  relates the water use of specific crops to  $ET_0$ . This approach takes into consideration the fact that trees need different amounts of water throughout their annual cycle. The mathematical representation is:

$$ET_{crop} = K_c * ET_0 \quad \text{Equation 1}$$

SAPWAT<sup>19</sup> makes use of the dual crop coefficient approach. The crop coefficient ( $K_c$ ) is subdivided into smaller components: a basal crop coefficient ( $K_{cb}$ ) and an evaporation coefficient ( $K_e$ ) as has been identified by expert consultation in Rome.<sup>20</sup> Equation 1 then becomes Equation 2<sup>16</sup>:

$$ET_{crop} = (K_{cb} + K_e) ET_0, \quad \text{Equation 2}$$

where  $ET_{crop}$  is crop evapotranspiration (mm/day),  $ET_0$  is reference evapotranspiration (mm/day),  $K_{cb}$  is the basal crop coefficient and  $K_e$  is the soil evaporation coefficient. Detailed information on the calculation of crop evapotranspiration is available in SAPWAT's user manual. The value of  $K_{cb}$  is read from the table entitled 'Cropdetail' which gives growing period lengths and  $K_{cb}$  values for different crops, while  $K_e$  is calculated from weather data.

The total volume of water that can evaporate from a soil surface is influenced by soil water content, soil characteristics and canopy cover. SAPWAT uses monthly or daily weather data as a basis for calculating daily Penman–Monteith reference evapotranspiration ( $ET_0$ ) values for a site, as described by Allen et al.<sup>19</sup> Weather data in SAPWAT come from five possible sources: CLIMWAT, manual weather stations, automatic weather stations, and user's own weather station data or imported data from external sources.<sup>16</sup> SAPWAT included the full set of CLIMWAT data, as well as 50 years' daily data for each quaternary drainage region of the country,<sup>21</sup> and the daily value for some standard and automatic weather stations.

Using the already built-in weather data information, climate station, soil type and relevant irrigation technologies, the crop water requirement for the base period was estimated for selected fruit crops. The H10C quaternary weather station data was used for the estimation of crop water requirements. This weather station is the closest to the Ceres dam (main source of water supply) and to the farms in the region.

In order to estimate irrigation crop water requirements for the future, an artificial weather station called 'H10C post climate' was created in SAPWAT. Future relative (%) changes in mean annual rainfall, mean annual temperature, and change in the Penman–Monteith reference potential evaporation for the 'high' and 'low' GCMs, based on the A2 emission scenario by Schulze<sup>22</sup>, were used. These scenarios represent two of the five climate models ('high' = ECHAM5/MPI-OM; 'low' = IPSL-CM4) used in the 'average of models' approach adopted.<sup>22</sup> The future relative changes (%) are presented in Table 2. Using the information presented in Table 2, the artificial weather station created was utilised to estimate crop water use for future climate. The 2046–2065 data are a representative of the mid-century data.

There will be a general increase in temperature in the Western Cape in the future.<sup>12</sup> Figure 1 presents the projected temperature anomalies.<sup>12</sup> The increase in temperature will result in higher evaporation and possibly result in lower run-off. The average temperature in the Western Cape is projected to increase by approximately 1–2 °C in the mid-century.

**Table 2:** Future projected change in climate parameters for H10C station

	Change in mean annual rainfall	Change in mean annual temperature	Change in Penman–Monteith reference potential evaporation
Low	+10%	+20%	+11%
High	+8%	+12%	+7%

### Impact of climate change on chill unit accumulation

Temperature during winter affects the development and growth of the buds of deciduous fruit, even though this might not be visible from the outside during the dormant period.<sup>23</sup> Temperatures during winter can also influence flower quantity and quality, the timing and abundance of flowering.<sup>23</sup>

Chill unit models provide information on how cultivars fare under the current and future climate conditions, inform producers of the stage of phenological development during the growing season and prediction of maturity dates which improve market delivery of fruits. Three important monitoring systems for chill units have been commonly applied: the Utah (Richardson) model<sup>24</sup> measuring RCU, the Infruitec model (daily positive Utah model) measuring Infruitec chill units and the dynamic chill model<sup>25,26</sup> measuring dynamic chill portion (DCP). Studies on winter chill and chilling requirements often implicitly assume that all models can be used interchangeably because the choice of model is not important.<sup>27</sup> However, many studies have shown that the choice of model is very important.<sup>28</sup>

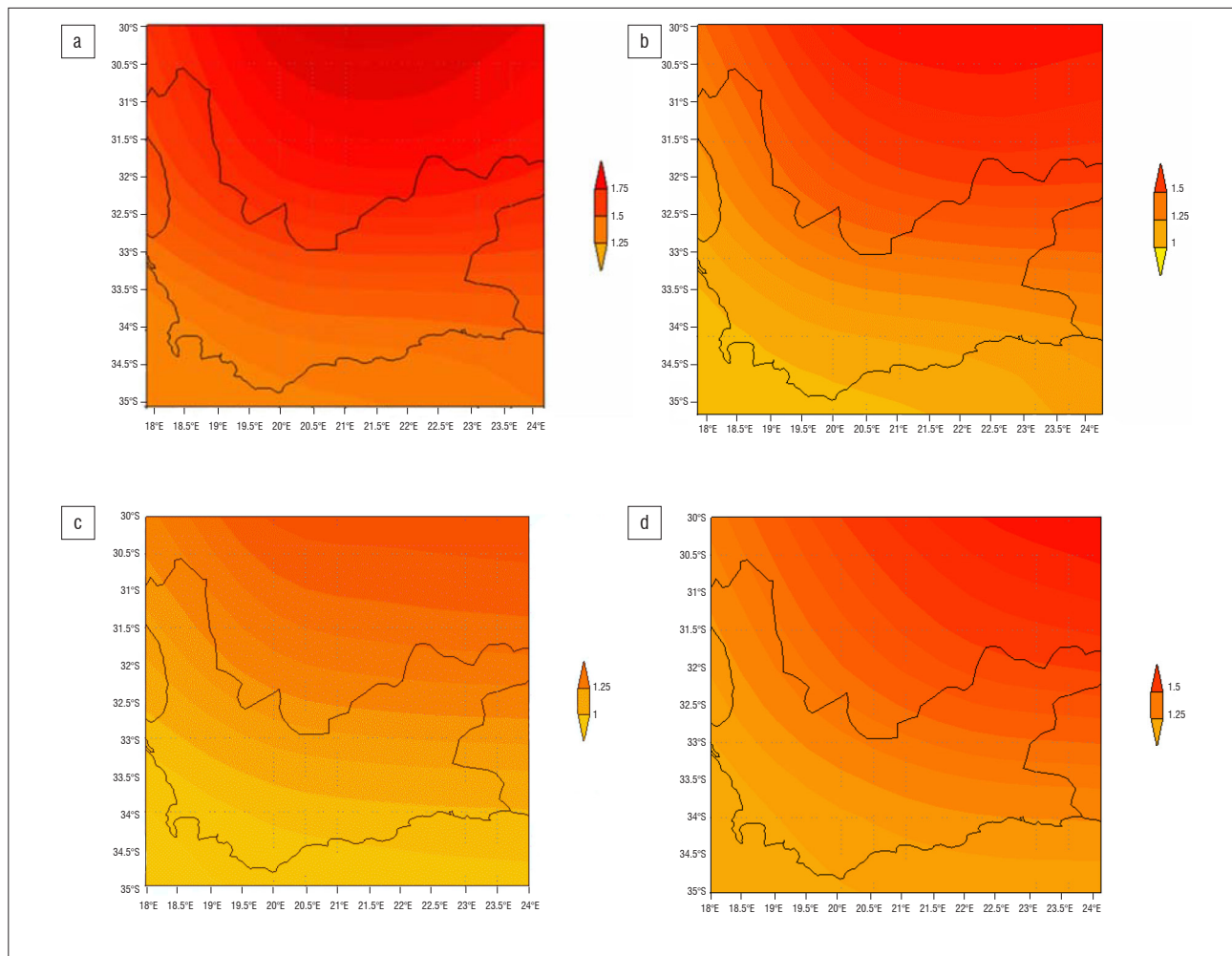
The Richardson and Infruitec models accumulate in a similar manner; the accumulation table is set out in Table 3. The Utah model allocates chilling units for each hour at a given temperature, with temperatures between 2.5 °C and 9.2 °C being the most conducive for chill unit accumulation (Table 3). Richardson suggests that the full chill unit can be acquired when the temperature in an hour is between 2.5 °C and 9.2 °C. This model has been approved by the South African deciduous fruit industry in the southwestern Cape.<sup>29</sup> High temperatures and temperatures below 0 °C are not effective for chilling. Higher temperatures in some models neutralise the positive effects of chilling and negative chill units are applied when temperatures surpass the threshold or when they are lower than the threshold.<sup>24</sup>

**Table 3:** Accumulation table for Richardson and Infruitec chill unit models

Temperature (°C)	Richardson units	Infruitec units
< 1.4	0	0
1.5 – 2.4	0.5	0.5
2.5 – 9.1	1	1
9.2 – 12.4	0.5	0.5
12.5 – 15.9	0	0
16 – 18	-0.5	0
> 18	-1	0

Sources: Hacking<sup>31</sup>, Zhang and Taylor<sup>32</sup>





**Figure 1:** Projected temperature anomalies for the Western Cape, South Africa: (a) December–February, (b) March–May, (c) June–August and (d) September–November.

The Infruitec model calculates chill units by making use of the average temperature for each hour, added together every 24 h. In a situation in which the total for the 24-h period is negative, it is taken as zero, but if the total is positive, it is added to the monthly total. This is important in warm growing regions in order not to miss important effects and introduce the risk of the model failing when simulating warming scenarios. Originally, these units were called ‘modified Utah chill units’<sup>30,31</sup>, then ‘positive daily Richardson units’, and finally ‘daily positive Utah chill units’<sup>29</sup>. This model has been established to give a more precise estimate of winter chilling in regions with mild winters, as well as in areas suffering from very cold winters.<sup>32</sup>

The dynamic model<sup>25,26</sup> was introduced in the 1980s as a new concept for the negation process<sup>32</sup>. This model is based on the premise that winter chill accumulates as a result of a two-step process. In the first step, the cold temperatures initially result in the formation of an intermediate chilling product. This process is reversible, and the intermediate product can be destroyed by high temperatures. Once a critical amount of this chilling product has accumulated, it converts to a chill portion, which cannot be destroyed or reversed. The dynamic model is unique in a number of ways: (1) the importance given to the sequence of temperatures during the cold season<sup>28</sup>; (2) the explanation of the observed negative effect of high temperatures<sup>28,33,34</sup>; and (3) the limit to the quantity of chill that can be reversed<sup>35</sup>.

A review of the literature shows that the dynamic model is the most plausible model – more complex but also more accurate.<sup>28</sup> The ‘chilling hours approach’ is very sensitive to temperature increases, and has been found to perform poorly, especially in warm growing regions.<sup>28</sup>

All the models (Richardson, Infruitec and dynamic) have been applied in South Africa<sup>36–38</sup> and the dynamic model has been found to produce good and consistent results<sup>28</sup>. Based on this justification, we adopted the dynamic model to estimate accumulated chill portion for major fruit crops in Ceres.

The models make use of hourly temperature data to calculate accumulated chill units or portion. Hourly temperature data are not available for the base period. Available for use in this study is the daily maximum and minimum temperature. The sine curve mathematical formula is used to convert daily maximum and minimum temperature data to hourly data, thereby attempting to simulate a sinus curve of hourly data, derived from daily maximum and minimum data values.

The temperature curve shape responds to the daytime solar cycle, and the temperature wave from sunrise to sunset can be described by Equation 3<sup>7</sup>:

$$T(t) = (T_{max} - T_{min}) * \sin\left[\frac{\pi t}{D + 4}\right] + T_{min} \quad \text{Equation 3}$$

In order to define night-time cooling, starting at sunset, Equation 4<sup>7</sup> is used, given as:

$$T(t) = T_{ss} - \left[\frac{(T_{ss} - T_{mn})}{1n(24 - D)}\right] \ln(t), \quad \text{Equation 4}$$

where  $T(t)$  is temperature at time  $t$  after sunrise or at time  $t$  after sunset,  $T_{max}$  is maximum temperature,  $T_{min}$  is minimum temperature,  $D$  is day length (in hours) and  $T_{ss}$  is temperature at sunset.

The calculated  $T(t)$  is used to estimate the accumulated chill units. Change in mean annual temperature, as presented by Schulze<sup>22</sup>, is used to adjust the base temperature for the estimation of future accumulated chill units. H10C quaternary weather station data in SAPWAT were extracted for calculation of accumulated chill units. Apart from the horticultural models, other modelling approaches have been proposed.<sup>39,40</sup> However, these models have not been extensively applied on fruit trees.<sup>28</sup>

## Results and discussion

### Impact of climate change on crop water requirement

Table 4 presents the results of the crop water requirements from SAPWAT for both the low and high GCMs. The results show that water requirements will increase substantially for both types of irrigation, with both low and high GCMs following a similar trend. Table 4 indicates that the crop water requirements for fruit crops range between 2830 m<sup>3</sup>/ha and 4130 m<sup>3</sup>/ha for sprinkler irrigation in the base climate while that for the future climate ranges between 3400 m<sup>3</sup>/ha and 4880 m<sup>3</sup>/ha for low GCM and between 3280 m<sup>3</sup>/ha and 4690 m<sup>3</sup>/ha for high GCM. In the case of drip irrigation, the values are smaller with the base climate crop water requirement ranging between 1950 m<sup>3</sup>/ha and 2900 m<sup>3</sup>/ha, while that for future climate ranges between 2320 m<sup>3</sup>/ha and 3390 m<sup>3</sup>/ha for low GCM and between 2190 m<sup>3</sup>/ha and 3280 m<sup>3</sup>/ha for high GCM. Of all the fruit crops considered, peaches use the most water – both in the present and projected future climates.

**Table 4:** Estimated crop water requirement (m<sup>3</sup>/ha) for the base and future climate of Ceres

	Crop option	Sprinkler irrigation			Drip irrigation		
		Base	Future (low)	Future (high)	Base	Future (low)	Future (high)
<b>Fruit</b>							
Apples	Bud break: Mid spring	2980	3510	3320	2110	2510	2390
Apricots	Bud break: Early spring	2830	3400	3280	1950	2320	2190
Pears	Bud break: Late winter	3980	4690	4470	2790	3320	3180
Nectarines	Bud break: Mid spring	3480	4090	3890	2350	2780	2650
Peaches	Bud break: Mid spring	4130	4880	4690	2900	3390	3280
Grapes	Bud break: Mid spring	2870	3410	3310	2170	2550	2460
Plums	Bud break: Early spring	3390	3950	3790	2180	2580	2480

In general, Table 4 shows that water use for drip irrigation is less than that for sprinkler irrigation because of efficiency differences in the irrigation systems, with less water applied during drip irrigation.

Crop water requirement (or water use) is dependent on the cultivar of each crop chosen, as cultivar differences also play a major role. Apart from cultivar, planting density and other management practices also play significant roles in determining crop water requirement. Table 4 shows that crop water requirements will increase as a result of projected climate change. The change can be attributed to the increase in temperature projected for the future. The crop with the highest deviation from the base climate in both irrigation systems is apricot (20% for sprinkler irrigation and 19% for drip irrigation for the low GCM). Savings in irrigation water usage could be achieved through the use of accurate and timely irrigation forecasts during the vegetation period. Looking at the current water situation in South Africa and the recent drought, farmers

will have to strategically manage water. The Koekedouw Dam in Ceres, which is the main source of water for the orchards, stood at 35% of its 17.2 million m<sup>3</sup> capacity in November 2015. Based on the findings presented in Table 4, an important adaptation strategy is to suggest a more efficient irrigation system to mitigate the impact of increased water scarcity caused by climate change. Table 4 shows that future crop water requirements for drip irrigation systems are still lower than the current water requirements under sprinkler systems. Accordingly, despite a substantial increase in water requirements under drip irrigation, the total water requirement will be less under a drip system, compared to a sprinkler system.

### Impact of climate change on chill unit accumulation

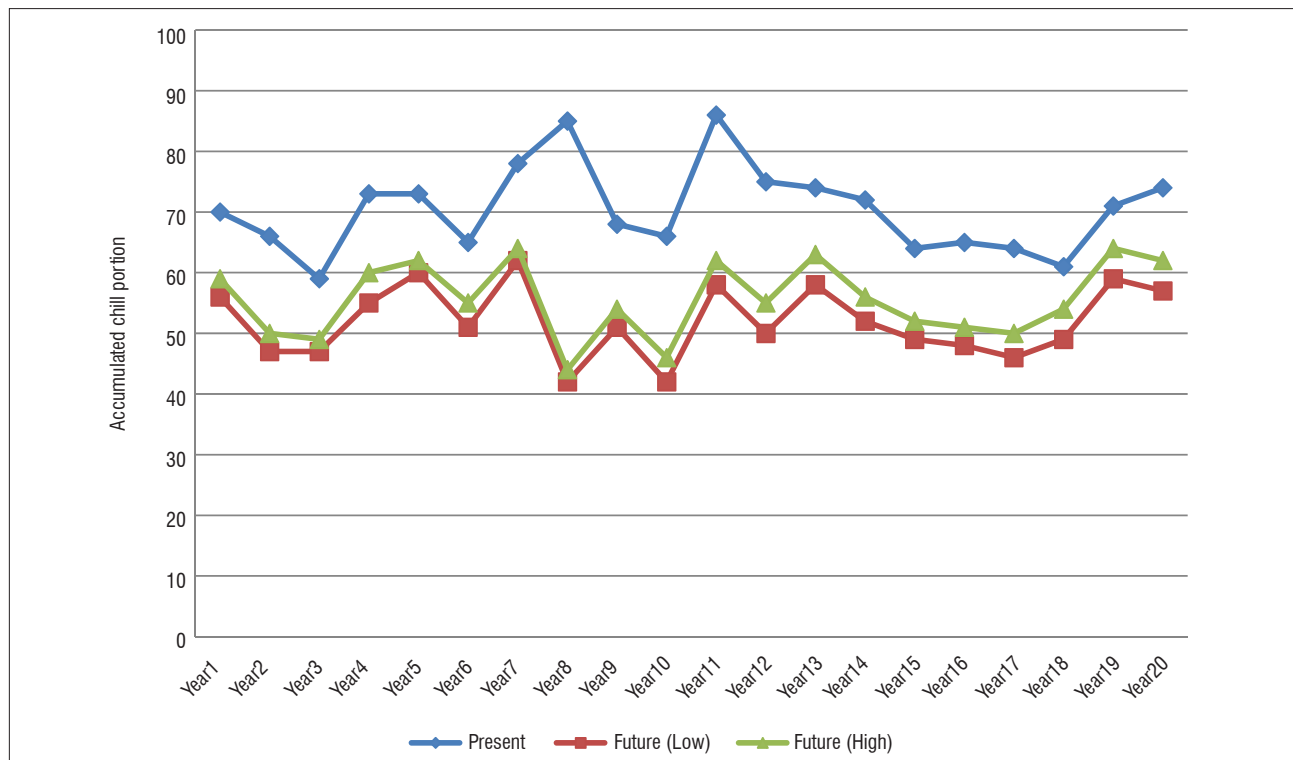
Figure 2 presents the accumulated chill portion in DCP from the dynamic model for the present (1971–1990) and representative mid-century future (2046–2065) for both the low and high GCM. The calculation was done from May to August for each year of the study period. The mean accumulated chill for the present climate is 70 DCP while that of future low and high GCMs are 52 DCP and 56 DCP, respectively. Figure 2 indicates that, with increase in temperature, the accumulated chill units will reduce in the future. We observe a high level of correlation ( $r=0.9832$ ) between the future low and high accumulated chill units, confirming the same direction of movement for both the low and high GCM estimation.

Results from the model confirm that the accumulated chill units will reduce in the future as a result of climate change. This reduction will have a significant impact on fruit production in the study area. It is evident that farmers will have difficulty in the future in producing fruit crops that require higher chill accumulation, such as apples and pears. Other fruit crops with moderately low chill unit requirements, such as nectarines and plums, are not likely to be affected. This provides the producers with alternatives but may impact significantly on South Africa's long-term export strategy, given the contribution made by Ceres farmers. Therefore, adaptation in the medium to long term is required for future sustainability of the fruit industry.

## Conclusion and recommendation

South Africa is a major exporter of fruit crops. More importantly, because of its geographical location in the southern hemisphere, it contributes to all year availability of fruit in the global market place. Deciduous fruit production is already at a marginal level; the projected impact of climate change will add more stress for fruit growers. In the case of apples as an example, South Africa is the 8th largest producer according to 2014 statistics. The country has a 6% share of the world market. Any changes in the status quo because of projected climate change will destabilise global supply with an inevitable impact on the delicate South African economy. Pressure has already been built up within the fruit industry and an effective, quick and integrated response is required to maintain market share.

It is clear that climate change will affect cropping practices in the future. Therefore, when suggesting adaptation measures to be applied to increase water use efficiency, a holistic approach that incorporates productive use of water by crop, the use of water in the root zone for transpiration and conversion into marketable product, as well as the delivery of water from source to soil efficiently, needs to be considered. In order to remain in production, farmers need to adapt to climate change stress by putting in place water resources and crop management plans. Producers must pay close attention to the usage of efficient irrigation technology as well as plant the right crop in the right place, or they must be fortified with a collection of management or adaptation tools to anticipate and address climatic disparities of cultivar and climate. Adaptation plans could include allocation of water optimally to irrigators and competing users in times of shortage, especially taking account of food security needs, and other factors relating to efficient water use. Water pricing incentives have a role to play in the framework of food security at provincial and national levels. The incentives also play a role in ensuring good quality fruits which will increase the export value and generate foreign income.



**Figure 2:** Comparison between the accumulated chill in the present and future climate using the dynamic chill portion model.

Breeders need to breed more drought-resistant varieties of deciduous fruits, with more rapidly responding phenologies that require lower positive chill units. This should, however, be done now because deciduous fruit species, for example, have long response times. In the short term, producers may opt to rely on the use of artificial rest-breaking chemicals in cases of low accumulation. However, chemicals can, especially when applied at the wrong time, lead to phytotoxic damage to fruit buds resulting in poor fruit sets. It can also increase the production costs and hence have an impact on the profitability of such an enterprise.

The value of this study lies in its ability to offer the projected future values that will guide producers in the selection of cultivars when re-establishment of their orchards is done. It might be easier for annual crop farmers to implement management practices such as a change of the planting date or a complete shift to another variety or cultivar at will, from one season to another. In the case of deciduous fruit farmers, a substantial and long-term investment is required for the establishment of the orchards, making them more vulnerable to the long-term effects of climate change compared to the growers of annual crops. In the case of deciduous trees, once orchard managers or farmers have selected and planted their tree cultivars, they require these trees to remain in production for decades. Adaptation will likely require a transition to different species or cultivars or the development of management practices (planting density, pruning practices and irrigation regime) that can help overcome shortages in winter chill. But this adaptation needs to be anticipated years in advance. The present study offers a means of making this possible.

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### Authors' contribution

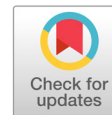
The study is based on O.A.'s PhD work entitled 'The economics of climate change adaptation strategies in the Ceres region, Western Cape'. O.A. was responsible for the conceptualisation of the study, data collection, modelling and writing of the first draft. H.J. co-supervised the study and read and made contributions to the first draft.

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# The role of plant breeders' rights in an evolving peach and nectarine fresh fruit sector

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The evolving impact of plant breeders' rights was investigated in a bid to provide a basis for understanding the complex relationship that exists between scientific, legislative and market matters that shape the peach and nectarine fresh fruit sector. The results show that there is complementarity among varietal legislation, deregularisation, international trade policies, market trends and research intensity. Plant varietal legislation is found to play a facilitative role in ensuring the growth in the sector which has evolved from merely facilitating access to better quality cultivars which were bred beyond South Africa's borders, to the provision of good quality germplasm that aids in the breeding of locally bred varieties which better meet the production needs of local farmers. The results of the analysis show that strengthened varietal legislation has contributed significantly to cultivar development, reduced varietal concentration, increased resource (land) utilisation and increased export revenue generation and market penetration. The study warns of the negative effects that widening the scope of the *Plant Breeders' Rights Act* would have on innovation and cultivar access by poor farmers. Because of the strong ties existing between innovation and R&D investment, the recommendation is for an increase in R&D investment in the local research institution.

## Significance:

- Insights into the impact of legislation on the industry's growth and development are given.
- Empirical evidence related to the sector's performance of the innovation market is presented.

## Introduction

There is a general consensus that technical innovation can aid in solving diverse challenges facing the agriculture sector. According to Nhemachena et al.<sup>1</sup>, integrated innovations in areas such as seeds, biotechnology, crop protection, grain storage and transport are critical in improving global agricultural productivity. Seed development, in particular, has been hailed as one area of great importance as the seed contains the genetic code which sets the potential frontline of the production quantity and quality of an agricultural industry.<sup>2</sup> As seed or cultivar development also plays a pivotal role in ensuring global economic development<sup>3</sup>, it is necessary to promote the exchange of such technologies across country borders because such innovations require substantial investments over long time periods (10 to 15 years<sup>1</sup>) to yield returns. The development of Intellectual Property Rights (IPRs) for plant varieties, such as plant breeders' rights (PBRs), has been instrumental in providing a secure business environment which allows breeders to achieve recognition for their efforts and receive compensation for their investments, while promoting the exchange of plant material.

The provision of IPRs for plant varieties has been a bone of contention since the introduction of the rights to living organisms.<sup>4</sup> There is a general notion that plant variety laws favour the interests of multinational cooperates that are involved in their development at the expense of the farmer and the consumer<sup>5</sup>, particularly in developing countries<sup>6</sup>. The mixed results that are reported on the impact of plant variety legislation continue to fuel heated debates on whether such legislation stimulates or discourages shared economic growth. Various reports in developing countries have shown that plant variety legislation has contributed to higher foreign direct investment; increased genetic diversity; increased production of varieties which produce higher yields with a better quality agricultural output which have improved food security; and facilitated the provision of varieties which promote the use of sustainable farming practices.<sup>1</sup> These reports imply significantly large economic benefits. In contrast, other findings show that the presence of PBRs has deterred seed development and hindered the economic participation of small-scale farmers in developing countries and has, overall, left the developing community worse off.<sup>2,7</sup> Some find little evidence showing the achievement of intended goals.<sup>8</sup>

For the global peach industry, the development of plant IPRs was followed by the commencement of 'The Golden Age of Peach Breeding'<sup>9</sup> – an era in which milestones in breeding techniques and in the quality and quantity of research outputs were achieved. Not much has been documented of the effects of this controversial legislation on peach production. Thus, a myriad of questions remain unanswered. A few of these questions – which were investigated in this study using South Africa's dessert peaches and nectarines fresh fruit sector as a case study – are:

- Have the benefits of agricultural biotechnology proliferated globally<sup>10</sup>?
- Has the legislation which promotes varietal exchange made any impact on variety adoption and cultivar concentration?
- Have these developments affected market concentration and participation in global markets?
- Has the market-oriented PBR legislation been to the benefit or detriment of South Africa, and how can the legislation be amended in such a way that the research community can maximise its gains?

## History of plant variety protection

The initial idea of granting varietal ownership largely came about as a result of the need for accountability in a market that was dominated by products which showed wide variations. There was a need for a legally binding warranty which would ensure that the packed seeds were actually of the named variety on the label of the product.<sup>3</sup> Hence, the first type of plant protection legislation – plant patents – enabled the carrying out of quality tests that certified the precise characteristics of a seed under a specific name which was recorded in an official seed register.<sup>10</sup> The patent defined the technological territory of an invention and, therefore, formed the basis of determining infringement, so enabling the inventor to demand compensation for the use of their invention.<sup>11</sup> Under patent law, an applicant was and still is expected to supply a detailed description of the invention which is being claimed as novel. The inventor is required to disclose the description of the invention so that others skilled in the art may replicate the invention, thus ensuring that knowledge is socially diffused.

In 1953, countries agreed to the International Code of Nomenclature of Cultivated Plants which detailed the definition of plant varieties and norms for granting varietal names. This agreement created a technical space for the granting of rights for varieties as it identified the fundamental differences that occur within species.<sup>12</sup> Based on this agreement, the International Union for the Protection of New Varieties of Plants (UPOV) Convention developed the *sui generis* system in 1963 which enabled protection of new plant varieties. This form of varietal protection was referred to as ‘plant breeders’ rights’. The greatest contribution of the PBRs was that they enabled the breeders to have the right to earn royalties by allowing other parties to use their reproduced seed. This early Convention was, however, confined to acts done for the purpose of trade and provided for farmers’ and breeders’ privilege. The farmers’ privilege allowed for farmers to reproduce any genetic materials for non-commercial use without requiring permission or payment from the right holder. Breeders’ privilege allowed the uncompensated use of a protected variety as parent material in the breeding of new varieties.

The UPOV Convention regulations merely played the role of harmonising and rationalising seed certification schemes across countries which chose to be part of UPOV. However, the Convention’s reach was limited because it only appealed to industrialising countries, as these were involved in seed development. The Convention was reviewed in 1972, 1978 and 1991 with the aim of further strengthening plant variety protection as a way of attracting more countries. Continuous amendment has resulted in the gradual erosion of residual rights. For instance, UPOV 1991 extended protection to all species, unlike the 1978 Convention which allowed member countries to designate which species or genera they wanted to include for protection. In 1991, the breeder exemption was adjusted to exclude varieties which show minor differences from original varieties, i.e. essentially derived varieties.<sup>3</sup> The same amendment made the use of saved seed for non-commercial utilisation a flexible requirement that is adjusted by the legislating state or country.<sup>11</sup>

South Africa acceded to the UPOV Convention in 1978<sup>13</sup>, which was followed by the amendment of the South African *Plant Breeders’ Rights Act*. One of the most important changes was the extension in the time for PBR protection from 15–20 to 20–25 years. In general, the strengthening of plant variety protection has had a positive impact on South Africa’s agricultural sector. For a country that was trying to change historical trends of heavy state dependence in the area of research and development (R&D) funding, the PBRs did well in providing an avenue for revenue collection which enabled research organisations to generate income that funds their research activities. The income earned from royalties and IPRs during 2000 was reported to make up 10.3% of the total R&D expenditure of the national parastatal – the Agricultural Research Council.<sup>14</sup> This amount increased to 12% in 2012.<sup>15</sup> However, the share of royalties is largely the result of the decreasing amount of funding which the organisation is receiving, therefore the trend of revenue collected (after adjusting to inflation) may be described as stagnated.

## Research methods and data

Not much literature exists on the impact of IPRs on plants in developing countries, as compared with the developed countries. This type of analysis has not been carried out in many of these countries because of inefficient time series data being available owing to the later stage at which developing countries joined the UPOV Convention.<sup>12</sup> Studies that have analysed changes in plant variety protection in developed countries include those done by Diez<sup>16</sup>, Srinivasan<sup>17</sup> and Pardey et al.<sup>4</sup> These studies have analysed the trends and changes in plant variety protection policies; the effects of IPRs on plant breeding investment; production of new varieties; and market power or concentration, as well as varietal concentration ratios. Louwaars et al.<sup>18</sup> and Tripp et al.<sup>12</sup> conducted extensive studies on IPRs in five developing countries: China, Colombia, Kenya, Uganda and India. The two studies analysed similarities and differences in the individual countries’ evolution of plant variety protection policies; enforcement and costs of plant variety protection; production of new varieties; and market competition. A study by Nhemachena et al.<sup>1</sup> in South Africa focused on assessing the sources of IPRs and determining their impact on plant protection variety registration.

This study focuses on the sources of IPRs as a way to show how PBR legislation has influenced the development and use of locally bred and imported varieties. This is done by assessing adoption trends and varietal concentration ratios. An analysis of the shifts in production areas is also done to show how the strengthened legislation has managed to have a positive effect which seeps down to farm production level through improvements in resource utilisation. An assessment of export market distribution is included to show how institutional strengthening has gone further to affect the country’s export market by improving market penetration and competitiveness.

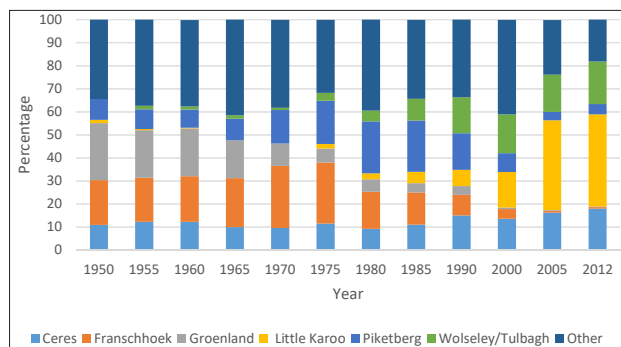
The PBR analysis undertaken in this study uses secondary data recorded between 1950 and 2014. Data on the cultivar adoption were collected from deciduous fruit tree censuses published in the annual reports of deciduous fruit producer organisations. Production distribution per cultivar was measured per tree during the 1950–1976 period and per hectare thereafter. This difference in the form of data is not expected to affect the results of this analysis as cultivar adoption was measured as a percentage of the total production area’s statistics. Information on the origins of the cultivars was gathered from deciduous fruit cultivar registries, research bulletins and annual research reviews. Data on export volumes and market distribution were collected from the annual reports of deciduous fruit producer organisations.

## Results and discussion

### *Changes in dessert peach and nectarine production*

#### Production area

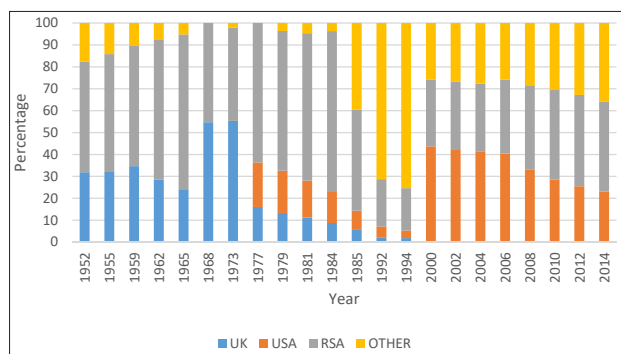
Figure 1 shows that the distribution of nectarine and dessert peach production has significantly changed over the years. In 1950, all dessert peach and nectarine production occurred in an area classified as the High Chilling Units (CU) Zone as it provides over 800 h of temperatures below 7°C in a production season. These conditions were provided in the Groenland, Franschhoek and Ceres production regions. Figure 1 shows that in 1950, 55% of the production was concentrated in these three regions. However, by 1980, the percentage production area of these three regions had reduced to 30% while Piketberg, a production region which provides 466.5 CU and is classified in the Medium CU Zone, became the main area for peach and nectarine production. There was no significant change in the production district distribution in the 1990s. However, after 2000, the Little Karoo production district – which provides 359–530 CU and is classified in the Low CU Zone – became the fastest growing production district as its share in total production area increased from 5.5% to 40% of the total production area between 2000 and 2012. The level of concentration of production has also increased with time as the area planted to other minor production regions has diminished over time.



**Figure 1:** Trend in regional distribution of peach production in South Africa, 1950–2012.

**Cultivars used in production**

The shift to warmer production areas was made possible by the use of cultivars which were adapted to warmer winter temperatures. Farmers also made use of dormancy-breaking chemicals which would enable the trees to progress to fruit-bearing stage without the provision of low, dormancy-breaking winter temperatures. The critical role that cultivar choice serves in this transition is shown in the narrow selection of cultivars. As shown in Figure 2, the industry continued to use the South African (RSA)-bred Early Dawn cultivar. However, it utilised increasing percentages of the UK-bred Peregrine and Duke of York cultivars and the US-bred Flamekist, Armking, Independence and Springcrest cultivars during this transition. As shown in Figure 2, the production share of locally bred cultivars decreased from 51% to 44% between 1950 and 1973 as a result of the increase in adoption of the UK-bred cultivars. As the use of the UK-bred varieties aided in overcoming the climatic limitation, their share in production rose from 32% to 55% between 1952 and 1967. Nevertheless, the influence of the UK-bred cultivars was limited owing to their limitations in pest resistance. Consequently, the adoption of RSA-bred cultivars rose to 73% in the early 1980s through the adoption of a new group of cultivars (Rhodes and Van Riebeeck) which had been bred to withstand higher temperatures and provide high pest tolerance, which was an essential quality attribute in cultivar selection for local farmers. Here the PBR legislation was instrumental in facilitating the availability of a wide variety of good-quality germplasm that the local breeders could utilise.



**Figure 2:** Share of area planted to different nectarine and dessert peach varieties classified according to genetic origin, 1952–2014.

The 1990s constituted a period which was characterised by market deregularisation and trade liberalisation. These changing market conditions created a demand for the adoption of many different, new cultivars<sup>19</sup>; particularly US-bred cultivars, as their share in production area increased from 4% in 1994 to 44% in 2000. Prior to 1990, the US-bred cultivars had struggled to acquire market share in South Africa, being planted to a maximum production share of 19% in 1979 as shown in Figure 2. However, with the easier importation of production inputs which resulted from better trade relations, South African farmers realised that they could viably utilise the US-bred cultivars. The US-bred cultivars were especially

popular because they had lower labour cost implications as a result of their dwarf tree structures which required less pruning and trellising. The introduction of modified production practices tailored to the new cultivars facilitated the improved utilisation of land, as these allowed for high-density plantings of between 1667 and 3333 tree/ha.<sup>20</sup> These densities were much higher than the 600 trees/ha that was the industry average before 1970. The RSA-bred cultivars that were adopted after 1994 met these high-density planting requirements, hence their continual use after 2000, as shown.

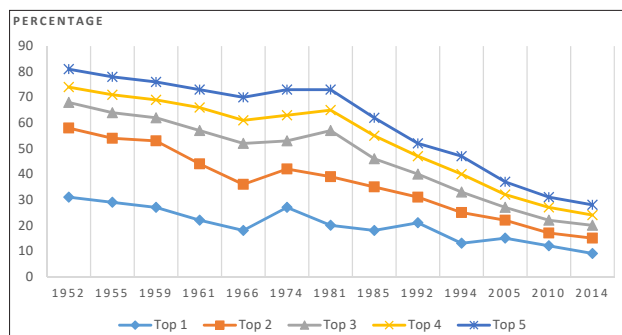
**Varietal development and concentration ratios**

As outlined in the section above, the significance of the *Plant Breeders’ Rights Act’s* impact gradually shifted over time from that of providing cultivars planted in the field to that of providing cultivars mainly used as germplasm for breeding. This shift is especially true for nectarine cultivar development, which was a direct result of the variety exchange policies as all parent material was externally sourced, unlike the case of dessert peaches in which local wild varieties (landraces) were frequently used. Table 1 shows that South Africa experienced an increase in the rate of cultivar development between 1965 and 2014. The most significant was recorded in the last two decades, in which 21 cultivars were developed between 2005 and 2014, while 9 cultivars were bred during the 1985–1994 period. The influence of PBR policy on the Agricultural Research Council’s productivity was also enabled by the availability of advanced breeding technology and the adoption of modern breeding techniques. Of much influence was the change in the national research funding policy, which gradually shifted towards funding individual projects based on the success of the adoption of their research output. The competitive way in which research funds are allocated<sup>21</sup> has resulted in reductions in funding of other activities, such as soil research, as well as in similar breeding projects which rely on the same funding sources<sup>22</sup>.

**Table 1:** Number of dessert peaches and nectarines bred in South Africa, 1965–2014

Years	Dessert peaches	Nectarines	Total
1965–1974	1	–	1
1975–1984	2	1	3
1985–1994	4	2	6
1995–2004	4	5	9
2005–2014	4	17	21

As a consequence of success in local breeding, the fresh fruit sector utilises an increasing number of varieties, as shown in Figure 3. As illustrated, the area planted to one variety has decreased (shown by the negatively sloped graphs). The gradients of the graphs’ slopes increase with an increase in the number of cultivars, indicating that cultivar concentration has shifted from the Top 1 cultivar to the Top 5 cultivars. This shift indicates a general improvement in the quality of cultivars, as the difference in production share between the shares of the Top 1 and Top 5 category has reduced. As shown in Figure 3, the percentage area shares planted to the Top 1 and Top 5 cultivars were 31% and 81% in 1952, respectively, while the area shares planted to the Top 1 and Top 5 cultivars were 9% and 28% in 2014, respectively. Improvement in cultivar quality is further highlighted by the fact that the concentration levels of the Top 1 cultivar in 1952 are comparable with those of the Top 5 cultivars in 2014. Lower varietal concentration is advantageous to the sector, as it implies that the production risk is spread. That is to say, if the yield of one cultivar were to be negatively affected by, for example, a newly discovered disease, farmers would have the option to switch to alternative cultivars that perform on par with the affected cultivar. Lower varietal concentration also has enabled better fruit handling, as the harvest season is spread over a longer period. Staggered harvests have had positive implications for improving fruit quality and reducing post-harvest losses.



**Figure 3:** Varietal concentration of nectarine and dessert peach cultivars in South Africa, 1952–2014.

One of the limitations of the tree census data used in this section is that the data for cultivars which had small shares of the production are clustered. This clustering introduces some ambiguity as to the effect of the *Plant Breeders' Rights Act*, especially in a case in which a significant portion of the area is reported as 'other varieties', as shown during 1992 and 1994. In order to uncover more detail, this PBR analysis is extended in the next section to investigate the impact of legislation on exports. Here, the details on cultivar origins are recorded with less aggregation.

### Changes in dessert peach and nectarine exports

Fruit firmness is the main characteristic used to determine whether a cultivar can be used for export. An export regimen typically endures 3–4-week voyages by sea<sup>23</sup>; therefore, cultivars are required to have some level of firmness at harvest for them to withstand harsh transportation conditions which can cause reductions in fruit quality and shelf life. Through the use of the PBR legislation, varieties which better meet these needs have been introduced and as a result, the proportion of annual peach and nectarine production that is exported as fresh fruit increased from 1.8% to 6% between 1949 and 2012.<sup>22</sup>

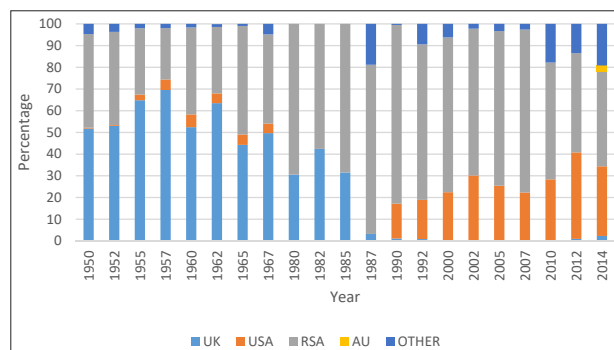
Because of this critical prerequisite, there is a difference in export cultivar composition from that which is reported at production level. To provide a detailed analysis, dessert peach exports will be analysed separately from nectarine exports.

### Changes in dessert peach cultivars use

Figure 4 shows the trends in cultivar use for dessert peach exports, classified according to the country of origin. As shown in Figure 4, South African dessert peach exports were mostly made up of UK-bred cultivars (Peregrine and Duke of York) and RSA-bred cultivars (Early Dawn, Inkoos and Marina) between 1950 and 1957. The UK-bred cultivars had higher export volumes, as their share in peach export volumes increased from 50% to 70%. With time, the industry began to realise that this concentrated cultivar use limited the industry's growth as the export of Peregrine and Early Dawn produced two distinct supply peaks during week 47 and week 1, respectively, which depressed prices to uneconomic levels. As a result, there was the need to introduce more cultivars that would stagger the fruit deliveries and maintain sustainable market prices. To rectify the situation, three more RSA cultivars – Rhodes, Culemborg and Van Riebeeck – were introduced, resulting in an increase in the RSA-bred cultivars' share in export volume percentage to 82% in 1990.

The most significant change in cultivar use patterns in the history of the sector was experienced after 1990 when agricultural market and political reforms led to the opening up of the country to new international markets. Thus, factors relating to international demand, as opposed to local sustainable production, began to play a greater role in cultivar selection. Consequently, US-bred cultivar share in exports increased from 16% to 32% between 1990 and 2014 owing to the large demand-pull effect of the export market. These cultivars were in line with the new consumer preference that had drifted towards a particular type of peach cultivar which was defined by its bright colour, sweet taste and preferred fruit size range.<sup>24,25</sup> According to Janick<sup>26</sup>, importers also preferred these

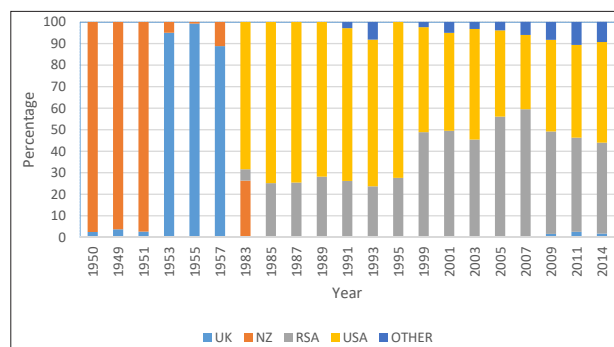
cultivars because they handled better, showed fewer bruises, and were less prone to diseases like brown-rot, which causes high post-harvest losses. Worth noting, is the continual presence of locally bred varieties which remained competitive in exports until 2014.



**Figure 4:** Changing distribution of nectarine and dessert peach export varieties by country origin, 1950–2014.

### Changes in nectarine cultivars used for exports

Differently from dessert peaches, South African exporters relied solely on imported nectarine cultivars from 1950 to 1986, as shown in Figure 5. From 1950 to 1966, only two cultivars met the export conditions of the industry. The New Zealand bred cultivar, Goldmine, constituted between 82% and 100% of the export volumes, while the UK-bred cultivar, Early River, made up the remainder. Census figures show that the Goldmine variety's performance on the market fell severely, as its export cartons reduced from 28 456 cartons to 5763 cartons between 1950 and 1957. However, as there was no alternative, this cultivar remained the main export cultivar. With the use of PBR legislation, the country was able to start using US-bred varieties – May Glo, Fantasia and Flavortop – after 1980. As shown in Figure 5, US-bred cultivars dominated the market by 1982, when 69% of the export volumes comprised US-bred varieties.



**Figure 5:** Changing distribution of nectarine export varieties by country origin, 1950–2014.

US-bred cultivars dominated export volumes until the 1990s. By 2000, the RSA-bred cultivars had gained ground and, in 2014, their export volume share was 40%. Other factors which drive their export use, in addition to high supply from local production adaptability, are: increasing consumer health awareness<sup>27</sup>, consumers' lack of loyalty to a specific cultivar, and the availability of new markets. Taking advantage of the institutional environment, exporters used a total of 167 cultivars in 2014. This use was a huge increase from the two cultivars which were used in 1966. The availability of a diverse number of cultivars has allowed exporters to implement an innovative marketing strategy which makes use of harvest dates, as opposed to volumes, as was done in the 1950s. Through the delivery of fruit harvested earlier and later in the season, the country has taken advantage of the high off-season prices and obtains premiums that range between 50% and 100%.<sup>28</sup> This has become the source of South Africa's competitive advantage against its biggest competitor – Chile – which has its competitive advantage based on volumes.



### Changes in export destinations

South African nectarine and dessert peach exports were mainly targeted towards supplying the UK market for the first part of the 1950s, as shown in Table 2. Volumes destined for the UK decreased from 63% to 29% between 1970 and 1975 as a result of export bans issued against South Africa during that time. As shown, the percentage of export volumes delivered to the alternative market, Europe, increased from 26% to 98% between 1970 and 1980. After 1990, the export restrictions were removed, and South Africa began to enjoy a wider export distribution, as shown by the larger diversity in export markets. The weakening demand in Europe played a part in the expansion towards the Middle Eastern and Asian markets, which showed strong growth potential.<sup>27</sup> A critical factor motivating this shift is the latter markets' less stringent non-tariff measures (ethical; sanitary and phytosanitary; and technical barriers to trade) when compared with the European Union.<sup>29</sup> The two largest export destinations classified under 'other' in 2012 were the United Arab Emirates and Mauritius – constituting 16% and 5% of export volumes, respectively.

**Table 2:** Distribution of dessert peaches and nectarines on global market (percentages)

Year	UK	Europe	USA	Other
1950	97	3	0	0
1955	72	28	0	0
1960	63	24	1	12
1965	65	19	0	16
1970	63	26	1	10
1975	29	65	3	3
1980	0	98	0	2
1985	0	97	0	3
1990	50	48	0	2
1995	40	42	0	18
2000	32	38	0	30
2005	52	22	0	36
2010	47	16	0	37
2014	49	21	0.5	29.5

### Summary and conclusion

The evolution of PBRs through the UPOV Convention from 1961 through to 1991 has positively affected the South African fresh peach and nectarine sector. The study has shown that the incentive that has been provided by PBRs has interacted with several factors such as deregularisation, international trade policies, market trends, adoption of non-variety technologies and research intensity. The combined effect of these factors led to the growth and development of the peach and nectarine fresh fruit sector. This study did not try to separate attribution between these different factors, but rather highlighted the critical facilitative role that the PBR legislation has played in contributing to the sector's growth.

During the early years after the introduction of the PBR legislation, the protection of plant variety served as a vehicle which enhanced the use of foreign-bred cultivars within South Africa. The importance of PBR legislation was shown by the widespread adoption of foreign-bred cultivars at production stage and their wide use for exports. These were instrumental in facilitating the penetration of export markets and encouraging the growth of export volumes. The use of these import

varieties also facilitated peach and nectarine production in areas which were once deemed unsuitable. The paper also highlighted a phase in the 1950s which testifies to how growth in exports can be halted by the lack of genetic diversity. During a later period, the role of PBR evolved to that of stimulating the development of locally bred varieties. The rate of cultivar development by local breeders more than doubled between the periods 1995–2004 and 2005–2014. The market share of locally bred cultivars has seen an increasing trend owing to the cultivars' good qualities. The wider availability and accessibility of better adapted cultivars has resulted in spreading production risk and higher remuneration across export markets.

The PBR legislation has provided a way for the local agricultural research parastatal to generate additional funds to finance its research projects. In 2014, 12% of the funding of the national agricultural research institution was acquired through royalties. Although the percentage of royalties from total research funding shows an increasing trend, the amount collected remains insufficient to meet all the funding needs of the institution. Encouraging growth in royalties collected by the Agricultural Research Council would require strengthening varietal legislation through widening PBR legislation's scope of protection and improving enforcement. However, the feasibility of such an amendment is constrained by the limited state administrative resources. Such a change is also likely to have negative welfare effects on local breeders and poor farmers as it will result in the reduction of the residual rights which are available at present. Focusing on raising funds through royalties will most likely cause an overemphasis on the need to address the research needs of commercial farmers who have the finances to purchase improved cultivars. Research resources will also be devoted to developing cash crop seeds instead of other crops (e.g. indigenous crops and unexplored crops such as rice) which may become more lucrative if given adequate research support. Therefore, policymakers are encouraged to carefully consider the mixed effects of such changes in legislation if they are to be implemented.

The study has shown that locally bred cultivars have made significant contributions to increasing resource (land) utilisation, export revenues and market penetration. As benefits are high, this provides a motivation for an increase in R&D funding to the local breeding organisation, the Agricultural Research Council. Civil society and agribusinesses share the benefits of research investments, therefore both government and the private sector should be equally motivated to support local breeding. The provision of private and public research funding would be a more viable way to secure finances for agricultural research, as the measures that would be required to increase royalty collection may not be feasible.

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# Teacher participation in science fairs as professional development in South Africa

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This research was undertaken to understand the perceptions of the Physical Sciences teachers who participate in the South African 'Eskom Expo for Young Scientists', regarding the educational significance of the science fair, and the extent to which expo participation provides an opportunity for professional development. The educational significance of this article is found in its contribution to the professional identity of teachers in their roles as organisers, mentors and judges. The model of Beijaard et al. (Teach Teach Educ. 2004;20:107–128) was used to characterise the teachers' professional identity in terms of professional knowledge, attitudes, beliefs, norms and values, as well as emotions and agency. Interviews with the Physical Sciences teachers were analysed using thematic analysis, ultimately interpreting and linking the categories of responses to the theme of professional identity. The study found that expo participation contributes to pedagogical knowledge, content knowledge (as both procedural and declarative or factual knowledge) and pedagogical content knowledge. Self-efficacy beliefs were strengthened, positive attitudes were developed, and strategies of inquiry-based learning and effective methodological instruction were observed during participation, which contributed to the participants' school-based teaching. Teachers learn both from their engagement with learners, and through networking opportunities with fellow teachers. Teachers themselves value these aspects, and consequently, science fair participation is a sustainable form of professional development. It is recommended that the opportunity for professional development that is provided by teachers' participation in such school-level science fairs should be acknowledged and promoted by schools and fair organisers.

## Significance:

- Science expos offer professional development to participating teachers and improve learners' academic performance.

## Introduction

In South Africa, academic performance and the improved skills of mathematics and science learners are priorities that the government supports through the Department of Basic Education and the Department of Science and Technology.<sup>1</sup> The Department of Science and Technology supports science fair events, which fall under the umbrella of the Eskom Expo for Young Scientists. This series of science fairs has taken place at schools at regional and national levels for several decades, having begun with leading high schools in 1980.<sup>1,2</sup> The vision of the Eskom Expo for Young Scientists (which we refer to simply as the Expo) is to encourage the participation of the most innovative and gifted learners across South Africa, from both rural and urban areas.<sup>1,3</sup>

It is thought that science fairs help learners to improve in both mathematics and science.<sup>4,5</sup> Science fairs rely on teachers to motivate and assist learners to identify potential projects, and to help them to present their projects. The roles of teachers in science fairs include mentoring, organising, collaborating, networking and judging.<sup>5</sup> While teachers participate in science fairs in various roles, it is not clear why they do so, especially for those who participate over long periods.

It has been reported that teachers believe that science fairs enhance the skills, attitudes and knowledge of learners, and encourage future careers in scientifically orientated professions.<sup>4</sup> They also believe that science fair projects have educational significance, in particular, that science fairs challenge learners with academic rigour, establish useful skills, and complement other efforts to address the science achievement gap.<sup>4,6</sup> Bencze and Bowen<sup>7</sup> and McComas<sup>8</sup> find that science fairs benefit learners through science inquiry and provide an advantage in science literacy.

## Problem statement

The literature that was reviewed explored learners' benefits in participating in science fairs, for example, Bigler and Hanegan<sup>9</sup> and Wirt<sup>10</sup> report that many learners who participate in science fairs improve their scientific skills, subject content knowledge, understanding, and interest levels. What this research sought to understand was the educational significance that teachers attach to science fairs.

The following research questions address the teachers' views on the significance of participation in terms of their professional identity, the details of their participation in these fairs, and what inspired them to become involved.

- What is the teachers' perceived educational significance of their participation in science fairs with regard to their professional identity and professional development?
- What is the educational significance of science fairs in the opinion of the teachers who participate as organisers, mentors and judges?

## Conceptual framework: Professional identity and roles

The conceptual framework used in this study consisted of two aspects, thereby forming a simple systems model (Figure 1). The major elements of this model are the teachers' professional identity with its components, as posited by Beijaard et al.<sup>11</sup>, the roles that teachers play in science fairs, and a postulated link between teachers' professional identities and their roles. It was further postulated that teachers' participation contributes to and benefits the teachers in terms of their professional development.

Professional identity is defined as the process of interaction between a person and their context, and may be characterised by professional knowledge, attitudes, emotions, norms and values, beliefs<sup>11-13</sup>, and agency<sup>11</sup>. The concept of professional identity is used to characterise the dynamic aspects of science teachers in the context that frames their professional activities. The resulting choices made by the teachers link their professional identity to their roles, and hence are placed in the forward component of the 'process' element of the simple systems model. It is put forward that participation in science fairs strengthens or influences aspects of the teacher's professional identity (an assumption supported by Botha<sup>14</sup> and van Putten<sup>15</sup>); this link is shown as the feedback component of the framework (Figure 1).

Teachers' professional knowledge involves content (or subject matter) knowledge, pedagogical knowledge, which relates to processes and practices of teaching and learning<sup>16</sup>, and pedagogical content knowledge (PCK)<sup>17</sup>, which is an integration of content, pedagogical and other various factors. Rollnick and Mavhunga<sup>18</sup> refine PCK as topic specific PCK. Anderson<sup>19</sup> reports that teachers' beliefs about their goals of science education and the nature of science have a strong impact on classroom practice. Norms and values manifest in facilitation and contextual interaction. Science fair projects promote teachers' positive attitudes as facilitators of learning.<sup>5,20-22</sup> Collaboration, commitment and context are elements that contribute to teachers' attitudes<sup>13</sup> and may manifest as a caring attitude<sup>23</sup>. Collaboration and the acceptance of values manifest as emotions<sup>24</sup>, and emotions involve caring attitudes<sup>14,15</sup>. Agency is the ability to pursue one's goals, and to pursue a goal that benefits an individual, based on his or her values.<sup>11,12</sup>

Participation in any of the three primary roles (mentoring, organising and judging) creates opportunities for secondary roles. These secondary roles comprise networking and collaboration, and integration (of activities, experiences and knowledge) into the curriculum (Figure 1). In the mentoring process, teachers have an opportunity to involve learners

in inquiry-based learning.<sup>25</sup> It is argued that teachers are enriched with intuitive knowledge and skills for judging learners' projects.<sup>5</sup> Collaboration promotes networking, which provides teachers with the opportunity to teach content knowledge, use effective pedagogy and new teaching strategies, and escalate inquiry incorporation.<sup>26</sup> Teamwork amongst teachers in mentoring learners to carry out projects at science fairs informs teachers' content knowledge with more pedagogical techniques (technological knowledge and technological pedagogical content knowledge), and offers enhanced access to science, technology, engineering and mathematics resources. It was hypothesised that teachers' experiences through their role in the Expo affects their professional identity, and thus reinforces their professional development through the integration of resources. Teachers incorporate inquiry-based activities from science fairs into their science curriculum and form a repertoire of what they can and cannot do,<sup>20,27</sup> thus it influences their professional beliefs. This investigation sought to establish how teachers themselves linked the various roles to aspects of their professional identity.

## Research methodology

The QUAL–quan research design and approach of this study was situated within an interpretive and descriptive paradigm, which was used to develop an understanding of high school Physical Sciences teachers' experiences and perceptions of their involvement in the Expo as mentors, judges and organisers.

### Sample and participants

Both purposive and convenience sampling were employed in the study because the participants were chosen according to the pre-selected criteria, as suggested by the research questions.<sup>28</sup> Convenience sampling refers to the selection of participants who are easily and conveniently accessible to the researchers.<sup>28</sup> The teachers and researcher were based in the same area, Pretoria, thus it was convenient for the researcher to stay in contact with them. Only schools participating regularly (at least five times in the past 10 years) in the Eskom Expo for Young Scientists (Northern Gauteng Region) were selected. Five urban public high schools and 10 Physical Sciences teachers (two from each school) were identified to participate in this study. School principals and Heads of Department in the science departments of these schools decided which of the Physical Sciences teachers should be interviewed. The teachers were required to have taken part in the Expo more than once in order to be selected, thus it was expected that they would be able to provide deeply descriptive data for the purposes of this study.

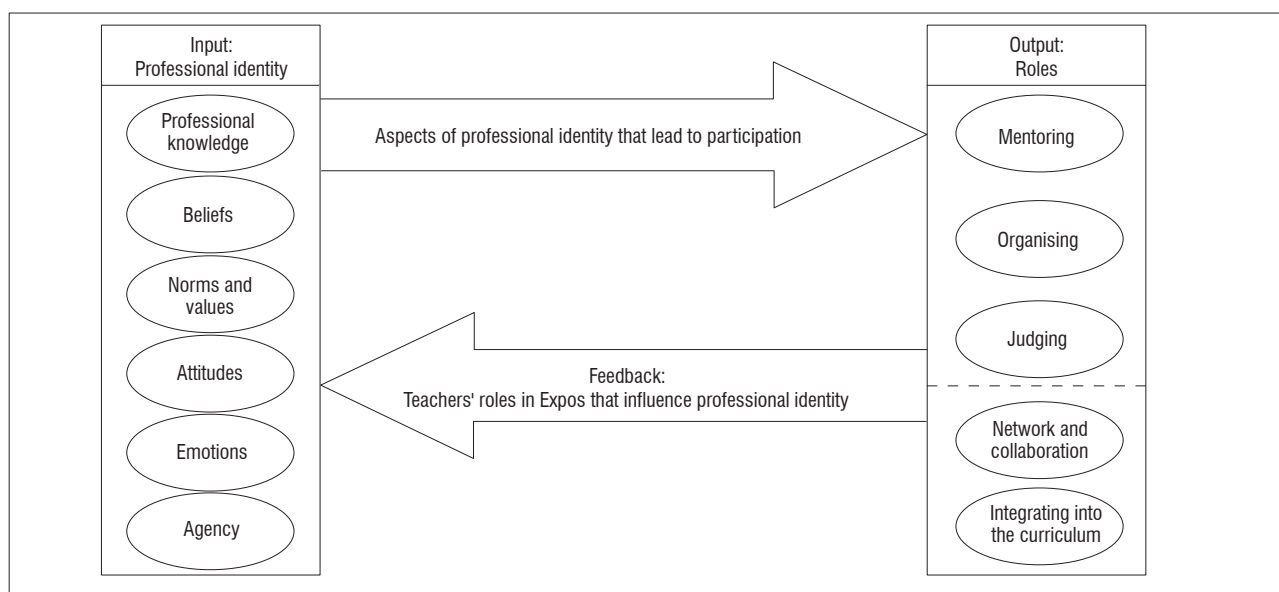


Figure 1: Conceptual framework of professional identity of teachers and their roles in science expos.

### Research instrument and data collection strategies

The teachers took part in in-depth, face-to-face, semi-structured interviews. The semi-structured interviews allowed the participants to answer pre-determined interview questions, and allowed for further probing. With the permission of the participants, the researcher used an audio recorder to capture the interviews, which were then transcribed.<sup>29</sup> Written notes were also taken during the interview process. The selected teachers had already indicated that they would voluntarily participate, but they were again reassured that they were free to withdraw at any time if they felt either uncomfortable or inconvenienced by the study. The interview schedule was divided into two sections. Section A sought to establish the biographical data of the teachers, while Section B consisted of open- and closed-ended questions seeking to determine the teachers' opinions on the significance of the Expo to teachers.

### Data analysis

The audiotaped interviews were transcribed verbatim. These transcriptions were then analysed through encoding the teachers' responses by identifying key words or phrases, which were grouped into sub-categories, categories, subthemes and/or themes.<sup>30</sup> The responses to the open-ended questions in this study were analysed qualitatively through the use of open coding through inductive analysis. However, the responses to the closed questions were only analysed quantitatively. In each question asked, a particular key word or phrase was counted once, and further mentions of the same word or phrase in the answer to the particular question were not counted. The answers in which each key word or phrase were found, were counted and the counts expressed as a frequency of responses. The assignment of the key word and phrases to the subcategories was initially done by the first author, then all assignments were exhaustively checked individually by the second and third authors against all scripts. Disagreements were discussed until consensus on assignments was obtained. As each count occurred only once, the sensitivity of the relative frequencies of the subthemes and themes to the details of the assignment at the lowest levels is minimal.

### Quality assurance

The interview protocol was piloted with two teachers from one school to verify its validity before it was used in the main study. Two experts in the field of science education validated the research instrument. In addition, the transcriptions of the interviews were sent to all of the participants for checking, and positive confirmation of the acceptability of the record was obtained from all.

### Ethical considerations

Ethical approval to proceed with the study was obtained from the Faculty of Education at the University of Pretoria (SM 14/11/01). The Gauteng Department of Education, the school principals, and the participating teachers gave permission for the interviews to be conducted. To ensure confidentiality and privacy in this study, the schools' names and the teachers' names were replaced with pseudonyms or codes, and at no point are their actual names revealed.<sup>31,32</sup>

## Findings and discussion

### Biographical information

Of the 10 teachers who participated, 9 were women. The participants' ages ranged from 24 to 59 and their years of experience in teaching Physical Sciences (Physics, Chemistry or Physical Science) ranged between 1 and 30 years. All of the teachers had experience as organisers and/or judges and/or mentors in both school mini-science expos and regional science expos. The schools in which the teachers were employed at the time of this study were labelled as Schools A, B, C, D and E (Table 1).

All the schools were well-resourced schools. Schools A, C and E are within a high socio-economic environment. Schools B, D and E accommodate some learners from townships. Schools A, B and C had predominantly Afrikaans-speaking learners, with only a few black learners. To a large extent, the racial profile of the learners was affected by the languages offered: School D comprised learners from all racial groups, while School E comprised 70% white Afrikaans-speaking learners, while the other 30% were English-speaking learners who included black, Indian and coloured learners. The five schools were recognised as being amongst the top academic performers in the Gauteng Province, with one of these schools being the top performer in South Africa in terms of the Grade 12 performance of their learners in the recent national examinations.

### Educational significance of teachers' participation in the Expo

Table 2 shows the benefits that teachers reported according to their roles in the Expo and the effects of these benefits on their professional identity, as categorised from the analysis of the interviews. Learners from all of the schools at which teachers were interviewed have excelled in both academic performance and the Expo competitions.

**Table 1:** Teachers' pseudonyms and biographical information

Pseudonym	School	Race	Gender	Teaching experience (years)	Qualifications
Annlin	School A	White	Female	5–10	HED <sup>a</sup> , BEd, BEd Hons
Glory		White	Female	5–10	BSc, PGCE <sup>b</sup>
Bernie	School B	White	Female	20–30	BSc
Jacob		White	Male	20–30	BSc, HED, ACE
Carla	School C	White	Female	20–30	BSc, HED, BEd <sup>c</sup>
Jade		White	Female	1–4	BEd
Danielle	School D	White	Female	20–30	BSc, HED
Fransie		Indian	Female	5–10	BEd, BEd Hons
Harmony	School E	White	Female	20–30	BEd <sup>c</sup> , BSc Hons
Ina		White	Female	1–4	BEd

<sup>a</sup>The HED (Higher Education Diploma) prior to 2001 existed as a 4-year university higher diploma as a first qualification. With a prior bachelor degree it was a post-bachelor degree higher diploma of 1 year, similarly to the Postgraduate Certificate in Education.

<sup>b</sup>PGCE, Postgraduate Certificate in Education.

<sup>c</sup>The BEd prior to 2001 (Report 116: Qualifications structure for universities in South Africa, National Department of Education, 1995) was a 1-year postgraduate qualification which followed the initial bachelor-level teacher qualification and is placed at the same level as the current BEd Hons (Higher Education Qualifications Sub-Framework of 2013).

**Table 2:** Teachers' participation in science Expos linked to their professional identity

Sub-themes <sup>a</sup>	Categories	Sub-categories	Responses: UT (T): [G, O, J, M] <sup>b</sup>
Professional knowledge	Subject content knowledge	Procedural knowledge Declarative knowledge Knowledge of the curriculum Methodological integration	10 (317): [195; 44; 63; 14]
	Pedagogical knowledge	Assessment tasks Enhanced teaching skills	
	Pedagogical content knowledge	Critical thinking skills Skills of discovery Judgement skills Discovering misconceptions of learners	
Beliefs	Beliefs	Scientific literacy Knowledge broadened and enhanced Academic improvement of learners	10 (195): [101; 18; 10; 66]
Attitudes	Attitudes	Mentoring skills Organising skills Learners develop higher thinking skills Learners are offered science career opportunities	10 (168): [102; 24; 8; 34]
Norms and values	Norms and values	School ethos Administration /time management School support by hosting expos Acknowledgement and awards won by learners in school Budget for expo competitions Teachers collaborating within the school	10 (105): [42; 42; 6; 15]
Emotions	Emotions	Experienced enjoyment by interacting with the learners	10 (100): [42; 16; 19; 23]
Agency	Agency	Networking as a resource	7 (23): [17; 6; 0; 0]

<sup>a</sup>Grouping of responses according to Beijaard's et al.'s<sup>1</sup> professional identity model.

<sup>b</sup>UT refers to the number of teachers from the sample of 10 who provided a response (at least once) that was classified into a group referred to as 'unique teacher'; T refers to the total number of times a similar response was identified in the teachers' statements, at least once in a particular question (whilst repetitions were not counted). G refers to the response-count to direct questions on educational significance and their reasons for sustained participation, while O, J and M refer to the response-count of the various role-based questions – teachers as organisers, judges and mentors, respectively.

Beijaard et al.'s concept of professional identity<sup>11,33</sup> was used as a theme in the analysis, and formed the most important segment of the conceptual framework. Professional identity consists of professional knowledge, beliefs, attitudes, norms and values, emotions, and agency, with each of these treated as a sub-theme.

Of these sub-themes, a gain in *professional knowledge* was most prevalent in the teachers' responses, with all of the teachers mentioning examples of the knowledge gains that they had experienced as a result of their participation in the Expo. These perceived gains included content knowledge, pedagogical knowledge and PCK (Table 2).

The content knowledge improvements primarily included procedural knowledge, with some declarative knowledge and curricular knowledge enhancement. Pedagogical knowledge included the methodological integration of practices gained from participation in the Expo, critical

thinking skills, assessment, and enhanced teaching skills. Their PCK was enhanced through the ability to judge student activities in relation to scientific knowledge, the guidance of discovery, and gaining awareness of the learners' misconceptions. One teacher – Fransie – mentioned that she had learnt to become aware of the learners' misconceptions and how they thought, both of which are aspects of PCK:

*Understanding how the learner thinks, that's the most important. You understand how they grasp certain concepts, often when they are explaining to you, their project. You'll pick up on misconceptions that they may have, so you are more aware of how they think, how they understand knowledge, how they construct that knowledge.*

Many in-service teacher training programmes were offered to the teachers with a view to enhancing PCK.<sup>34</sup> This training was done as it was thought to facilitate science teaching and learning, particularly of learners in terms of science literacy and the nature of science using inquiry-based learning.<sup>19</sup> Seven teachers (Bernie, Carla, Jacob, Fransie, Glory, Jade and Ina) confirmed that they hosted mini-expos for learners in their school, and they indicated that they believed that the Expo was good for learners as they learnt how science functions beyond the normal expectation of school- or curriculum-bound science. Six teachers (Carla, Annlin, Bernie, Jacob, Ina and Jade) mentioned the methodological integration of science expo activities into the school science curriculum and stated that this was educationally worthwhile for both the teachers and learners.

The sub-theme of teachers' *beliefs* was deemed to be the most frequently occurring sub-theme according to the number of responses (Table 2). The teachers mentioned that, from their point of view, through participation in the Expo, their learners gained scientific literacy; improved their academic performance, scientific investigative and research skills; and gained enhanced science factual knowledge. This belief is in agreement with that of researchers, who argue that learners who participate in science fairs are exposed to a broad diversity of education.<sup>7</sup> In turn, it may be expected that such beliefs influence pedagogical strategies.<sup>11</sup>

In the sub-theme *attitudes*, all of the teachers reported that they were stimulated through mentoring and organising activities as they performed their roles in the Expo, and that their skills in enacting these roles were developed. The teachers' attitudes were empowered and strengthened when working with their learners, and in becoming successful at Expo competitions. Carla reasoned as follows:

*I love thinking out of the box. I would be a great inventor, because I'm constantly looking for 'but why is this working in such a manner or in such a way and isn't there a possibility of bettering it?' So through investigation you become an entrepreneur, and I love being an entrepreneur, because I think you need to encourage children to become an entrepreneur.*

The teachers mentioned that learners participating in the Expo acquired discovery skills, critical thinking skills, presentation skills, and the desire to emulate professional scientists, and they were exposed to science career opportunities (enhanced interest in science careers, winning prizes and networking with both scientists and peers). This finding supports those of Egenrieder<sup>20</sup>, Nath<sup>21</sup> and Sahin<sup>22</sup>, who report that teachers who participate in science fairs develop facilitation attitudes (including positive experiences and willingness to mentor). Thus, these attitudes affect the role of organising.

The *norms and values* sub-theme involved sub-categories of administration and management, guiding, collaboration with peers, the school ethos, the budget for expos, hosting mini-expo evening exhibitions for learners, as well as the acknowledgement of learners and learners receiving awards after participating in the Expo. Most of the teachers (nine) argued that the Expo was part of their school's ethos, and was compulsory for both them and their learners, which many had internalised and accepted. According to the interview responses, the schools provided positive institutional support to the science teachers by enabling them to collaborate with one another in mentoring, organising, judging and guiding the learners with their projects. Thus, this support enriched the teachers with inquisitiveness and passion, which strengthened their commitment. The concepts of school ethos and the teachers' collaborative attitudes concur with Grant et al.<sup>26</sup>, and You and Craig<sup>35</sup>, who contend that collaboration promotes partnership within the institution, which further enhances teachers' attitudes<sup>13</sup>.

In the sub-theme *emotions*, enhancement occurred through the teachers' opportunity to work with their learners (teachers gained enjoyment from interacting with the learners). The teachers mentioned that they were impressed by their learners' improvement in their scientific concept skills, and enjoyed seeing their learners being acknowledged and awarded by

the school. This finding is in agreement with that of Botha<sup>14</sup>, van Putten<sup>15</sup> and O'Connor<sup>23</sup>, who have found that 'emotions' involve caring attitudes, collaboration, pedagogical expertise, commitment and effectiveness. The teachers were emotional in that they were passionate and eager to help learners to be successful in the Expo despite time limitations. Once learners are successful, teachers' emotions are elevated.

*Agency* refers to being active in the process of professional activities with the intention of pursuing educational goals through the use of available resources (and even creating resources).<sup>1,12</sup> The participants explained that the Expo offered them the opportunity to network with teachers from other schools in which they discussed the science curriculum. The teachers reported that they collaborated with teachers from other schools as they enacted their roles in the Expo through the sharing of experiences related to science curriculum content knowledge. Ina spoke positively about her collaboration with other teachers:

*I always like to communicate with other teachers. Especially with Grade 10–12, especially with the science because I like from in my region, I like to talk to teachers in other schools to see where they are with the syllabus (sic).*

They further said that as they took part in the Expo, they gained some resources and, in return, they integrated these into their methodology and practices at their various schools. In addition, the schools' ethos was a further extrinsic factor that contributed to agency.

### *Professional development from teachers' participation in the Expo*

The findings revealed that teachers who are involved in the Expo experienced growth in all dimensions of their professional identity, especially professional knowledge, which is often associated with the specific goals of professional development workshops. This participation strengthens their positive attitudes and beliefs (which includes pedagogical as well as self-efficacy beliefs), provides opportunities to improve their support structures through networking, and promotes positive emotions (through sharing in their learners' achievements in both improved learning as well as awards gained through learners' participation in the Expo). Hardre et al.<sup>36</sup> report that professional development addresses professional identity and self-perception; the teachers' experiences of learners' conceptions; collaborating and social networking with other teachers through new knowledge, resource benefits, reciprocal sharing and learning; complementary and innovative skills, as well as the practical integration of inquiry-based learning in classroom practices. Similarly, Zivkovic<sup>37</sup> contends that professional development involves the enhancement and provision of new knowledge, as well as sharing experiences with different teachers. These contentions are in accordance with the benefits described by the teachers regarding their participation in the Expo (Table 2).

Participation in the Expo provides both the enhancement of their professional identities and the correct setting for professional development. Readiness for professional development correlates with professional identity, and this readiness is influenced by both intrinsic and extrinsic factors<sup>37,38</sup>, particularly if the teachers are themselves aware of the need for development<sup>39</sup>.

### *Perceived educational significance of the Expo analysed by roles*

Teachers' perceptions of the various Expo roles, specifically organising, mentoring and judging learners' projects were analysed. They gained new knowledge and were supported through the school ethos, as reflected in their job descriptions, by their schools hosting their own science expo. In addition, they found that their participation in the Expo provided opportunities for networking, which was a resource for collaboration and the sharing of experiences with fellow teachers, and similarly for the learners.

#### Mentoring

Ten teachers mentored learners during their Expo participation. The teachers mentioned how enriching their experiences were in this role.

From these findings, two sub-themes – the reinforcement of norms and values and pedagogical knowledge – were identified. The teachers noted that their mentoring function helped learners to be successful in both the Expo competitions and in their academic performance. They had the opportunity to interact with the learners and their colleagues, and to discover learners' misconceptions, as well as the difficulties that learners experienced in learning to perform investigations.

Norms and values include aspects of inquisitiveness, enjoying seeing learners being successful, and being passionate about science. The teachers also gained enjoyment from interacting with the learners, with ensuing positivity, which involves giving support to learners with their Expo projects, thereby demonstrating the teachers' caring attitudes towards their learners, as also found by O'Connor<sup>23</sup>.

The participants mentioned that, as mentors, they had learnt more about the scientific reporting process and improved their process skills and data interpreting skills. As creative teachers, they also found that they began to teach their learners to be creative and eloquent in their communication during their presentations. The teachers further asserted that they had encouraged their learners to consider scientific topics that were related to daily challenges, and to come up with suggestions to solve these problems.

### Judging

Eight of the teachers had acted as judges and reported that aspects of their norms and values were the most affected, as they enjoyed and were happy to see their learners gaining knowledge and showing success in the Expo competitions. They gained content knowledge and pedagogical knowledge equally from this role. Molefe<sup>5</sup> argued that teachers are enhanced with intuitive judging experience and skills for science projects.

Specific judging skills include developing critical thinking, recognising innovation and assessing practical work. The teachers stated that they also used some of the best projects to teach and demonstrate concepts to their learners in their classes. Furthermore, discovering new ideas and misconceptions was mentioned by six teachers as part of the gains in pedagogical knowledge in this role. One teacher, Glory, explained that as an Expo judge, she was also able to realise learners' misconceptions, and gained improved judging skills that assisted her in the methodology of her classroom practice. She again emphasised that, as a consequence of the Expo, she could address misconceptions, particularly with regard to variables: 'When we do the judging for the science fairs, we see that there are definitely learners who struggle with identifying the variables, for example.'

### Organising

Teachers benefit by gaining organisational and prompting skills as Expo participants.<sup>40</sup> Seven teachers reported having organised school-level mini-expos. Six of these teachers mentioned networking as a resource (contributing to agency) as a particular benefit of this role. They gained the opportunity to interact with learners and network with teachers from other schools concerning issues in science education. The teachers mentioned that they had learnt more about scientific investigation processes while enacting an organisational role. Aspects of norms and values were more affected by organising than by the mentoring and judging roles.

## Recommendations and concluding remarks

The findings in this study were based on the responses from 10 interviewed teachers from five urban, progressive public schools which were high performing in both academic and Eskom Expo competitions. A potential future research opportunity is thus to investigate under-performing and non-participating schools and their teachers in this regard. The findings regarding teachers teaching in under-resourced schools and low socio-economic environments might be different from those of the present study. The Expo is aimed at all schools, not only 'elite' schools. The sponsors of the Eskom Expos in recent years have focused on increasing the participation of learners from under-resourced schools.<sup>41</sup> A total of 1063 schools participated in the regional Expo in 2015, and of these schools only 167 (16%) were private schools, while in the national Expo in 2015 of 580 learners, 327 were medal winners of whom 137 (42%) were from under-resourced schools (Moodley P 2017, written communication, March 31).

The first recommendation is for a longitudinal study monitoring professional development and actual influence on classroom practice and change of professional identity over time to be conducted with three kinds of teachers: (1) beginner teachers in participating schools, (2) newly participating teachers from regularly participating schools, or newly participating schools for comparison, and (3) teachers who had participated in the past but had joined non-participating schools. In this respect, do these teachers continue to develop and participate and change the perspective of the new school on participation, or do they stagnate and regress? What are the reasons for either of these scenarios?

Workshops on scientific methods, the science curriculum, and Expo judging skills have to be provided for both teachers and judges (professional scientists) of science expos. This should be particularly provided at the regional level because the teachers in this study revealed that the Expo judges were often very strict as they expected precise scientific methods to be used by learners. This would provide a formal opportunity for the professional development of these teachers.

Finally, of significant importance, the study has shown that participation in the Expo should be recognised as an effective form of professional development. This is the case for teachers of Physical Sciences, but may be generalisable, which would need to be investigated further. This requires formal recognition of these activities through support and scheduling carried out by the provincial Department of Education.

In conclusion, it has been found that the Expo has educational significance for both the teachers and learners who are involved. Teachers, as participants in the Expo, have opportunities to interact with the learners during which they may discover learners' scientific misconceptions and gain new professional knowledge. Learners who take part in the Expo have an important opportunity to be inspired with ideas for future careers, and to improve their academic performance. The academic improvement of learners correlates with the findings of Kahenge<sup>42</sup>, Ngcoza et al.<sup>43</sup> as well as Molefe<sup>5</sup> who found that Expo learners do well in both Expo competitions and their general academic performance.

The findings reveal that South African expos provide opportunities for professional development, particularly with regard to teachers' professional knowledge. In particular, the participating teachers were aware that their content knowledge (both within and beyond the curriculum), their pedagogical knowledge (such as gaining insight into inquiry-based learning approaches), and topic specific PCK were enhanced. Simultaneously, their professional identity was reinforced through networking and collaboration with other teachers, affecting their beliefs, norms and values, and their agency.

Scientific method processes were enhanced for both teachers and learners. The incorporation of science activities into the school curriculum also creates a conducive learning environment within which to develop deeper insight into the nature of science, as well as encouraging critical and creative thinking skills.

The sustained enhancement of professional identity through knowledge, skills, attitudes, emotions, and agency indicates that participation in the Expo is a process, opportunity, and mechanism for the professional development of Physical Sciences teachers. This professional development is expected to be applicable to teachers of other sciences and subjects. Furthermore, and more importantly, this specific benefit of participation in the Expo over a full range of subjects needs to be recognised and supported by professional educational structures, such as educator councils and the various regional and national Departments of Education.

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## Authors' contributions

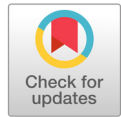
This paper emanates from the work that C.K.M. conducted to obtain his MEd at the University of Pretoria under the supervision of J.J.R.d.V. and M.W.H.B.; C.K.M. conducted all the research and J.J.R.d.V. and M.W.H.B. helped with the preparation of the manuscript.



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# The extent of South African authored articles in predatory journals

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We present a first estimate of the extent of predatory publishing amongst South African academics. This estimate is based on an analysis of all South African authored papers that qualified for subsidy over the period 2005 to 2014. The analysis shows that 4246 South African papers were published in 48 journals which we re-classified (refining Beall's classification) as either being probably or possibly predatory. A breakdown of these papers by year shows that the greatest increase in predatory publishing has occurred since 2011. Results are also presented of the distribution of these papers by individual university and scientific field. We conclude with some suggestions about predatory publishing and its pervasive consequence for our trust in science and how this should be addressed by the major stakeholders in the South African higher education system.

### Significance:

- This study is the first to analyse the extent of predatory publishing in South Africa.

## Introduction

The aim of this paper is to report on a study undertaken by CREST (Centre for Research on Evaluation, Science and Technology) to estimate the extent of predatory publishing amongst South African academics. A few South African studies and reports have appeared in recent years which have suggested that predatory publishing is not only present but is in fact becoming more pervasive – at least in some disciplines.<sup>1,2</sup> However, no study has been done that presents a systematic assessment of how many articles, authored by South African academics, have been published in predatory journals.

There has been a surge of interest in predatory publishing and its effects in recent years, with two kinds of 'studies' emerging. The first are scholarly publications that analyse the nature and dynamics of predatory publishing. Included in this category are studies by Bohannon<sup>3</sup>, Bowman<sup>4</sup>, Djuric<sup>5</sup>, Gasparyan et al.<sup>6</sup>, Jalalian and Mahboobi<sup>7</sup>, Kozak et al.<sup>8</sup>, Nelson and Huffman<sup>9</sup>, Shen<sup>10</sup>, Sipka<sup>11</sup>, Svab and Makivic<sup>12</sup>, Tin et al.<sup>13</sup> and Xia et al.<sup>14,15</sup> Arguably the most comprehensive of these is a report in 2012 by Truth<sup>16</sup> entitled 'Pay big to publish fast: Academic journal rackets'.

The second category of articles on predatory publishing is editorials and commentaries in journals which are more polemical and critical in nature. Articles of this kind are typically written by prominent scholars and editors of journals and point to the increasing prevalence of predatory publishing and its far-reaching consequences for scholarly publishing and specifically the peer-review system in science. Examples of the latter are Bartholomew's editorial in the *Journal of the Royal Society of Medicine*<sup>17</sup> and Moher and Srivastava's Correspondence note in *BMC Medicine*<sup>18</sup>.

## Predatory publishing: A threat to peer review?

Peer review in science has been around for more than two centuries. Most often authors date the advent of what we now call editorial peer review to the 1752 Royal Society of London's development of a 'Committee on Papers' to oversee the review of text for publication in the journal *Philosophical Transactions*. Others insist the Royal Society of Edinburgh had a similar system in place as early as 1731. The shortcomings of peer review have been well documented.<sup>19</sup> These include bias in the review process (institutional bias, gender bias), conflicts of interest between reviewers and authors, rejection of very innovative (radical) research, and so on. However, none of this evidence suggests the wholesale rejection of the peer-review mechanism. But a number of recent events have re-opened debates on peer review:

- The continuing growth in the demand for publishing journal articles (role of new big players such as India and China).
- Increased competition to publish (the effect of continuing globalisation and the role of ranking systems).
- The new opportunities to publish through the availability of online journals (and specifically mega journals such as *PLOS*).

The enormous pressure to publish and publish fast — preferably in the very best journals — influences both authors and editors. This pressure exists almost everywhere but is particularly intense in Asia (China and India). It is therefore no surprise that the most inventive ways to game the peer-review system to get manuscripts published have come from China and India.<sup>20</sup> The companies that provide fake peer reviews come from countries in Southeast Asia, and most of the authors involved in these cases come from the same areas. But it would be a mistake to look at this as a Chinese or Asian problem. This situation is no less true in South Africa where we have for some time now become aware (even if anecdotally) of the pervasive, and in some cases also perverse, effects of the Department of Higher Education and Training (DHET) funding system.

Although there is now widespread awareness, and presumably also knowledge, of what predatory publishing is, it is still important to have a clear understanding of what is meant by predatory publishing and how it is defined.

### What is predatory publishing?

The term 'predatory publishing' is usually attributed to Jeffrey Beall – a librarian at the University of Colorado in Denver (USA). Beall, who was until recently regarded as the unofficial 'watchdog' of predatory publishing, administered a website entitled 'Scholarly Open Access: Critical analysis of scholarly open-access publishing'. This website was rather abruptly closed on 17 January 2017. It is only very recently that Beall broke his silence on the closure of the website.<sup>21</sup>

In his first major publication on the topic published in *Nature* in 2012, Beall provided a first description of what is meant by predatory publishing<sup>22</sup>:

*Then came predatory publishers, which publish counterfeit journals to exploit the open-access model in which the author pays. These predatory publishers are dishonest and lack transparency. They aim to dupe researchers, especially those inexperienced in scholarly communication. They set up websites that closely resemble those of legitimate online publishers, and publish journals of questionable and downright low quality. Many purport to be headquartered in the United States, United Kingdom, Canada or Australia but really hail from Pakistan, India or Nigeria. Some predatory publishers spam researchers, soliciting manuscripts but failing to mention the required author fee.*

Beall uses the term 'predatory' to refer to journals that 'prey' on (often unsuspecting and often young) scholars to submit their manuscripts for the sole purpose of making money from these scholars. In this process, normal good editorial and review processes are violated or suspended.

Because these journals typically do not undertake any peer review (or very superficial peer review), they are thus able to accept large numbers of manuscripts within very short turnaround times and hence make their money through high volume. Beall's point is that predatory journals and publishers are in the business of defrauding scientists and scholars.

Even though Beall's listing is relatively new, there have already been a number of contestations around whether his classification of specific journals are in fact correct. He has also been criticised by a small number of scholars for his methodology and subsequent classification of predatory journals.<sup>23,24</sup> Many of these critics make the obvious point that one needs to distinguish between journals that do not adhere to good and ethical practices of publishing (including editorial and review practices) and journals (and publishers) that deliberately intend to defraud the scholarly publishing process for the purpose of making money. As part of the latter process, such journals (for which we also use the term 'predatory') typically engage in a range of practices (summarised below) that have the same characteristics as poor and 'sloppy' journals (the first category), but to a greater extent. As we argue below, the intention to deceive and defraud by these predatory journals is very evident in the use of fake journal metrics, excessive acceptance rates and extremely short turnaround times. We also argue that a very credible indicator of what constitutes predatory practices (as opposed to simply poor publishing practices) is evidenced by the exponential growth – especially in recent years – of the number of papers accepted and published by these journals.

In our study we did not take Beall's classification at face value but undertook a more in-depth assessment of the journals – tagged by him as predatory – in which South African authored papers have been published. We summarise what we mean when scholars refer to predatory journals and or predatory publishing in Table 1, where we compare the criteria or rules that we believe apply to standard (and ethical) scholarly publishing practices and those that are found in predatory publishing.

In the remainder of the paper we report on the results and consequences of our analysis of predatory publishing in South Africa.

**Table 1:** Comparing the characteristics of good practice in scholarly publishing with those of predatory publishing

Category	Standard publishing practice	Predatory publishing
Business model	Legitimate scholarly journals do not exist solely for profit	Predatory journals are open-access journals that exist for the sole purpose of making a profit
Origin of papers	Authors usually submit manuscripts to journals of their own accord	Predatory journals typically solicit manuscripts by spamming researchers (especially using their Yahoo and Gmail accounts)
Journal titles	Legitimate journals usually have field- and discipline-appropriate titles	Predatory journals often have bizarrely broad titles (e.g. the <i>Global Journal of Advanced Research</i> ) or titles with disjointed scopes (e.g. the <i>Journal of Economics and Engineering</i> )
Time to publication	Publication lag time is often correlated with the status of the journal (with the best journals taking more time to get to production because of high demand)	These journals boast extremely rapid (and unrealistic) response (review) and publication times. They often also publish extremely high numbers of papers per year. This is arguably one of the best indicators of whether a journal is predatory or not as it speaks to the capacity of any editor to handle literally hundreds of submissions per year through proper peer review.
Journal metrics	Journals indexed in Web of Science and Elsevier Scopus have well-defined and transparent impact factor values	These journals boast extraordinary and often fake journal impact factors as well as false claims about where the journal is indexed
Peer review (stature of editorial board)	Legitimate journals have editorial procedures and editorial boards that properly oversee the process of peer review	Predatory journals very often have fake editorial boards or – at best – editorial boards that consist of a small number of individuals from the same organisation or country. They often enlist members of editorial boards who are not experts in the field. They also often include scholars on an editorial board without their knowledge or permission.
Contact information	Legitimate journals provide accurate and appropriate contact information about their journal and editorial board	Predatory journals often list false or insufficient contact information, including contact information that does not clearly state the headquarters location or misrepresents the headquarters location (e.g. through the use of addresses that are actually mail drops)

## Methodology

The source for our analysis is CREST's proprietary database – SA Knowledgebase – that contains a list of all South African publications (articles, books, book chapters and conference proceedings) that have been submitted for funding to the DHET for the period 2005 to 2014. This database contains information about 116 373 papers authored or co-authored by South African academics in 8060 journals that are recognised by DHET for subsidy purposes. The database contains information about the authors, their institutional affiliations, journal title, publication year, the list in which the journal was indexed (Web of Science, IBSS or DHET-accredited journals) and the subject category of scientific field/ discipline (linked to the journal). In order to conduct the analysis for this paper, we consulted Beall's list on predatory journals and predatory publishers and tagged journals in our database if belonging to either.

It is important to emphasise that Beall maintained two lists: a list of standalone predatory journal titles (1220 titles at the time of writing this paper) and a list of predatory publishers. Since the closure of Beall's website, these lists have now been archived elsewhere.<sup>25</sup> The former list is simply a list of individual journals which, according to Beall, are predatory journals. For some of these he provided additional information in support of his judgement. The latter – a list of journal (and sometimes also book and proceedings) publishers – is much more comprehensive but at the same time arguably less reliable. In this instance, Beall usually argued that a particular publishing house (such as Academic Journals or OMICS) has a demonstrated history of publishing questionable journal titles. Because of this history, all journal titles listed by the publisher are hence regarded as being predatory journals. We estimate that there were just over 900 active publishers on Beall's list at the time of writing this paper. If one sums the number of journals listed under these publishers, the number comes to a staggering 23 400+ titles. But as we argue below, it is not always clear that every one of these journal titles should be 'tagged' as predatory.

If we take Beall's list as our point of departure, we have 57 journal titles in which 4245 South African authored papers have appeared between 2005 and 2014. We assessed each of these 57 titles and subsequently assigned each of the titles to four categories:

1. Not predatory: In these cases we believe that Beall is simply wrong in his classification of the journal.
2. Strong evidence for predatory: In these cases we concur with Beall's classification.
3. Weak evidence for predatory: In these cases we found some evidence that the journal might be a predatory journal, but do not think the evidence is strong enough to make a definitive judgement.
4. Insufficient evidence: In these cases we simply could not find any pertinent evidence to make a judgement either way. If one assumes that the 'burden of proof' in this case is on the 'assessor', these journals should probably be tagged as 'not predatory' – at least for the time being.

Before presenting further detailed results, we elaborate on our categorisation.

### Not predatory

First, there are clear-cut cases in which Beall has incorrectly 'tagged' a journal as being 'predatory'. Arguably the best case is Beall's inclusion of the *International Journal of Electrochemical Science* as a predatory journal. When asked in January 2014 why he classified this journal as predatory, Beall responded that the journal had lost its impact factor in Thomson Reuters Journal Citation Reports in 2012.<sup>26</sup> From this exchange it seems that one of the reasons for including the journal on his list was because Beall discovered that it was 'suppressed by Thomson Reuters in 2012'. However, the current information on the Journal Citation Reports web page reports citation data and specifically journal ranking data for this journal every year since 2013. It is simply the case that Thomson Reuters decided not to report on the journal citation profile in 2012. However, it is in fact standard bibliometric practice by Thomson Reuter's Web of Science to omit citation profile information when a particular journal does not

record a minimum number of citations during a particular year. It certainly should not be interpreted as some fraudulent practice on the part of the journal itself (and Beall should have known this).

We also do not believe that the *Journal of Animal and Plant Sciences*, which has been published by the Biosciences Unit of F.a.C.T Ltd, Nairobi (Kenya) since 2002, is predatory. There is another journal with the same name which has been published in Pakistan since 1991, but we do not see any evidence that this is a case of hijacking.<sup>27</sup> The Pakistani journal does not list the name of its editor (which is taken as evidence by Beall of a predatory journal), but for the remainder we could not find evidence of it being predatory.

Similarly, we could not find any evidence that *Mathematical and Computational Applications* is a predatory journal. On the contrary, it seems to be a well-established journal in a number of European countries and is published by the Multidisciplinary Digital Publishing Institute – an academic open-access publisher with headquarters in Basel, Switzerland.

### Distinction between weak and strong evidence for predatory

Based on our inspection of the remaining 47 titles, we argue that it is not always a clear-cut and unambiguous decision whether a journal is in fact a predatory journal. More investigation and a more precise 'scoring' or 'assessment' system whereby suspected predatory journals are subjected to rigorous scrutiny is needed. One way to do this would be to take the current criteria for identifying predatory journals (Table 1) and develop a set of operational rules according to which suspected journals could be assessed. In this study, we used three sources of evidence: (1) Beall's blogs on specific journals; (2) scholarly journals that refer to specific journals or publishers; and (3) our own case-by-case inspection.

As to the first source of evidence, Beall often made specific blog entries in which he discussed why he had categorised a specific journal as predatory. Where we could find such blog entries (there were not entries for all the predatory titles), we looked at the evidence and if we concurred with his assessment, we classified such a journal as predatory with strong evidence. We believe that these entries constitute 'strong' evidence because most of these entries are first-hand reports from authors who have been the 'victims' of these journals. They can rightly be accepted as first-hand qualitative evidence of instances of fraudulent practices. One example refers to a journal – the *African Journal of Business Management* – in which South African authors have published quite prodigiously. Beall had an extensive blog on this journal.<sup>24</sup> He described a scam involving the review process as follows:

*An author submitting a paper was asked to provide the names and email addresses of two potential reviewers. Some authors reportedly abused this process and created two fake identities, along with two new email addresses, submitting these names and emails as the two reviewers. Not surprisingly, these bogus reviewers praised the papers they reviewed, and the papers were published in the journal. Eventually some began to learn of and reveal the scam.*

As to the second type of evidence, there are a number of scholarly studies in which specific 'case' investigations have been made of specific journals.<sup>13,16</sup> Again, our approach was to look at these studies and then make a judgement on whether the evidence supports the classification of a specific journal or publisher as being predatory.

The final source of evidence was our own inspection of each of the journal titles. And in this case, we looked for the following 'indicators' that the journal is predatory:

1. Incompleteness or inaccuracy of information on the members of the editorial board
2. Fake claims about indexing of the journal or journal impact factor
3. Growth in the number of papers accepted for publication

It is important to emphasise that we would typically attempt to find evidence of at least two of the indicators referred to above. We accept that the first indicator, if taken on its own, would at best point to poor or sloppy editorial practices. We, therefore, did not take the first indicator (incomplete or inaccurate editorial board information) on its own as constituting sufficient evidence to make a judgement about the journal's predatory 'status'. The second indicator – making fake claims – was taken to be a much stronger indicator. We believe making false claims about journal metrics is a deliberate act on the part of the editor or publisher to deceive and should not be dismissed as mere ignorance on their part. We give some examples of how these criteria were applied.

Information provided by the *African Journal of Pharmacy and Pharmacology* on their editors is suspect to say the least. The information on the editor, Himanshu K. Gupta, does not correspond to the link to his name. Himanshu K. Gupta is listed as affiliated to the Department of Pharmacy Practice at the University of Toledo. But when one follows the link to his name, it takes one to the Ministry of Defence Government of India, Department of Nuclear Medicine in New Delhi. Another editor listed is Shreesh Kumar Ojha. She is listed as being with the University of Arizona, but the link to her name takes you to the United Arab Emirates University, Department of Pharmacology and Therapeutics, Al Ain, United Arab Emirates. We could not find her name on the staff list of the University of Arizona.

Three of the journals represented in our list (all from Kamla-Raj Publishers) – the *International Journal of Education Sciences*, the *Journal of Human Ecology* and the *Journal of Social Sciences* – are examples of blatant false claims in regard to the members of their editorial boards. For example, Prof. Kenneth Kennedy who is listed as an editorial member of the *Journal of Human Ecology* died in 2014 and Prof. Richard Brown who is listed as an editorial member of the *Journal of Social Sciences* died in 2003. Another telltale sign of predatory publishing is the overlap in the names of editorial board members across various predatory journals. Dr Bryan Hiebert who is listed as an editorial member of the *International Journal of Education Sciences* is also listed as an editorial member of the *International Scholars Journal* – also identified by Beall as most likely a predatory journal. The same applies to three Nigerian academics who also appear on the editorial boards of both journals: Dr Alfred A. Adegoke, Dr Godson C. Igborgbor and Dr Oyaziwo Aluede.

A very common example of false claims relates to claims that predatory journals make about indexing and journal impact factors. An example from our list is the *Journal of Natural Products (India)*. This journal is published in India (at <http://journalofnaturalproducts.com/>) and is not to be confused with a legitimate journal with the same title which is produced by ACS or the *Natural Products Journal* which is published by the Bentham Institute. On their website, the predatory journal cites two impact factor values for 2013: 1.265, purportedly produced by a company called the Universal Impact Factor and another value for the same year produced by another company called Global Impact Factor-Institute for Information Resources. Neither of these companies exists and so are not in the business of producing legitimate journal impact factors.

Predatory journals engage in various strategies to solicit business (most often by spamming potential authors) and publish as many papers as they can. As a result, one often sees that predatory journals record exponential increases in the number of publications over very short time frames, thereby raising the question about their capacity to undertake rigorous and appropriate peer review. The *African Journal of Business Management* is a case in point. Truth<sup>16</sup> records how the journal has expanded exponentially between 2007 and 2011:

*In 2011 it reached a startling 13,579 pages, and has grown by some 28% in 2012. In 2010, its total volume was 4,229 pages, while in 2009 it had 997 pp., in 2008 242 pp., and in its founding year 2007, 243 pp.*

Thomson Reuters was asked in 2010 to review the *African Journal of Business Management* and finally removed the journal from its list in February 2012, some 18 months after serious questions regarding the journal's practices were submitted to the knowledge firm.

Other journals by the same publisher – Academic Journals – which is based in Lagos, Nigeria exhibit similar characteristics, leading us to categorise them as 'probably predatory'. Two examples are the *African Journal of Agricultural Research* (242 papers) and the *African Journal of Biotechnology* (452 papers). The *African Journal of Agricultural Research* shows on its website that it has published 5242 articles since 2006. This number translates into an average of 476 articles per year. The same applies to the *African Journal of Biotechnology* which indicates on its website that it has published 11 688 articles since it was established in 2002. This translates into an average of 780 papers per year! Both these journals currently charge between USD550 and USD650 per submitted article. Even if we work on a lower average of USD500 per submission, it means that these two journals have generated USD2.6 million and USD5.8 million in revenue, respectively, for their owners. Academic Journals currently has 111 journals in its stable.

As we have argued that the third indicator is a very 'persuasive' indicator of probable predatory practices, we present information in Table 2 that shows the huge increases in recent years in journals in which South African academics have published (we have included only those journals that we have classified as 'probable' predatory journals in which at least 100 papers appeared over the past 5 years).

**Table 2:** 'Predatory' journals with South African authored papers: 2005–2014

Journal	2010	2011	2012	2013	2014	Total
<i>Journal of Social Sciences</i>	17	73	130	111	145	476
<i>African Journal of Business Management</i>	53	120	214	26		413
<i>Journal of Human Ecology</i>	3	31	54	87	104	279
<i>Corporate Ownership and Control</i>	24	42	46	62	66	240
<i>International Business and Economics Research Journal</i>	13	21	39	80	77	230
<i>International Journal of Educational Sciences</i>			17	40	130	187
<i>Anthropologist: International Journal of Contemporary and Applied Studies of Man</i>	1	17	49	33	50	150
<b>Total</b>	<b>111</b>	<b>304</b>	<b>549</b>	<b>439</b>	<b>572</b>	

In all the cases there is evidence of a sudden spike in the number of South African authored papers: often between 2010 and 2011 but also between 2011 and 2012. The only case where this trend is reversed is the *African Journal of Business Management* with no publications in 2014. This can probably be ascribed to the fact that this journal was removed from Thomson Reuters in 2012; it was 'exposed' as a predatory journal by Thomas<sup>2</sup> in 2015.

## Results

Using this fourfold classification allowed us to estimate the overall extent of predatory publishing in South Africa. For this estimate we exclude the 339 papers in the 10 journals that we have classified as being either 'not predatory' or for which we have 'insufficient evidence' to make a judgement. This leaves a total number of 3906 papers which constitute 3.4% of the total article production by South African authors over the past 10 years. The disaggregation by evidence categories is as follows: 2891 papers (or 2.5%) appeared in journals which we classified as *probably* predatory (strong supporting evidence) and 1015 (or 0.09%) appeared in journals which we classified as *possibly* predatory (weak supporting evidence). Our resultant classification of the journals is summarised in Table 3.

**Table 3:** Classification of 'predatory' papers by journal (2005–2014)

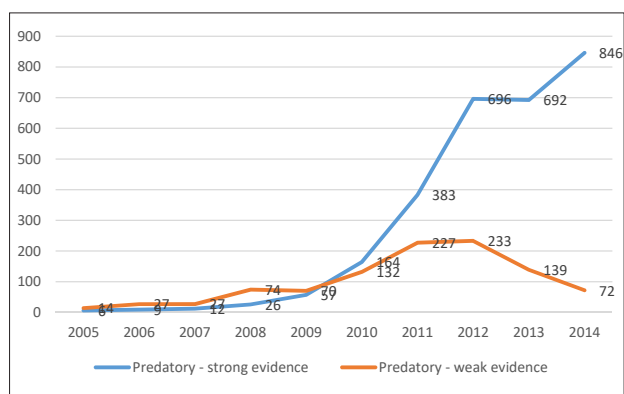
Journal	Listed in DOAJ	Not predatory	Insufficient evidence	Possibly predatory – weak evidence	Probably predatory – strong evidence	Number of papers
<i>Actual Problems of Economics</i>	No	9				9
<i>African Journal of Agricultural Research</i>	No			251		251
<i>African Journal of Biotechnology</i>	No			472		472
<i>African Journal of Business Management</i>	No				451	451
<i>African Journal of Food Science</i>	No			2		2
<i>African Journal of Microbiology Research</i>	No			105		105
<i>African Journal of Pharmacy and Pharmacology</i>	No			61		61
<i>Aging-US</i>	No			1		1
<i>American International Journal of Contemporary Research</i>	No				2	2
<i>Anthropologist: International Journal of Contemporary and Applied Studies of Man</i>	No				180	180
<i>Archives Des Sciences Journal</i>	No				15	15
<i>Asian Journal of Chemistry</i>	No				33	33
<i>Banks and Bank Systems</i>	No		21			21
<i>Canadian Journal of Pure and Applied Sciences</i>	Yes				1	1
<i>Cellular and Molecular Biology</i>	No				2	2
<i>Corporate Board: Role, Duties and Composition</i>	No				10	10
<i>Corporate Ownership and Control</i>	No				270	270
<i>Environmental Economics</i>	No		30			30
<i>European Journal of Science and Theology</i>	No			3		3
<i>European Journal of Sustainable Development</i>	Yes			1		1
<i>European Scientific Journal</i>	No			3		3
<i>International Business and Economics Research Journal</i>	Yes				241	241
<i>International Journal of Advanced Computer Technology</i>	No			1		1
<i>International Journal of Computer Applications</i>	No			2		2
<i>International Journal of Educational Sciences</i>	No				191	191
<i>International Journal of Electrochemical Science</i>	No	232				232
<i>International Journal of Engineering and Applied Sciences</i>	Yes				1	1
<i>International Journal of Sustainable Development</i>	No				14	14
<i>Investment Management and Financial Innovations</i>	No		9			9
<i>Journal of Animal and Plant Sciences (Nairobi)</i>	Yes	12				12
<i>Journal of Applied Business Research</i>	No				72	72
<i>Journal of Communication (Delhi)</i>	No				20	20
<i>Journal of Economics (Delhi)</i>	No				25	25
<i>Journal of Economics and Behavioral Studies</i>	No			111		111
<i>Journal of Environmental Biology</i>	No			1		1
<i>Journal of Governance and Regulation</i>	No				34	34
<i>Journal of Human Ecology</i>	No				289	289

Table 3 continued

Journal	Listed in DOAJ	Not predatory	Insufficient evidence	Possibly predatory – weak evidence	Probably predatory – strong evidence	Number of papers
<i>Journal of Industrial and Intelligent Information</i>	No			1		1
<i>Journal of Information Management</i>	No		1			1
<i>Journal of Media and Communication Studies</i>	No		1			1
<i>Journal of Medicinal Plants Research</i>	No				98	98
<i>Journal of Natural Products (India)</i>	No				2	2
<i>Journal of Physical Therapy Science</i>	No				1	1
<i>Journal of Psychology (Delhi)</i>	No				12	12
<i>Journal of Social Sciences</i>	No				502	502
<i>Journal of Sociology and Social Anthropology</i>	No				68	68
<i>Mathematical and Computational Applications</i>	No	21				21
<i>Mediterranean Journal of Social Sciences</i>	No				72	72
<i>Oncotarget</i>	No				2	2
<i>Problems and Perspectives in Management</i>	No				68	68
<i>Risk Governance and Control: Financial Markets and Institutions</i>	No				42	42
<i>Romanian Biotechnological Letters</i>	No				1	1
<i>Scientific Research and Essays</i>	No				73	73
<i>Studies of Tribes and Tribals</i>	No				66	66
<i>Studies on Ethno-Medicine</i>	No				32	32
<i>Technics Technologies Education Management</i>	No				1	1
<i>Turkish Online Journal of Educational Technology</i>	No		3			3
<b>Total</b>		<b>274</b>	<b>65</b>	<b>1015</b>	<b>2891</b>	<b>4245</b>

DOAJ, Directory of Open Access Journals

A cursory inspection of data presented in Figure 1 shows that the biggest increase has occurred in more recent years – especially since 2011. This is specifically true for article output in those journals that we have classified as being probably predatory.



Source: SA Knowledgebase, CREST

Figure 1: Increase in number of papers published by South African authors in predatory journals (2005–2014).

In the remainder of the paper we present further analyses of these results by university and subject category.

### The spread of predatory publishing by university

Is predatory publishing in South African higher education confined to certain universities only? To address this question we disaggregated the number of papers by university. The results (Table 4) show that academics at all South African universities are engaging in this practice. But is predatory publishing more prevalent at some universities than others? In order to achieve a comparison across universities that differ in size (amongst other things) we decided to normalise the number of articles in predatory journals by the total article production of universities for this period. The results reveal quite large differences.

If we focus on the first two columns of Table 4 (strong evidence category), small proportions of papers (less than the mean of 2.5%) were produced at the major research universities (the Universities of Cape Town, Stellenbosch, Pretoria, the Witwatersrand, Rhodes, KwaZulu-Natal, Free State and Western Cape) and one comprehensive university – Nelson Mandela University. At the other end of the spectrum we find that relatively large proportions (more than 10%) of all papers produced over the past 10 years at Walter Sisulu University (WSU), Mangosuthu University of Technology (MUT), University of Fort Hare (UFH), University of Venda (UNIVEN), Durban University of Technology

(DUT), Central University of Technology, Cape Peninsula University of Technology (CPUT), University of Limpopo (UL), University of Zululand, University of Johannesburg and Vaal University of Technology appeared in predatory journals. The pattern of predatory publishing in the category of 'possibly predatory journals' (weak evidence) is mostly similar with UFH, MUT, WSU, DUT, CPUT, UNIVEN and UL recording proportions of papers significantly above the national average.

### Predatory publishing by scientific field

Our final analysis focused on the subject categories or scientific fields in which these papers were published. Using the link between journal title and subject field (as in the Thomson Reuters Web of Science database), each predatory journal was linked to a single subject category or scientific field. Although the assignment of journals to a single subject

category is not always straightforward (even though we have utilised a category entitled 'Multidisciplinary science'), we believe that the general picture that emerged from this analysis presents a reasonably accurate picture of the spread of papers by subject category. We confined this analysis to journals classified as 'probably predatory'.

The distribution by field for papers published in the journals that we have classified as 'probably predatory' (strong evidence) shows that articles in the social sciences and humanities and the economic and management sciences dominate (Figure 2). This result is consistent with our disaggregation by university and why predatory publishing at some of the top research universities with large medical and natural sciences faculties is less common. Of course, the bigger question is why predatory publishing in South Africa is seemingly more prevalent in the broad field of the human sciences rather than in other fields.

**Table 4:** Classification of 'predatory' papers by South African university (2005–2014)

University	Predatory – strong evidence	Share of total papers	Predatory – weak evidence	Share of total papers	Total 'predatory'	Share of total papers	Total number of papers
CPUT	107	7.9%	80	5.9%	187	13.8%	1358
CUT	71	13.4%	11	2.1%	82	15.5%	528
DUT	86	10.5%	51	6.2%	137	16.7%	819
MUT	22	16.3%	13	9.6%	35	25.9%	135
NMMU	41	1.8%	8	0.4%	49	2.2%	2268
NWU	357	4.7%	51	0.7%	408	5.4%	7520
RU	11	0.3%	18	0.4%	29	0.7%	4286
SU	126	0.9%	20	0.1%	146	1.0%	14005
TUT	93	4.5%	26	1.3%	119	5.8%	2051
UCT	40	0.3%	4	0.0%	44	0.3%	14533
UFH	220	14.7%	160	10.7%	380	25.4%	1496
UFS	115	1.9%	36	0.6%	151	2.5%	6105
UJ	224	4.3%	18	0.3%	242	4.6%	5256
UKZN	269	1.9%	167	1.2%	436	3.0%	14449
UL	151	7.7%	68	3.5%	219	11.2%	1960
UNISA	546	6.9%	44	0.6%	590	7.5%	7863
UNIVEN	164	14.9%	74	6.7%	238	21.7%	1097
UP	108	0.7%	74	0.5%	182	1.2%	15348
UWC	50	1.3%	25	0.7%	75	2.0%	3801
UZ	33	3.7%	22	2.4%	55	6.1%	900
VUT	42	7.3%	12	2.1%	54	9.4%	573
WITS	63	0.5%	32	0.2%	95	0.7%	12929
WSU	76	16.0%	43	9.1%	119	25.1%	475
Total	3015	2.5%	1057	0.9%	4072	3.4%	119755

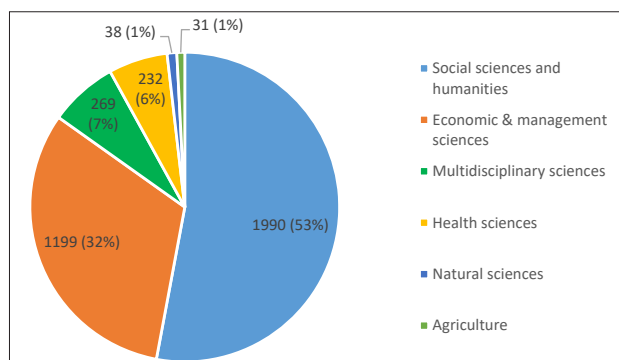
Source: SA Knowledgebase, CREST

Note: The totals in this table are slightly higher than those in Table 2 because we used fractional counting of papers (which means that co-authored papers were assigned to each university)

CPUT, Cape Peninsula University of Technology; CUT, Central University of Technology; DUT, Durban University of Technology; MUT, Mangosuthu University of Technology; NMMU, Nelson Mandela University; NWU, North West University; RU, Rhodes University; SU, Stellenbosch University; TUT, Tshwane University of Technology; UCT, University of Cape Town; UFH, University of Fort Hare; UFS, University of the Free State; UJ, University of Johannesburg; UKZN, University of KwaZulu-Natal; UL, University of Limpopo; UNISA, University of South Africa; UNIVEN, University of Venda; UP, University of Pretoria; UWC, University of the Western Cape; UZ, University of Zululand; VUT, Vaal University of Technology; WITS, University of the Witwatersrand; WSU, Walter Sisulu University



One possible explanation can be found in the indexing of many of these journals in the Proquest IBSS list. Unlike journals indexed in the Web of Science, criteria for inclusion of journals on this list do not include citation metrics or any other bibliometric measures of quality control. It may well be that there is a disproportionately high representation of journals (the majority of which are in the social and management sciences) with unacceptable editorial and review practices that are indexed on this list.



Source: SA Knowledgebase, CREST

Figure 2: Distribution of predatory articles (number, percentage) classified as probably predatory (strong evidence) by subject category.

## Discussion

Scholarly publishing in South African is strongly influenced by the DHET system of paying subsidies to universities for research publications. This, as we have argued elsewhere<sup>28</sup>, is the major driver behind the huge increase in publication output since 2005 and has become the major incentive for many academics to publish and publish as many articles as quickly as they can. If we assume that all the papers that we have identified as predatory received funding (at an average of around ZAR100 000 per full counted paper), an amount of ZAR100–R300 million (depending on whether we base our calculation on possible or probable) has been paid to universities for publications that have appeared in predatory journals, as classified by Beall. This should be cause for concern.

It is important to emphasise that it is not our view or intention to lay blame on individual academics who have published in predatory journals. There is enough evidence to indicate that many academics are quite unaware of these practices. Young and inexperienced scholars are often advised by senior academics to publish in such journals without knowing that this may compromise their academic career. It is equally important to point out that all of the 47 journals identified as predatory or possibly predatory in our database were at the time included in one of the three lists (the majority appears in the ProQuest IBSS list) recognised by the DHET for funding purposes. This means that academics (and their university research offices) were within their right to submit these papers for subsidy purposes and no 'rule' of the funding framework was violated. But this rather 'bureaucratic' position misses a main point of this article, namely that South African academics should not become complicit in predatory publishing on ethical grounds. Most of these journals do violate the basic rules of ethical publishing and research integrity and should therefore be avoided.

In a recent development, the US Federal Trade Commission has taken an interest in these 'predatory' publishers. More specifically, they have targeted the OMICS Group, a global conglomerate based in India and incorporated in Nevada that boasts more than 700 'leading-edge, peer-reviewed' open access journals. All the evidence provided by Beall on OMICS makes it very clear that it is in fact a predatory publisher. As reported, 'in a historic first for the FTC, the agency is suing the company, alleging that it misrepresented the legitimacy of its publications, deceived researchers, and obfuscated sizeable publication fees'<sup>29</sup>.

The results of our study have consequences at the systemic, institutional and individual levels.

At the systemic level, national departments and agencies such as the DHET, Council on Higher Education and the National Research Foundation will have to take actions to ensure that predatory publishing does not become the norm at South African universities – especially in the human sciences – and compromise the quality of scientific and scholarly publishing in the country.

Arguably the main responsibility lies with the DHET who will have to take a stand on whether it will in the future fund papers that have appeared in journals that have been unequivocally identified to meet all or most of the criteria of a predatory journal. Their response to the case of the *Mediterranean Journal of the Social Sciences* suggests that they would decide not to do so. In order to discourage the practice of publishing in predatory journals and in so doing bringing the South African higher education system into disrepute, we believe that the DHET should – as a matter of urgency – revisit the lists that are currently approved for subsidy purposes (most notably the IBSS) and even consider placing a moratorium on the continued accreditation of those journals that are suspected of being predatory.

But it is also an issue that the Council on Higher Education, who has the systemic responsibility to assure quality in higher education, will have to take up and act upon. Perhaps the time has come to organise a national indaba at which all universities and stakeholders are represented to discuss this issue and measures to address the 'scourge' of predatory publishing and other questionable publication practices by South African academics. And, finally, it is very clear that the National Research Foundation will have to take an explicit position on this matter as it is not inconceivable that academics, and especially young academics, could in future apply for funding and ratings with CVs that include any number of papers in predatory journals and conference proceedings. In a recent communication, the National Research Foundation has in fact released a statement about its position on predatory publishing and has reserved the right to not consider applications that show evidence of predatory practices.<sup>30</sup>

A number of South African universities have already taken steps to alert their staff to the dangers of predatory publishing, but a quick scan of university websites revealed that this applies more to the established research universities at which predatory publishing is less common. It is clear that the research offices at all South African universities need to proactively alert all their staff about the implications of predatory publishing. Equally importantly is the imperative to improve their validation procedures before papers are submitted for subsidy to the DHET. It is also important that academic librarians, who engage with academics on a daily basis, assume a responsibility in this regard.

Finally, at the individual scholar level, we argue that it is a specific responsibility for senior academics and specifically supervisors to be alert to the dangers of predatory publishing. In the same way that senior academics and supervisors inform and guide their younger colleagues and doctoral students about research ethics and the imperatives of conforming to good practice in research integrity, it now becomes an additional responsibility to guide young academics in their publication strategies and choices. Young scholars should, for example, be encouraged to consult the very useful *Think Check Submit* tool that can assist them in deciding where to publish.

It is well documented<sup>14,15</sup> that younger scholars, and very often doctoral graduates, are targeted by these predatory publishers. Unless they are properly informed and guided in their publication strategies, young scholars could find themselves building a CV that is increasingly based on publishing in questionable journals. There is even the danger that, if journal articles submitted as part of a doctoral thesis (so-called 'PhD by papers') are in predatory journals, the quality assurance process of the doctorate may be compromised.

In the final analysis, it is clear that predatory publishing poses a serious challenge to science in South Africa. If it continues to increase at the rate of growth seen in the past 5 years, predatory publishing may well become accepted practice in some disciplines and at some universities. Not only will it affect the very fabric of the science system (our confidence in the

peer-review system), but it will also undermine the trust and confidence of the general public in science and its products.

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## Authors' contributions

J.M. conceptualised the study on which the paper is based and wrote the main text of the paper. A.V. was responsible for data cleaning and generation of tables and charts for the paper.

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# Scientific and non-scientific information in the uptake of health information: The case of Ebola

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The Ebola virus disease outbreak in West Africa (2013–2016) claimed over 10 000 lives in less than 18 months. Low levels of familiarity with the disease, ease of transmission, scale of infection, gruesomeness of symptoms, lack of cure and high fatality rate created a global panic. From the perspective of the social psychology of communication and content analysis, this study examines media coverage of the crisis in Africa with a view to unpacking the scientific and non-scientific information that may have framed public understanding of the disease. Findings show that accepting scientific advice was not unproblematic, because of the similarity of early symptoms with known diseases such as Lassa, dengue and malaria fevers. Cultural and religious actors and beliefs posed a paradox for believers as the public assimilated disease prevention information into existing norms and practices. Rumours and conspiracy theories about Western governments and pharmaceuticals also contributed to the rejection of the scientific explanation of its origin. Fear of the devastating effects of the disease and the lack of a cure led to the stigmatisation of the infected and treatment centres and ultimately to public revolts. Findings show the importance of non-scientific information and actors in matters of health and illness in Africa.

### Significance:

- Scientific knowledge is not enough to change health behaviour. Non-scientific knowledge and actors, traditional and religious practices, rumours and conspiracy theories must all be factored into efforts to address behavioural change.

## Introduction

The Ebola virus disease (EVD) outbreak of 2013–2016 in West Africa claimed over 10 000 lives in less than 18 months. Ripples were felt across the world in a contagion of fear and global panic<sup>1</sup> – with effects extending as far as the USA<sup>2</sup> where it influenced voter behaviour. The disease ravaged Sierra Leone, Liberia, Guinea and Mali, all sharing land borders, on a scale never experienced before and was transmitted by air travel to Nigeria.

The first major outbreak of EVD in Africa was in 1976 in the now Democratic Republic of the Congo and Sudan, which share a land border. The disease incidence had, before the 1976 outbreak, been restricted to Central and Eastern Africa. The only case in West Africa was in Cote d'Ivoire in 1994, in which the patient survived.<sup>3</sup> Among the West African communities, therefore, experience with the symptoms and devastating effects of the disease was almost non-existent.

Studies of major health crises have shown that preventive scientific information competes in people's minds with other beliefs and practices as well as rumours and conspiracy theories.<sup>4,5</sup> A multimodal approach that examines both scientific and non-scientific information circulating in society is therefore essential towards understanding the aetiology of epidemics. This understanding is of greater importance in West African communities which are characterised by strong family and community bonds; long-established traditional practices and high levels of religiosity which guide ways of life and support livelihoods; long-standing suspicions of Western interests in medical interventions<sup>5</sup>; and, in some rural areas, limited engagement with Western medical practices. Also, forces shaping health behaviour are more complex than individual rational decisions based on knowledge about health risks and by the extent to which broader contextual factors support the performance of such behaviour.<sup>6</sup> In this study, through an analysis of storytelling in African newspapers, we sought to identify and unpack these competing messages, some of which may have delayed the early uptake of scientific information.

## Theoretical approach

### *Risk perception and communication*

Modern theories of cognitive psychology and neuroscience separate risk perception into two systems: the analytical and the experiential.<sup>7</sup> The analytical uses algorithms and normative rules while the experiential relies on images and associations, linked by experience, to emotion and affect, but both systems operate in parallel, and each seems to depend on the other for guidance.<sup>7</sup> We argue that both analytical (science) and experiential (common sense) systems operate as components of a social system whose elements constantly communicate with each other as scientific ideas are absorbed into everyday life. Science, as a key feature of modern common sense, changes everyday life, quite often, very fast, but the outcome of this meeting of new and old knowledge is contested by researchers. To some, it means the substitution of religion, myth and tradition in everyday life by science; to others it means the pluralisation of common sense.<sup>8</sup>

Also, communication between scientists and the public entails more than the transmission or extension<sup>9</sup> of information. For communication to be successful, it must evolve through a social exchange between parties towards a common understanding.<sup>10</sup> But while certain conditions may lead towards mutual understanding, we agree with Luhmann<sup>11</sup> that attaining this status does not always function to produce a consensus, but may result in an open situation of acceptance or rejection.

### Social representations theory

Common sense, a structured collection of descriptions and explanations, more or less connected to each other, and which everyone uses for organising their experience or interacting with others, influences the initial direction with which social groups engage with an unfamiliar phenomenon.<sup>12</sup> Social representations theory proposes that the transformation of common sense by science may initially lead to three alternatives: rejection, acceptance or assimilation/accommodation, providing a third to Luhmann's two options.

In his study of the reception of psychoanalysis in France in the 1950s, Moscovici<sup>12</sup> showed how three distinct sub-cultures of the society responded to the challenge of psychoanalytic ideas in different ways, all informed by pre-existing thoughts about actors, events and objects. The strategy of the communist press was to enforce a 'rejection' of psychoanalysis which it described as an instrument of Western imperialism to its readers. Marxism and psychoanalysis had spread in French culture after World War II, and the ensuing ideological conflict became a tool for analysing a scientific phenomenon. The Catholic community sought to 'accommodate' certain aspects into existing religious practices (e.g. confessing to a psychoanalyst is similar to a priest and penitent scenario), while the newspapers targeting the urban elite adopted the strategy of 'diffusion'. Moscovici 'not only showed a third way between distortion and diffusion, but suggested, by updating Durkheim's concept of collective representation, that both distortion and diffusion are special cases of a generic phenomenon, that of social representation'<sup>8</sup>. Moscovici's study shows that the three versions were framed and empowered by different representations<sup>8</sup> (Table 1).

**Table 1:** Social representations theory: Luhmann, Moscovici and health controversies

Luhmann <sup>10</sup>	Rejection		Acceptance
Moscovici <sup>11</sup>	Rejection	Accommodation/ assimilation	Diffusion
Health controversies	Rumours, conspiracy/ alternative causes	Stigma, confusion, paradox as premise for behaviour	Acceptance as premise for behaviour

Social representations theory proposes that communication between science and common sense or the 'reified' and 'consensual' universes,<sup>13,14</sup> can lead to pluralisation. The two formats, also referred to in risk perception literature as the analytical and the experiential<sup>7</sup>, are very distinct communicative formats which use different arguments and originate and enable different types of debates between spheres<sup>14</sup>. But with pluralisation, is there a hierarchy or are both in competition for recognition?<sup>15</sup>

The pluralisation of common sense informs Moscovici's thesis of cognitive polyphasia.<sup>12</sup> Moscovici argues that a diversity of knowledge forms can coexist within the same individual or group and this coexistence of cognitive systems is the rule rather than the exception, particularly in modern societies.<sup>12,16</sup> Cognitive polyphasia manifested during the measles, mumps and rubella controversy in the UK in which scientific knowledge, common sense, magic, politics and religion were used to make sense of the vaccine.<sup>17</sup> Cognitive polyphasia has also been found to manifest as a hierarchy, when one form is elevated over the other; as parallelity, when both serve separate functions; or as enhancement, when one empowers the other.<sup>18</sup>

### Scientific and non-scientific information

Social representations theory shows the importance of non-scientific information, experience with actors, similar objects and social groups in the acceptance of new science. Non-scientific information, from experience with collectives<sup>19</sup> and other actors, contributes to how laypeople interpret new scientific ideas and may significantly shape the perception of the idea. Non-scientific information may also be in the form of rumours and conspiracy theories which have trailed public health issues since the Tuskegee<sup>20</sup> and human radiation experiments<sup>21</sup>. Ethical issues in drug trials have eroded trust and created negative

stereotypes about Western collectives and actors symbolised in a 'Western conspiracy' and these are drawn upon by the public to make sense of global health interventions.

Rumours and conspiracy theories originate in periods of social duress from popular culture, stereotypes and preconceptions about people, issues and events. They express fears and suspicion and counter official explanations by bringing together seemingly unrelated issues or errant data in common sense to interpret events.<sup>22,23</sup> Wagner and Hayes<sup>24</sup> argue that it is not the historical truths of past events, compressed in images and metaphors, that make them useful in everyday discourse, but their symbolic truth in dealing with everyday issues. Rumours and conspiracy theories proffer reasons for the public to reject a Western explanation on the origin of disease and have in the past ignited public revolts in health controversies.<sup>5</sup>

### Stigmatisation

Research into social representations of mental health<sup>25</sup> and HIV/AIDS<sup>26</sup> have also shown that representations of diseases often lead to stigmatisation<sup>27</sup> – a negative consequence of assimilation into existing knowledge systems. Stigmatisation, informed by fears of inherent dangers in associating with infected persons and objects associated with them, often leads to attempts at distancing self and loved ones from, or social isolation of, the infected and associated objects.

### Research objectives

Wang et al.<sup>28</sup> studied the epidemiology of Ebola in West Africa while Mondragon et al.<sup>29</sup> looked at representations of Ebola in Spain. Other researchers have examined the roles of fear<sup>30</sup> and lack of trust<sup>31</sup> in containing the virus. We examined the representations of Ebola in West Africa through storytelling by African newspapers with a view to expanding knowledge of the psychosocial factors that contributed to the spread of the disease. Specifically:

- To correlate the intensity of coverage of EVD in newspapers to the disease-related fatalities as a measure of public anxiety.
- To identify the actors and countries or collectives that shape risk information about the EVD.
- To identify, categorise and analyse the interplay of scientific and non-scientific information on Ebola.

### Methods

#### Computer-assisted content analysis of newspapers

The media provide a researchable social space for the variety of views, actors and collectives involved in a public debate. Mayor et al.<sup>32</sup> found that findings from media text analysis are similar to interviews and Joffe and Haarhof<sup>33</sup> identified similarities and differences. Media text corpora have been used to study health controversies such as methicillin-resistant *Staphylococcus aureus*.<sup>34</sup>

For this research, the traditional content analysis cost-benefit approach<sup>35</sup> was enhanced with computerisation using the software QDA Miner/WordStat. The complexity of language, however, implies that the software will not replace but only augment careful reading and thoughtful analysis.<sup>36</sup> It has been used for media text analysis.<sup>37</sup>

A user-defined dictionary approach was adopted for its simplicity and cost-effectiveness over supervised machine learning.<sup>36,38</sup> The user-defined dictionary, created in WordStat, was used for a bottom-up approach to the qualitative analysis and arranged in categories for the quantification. The combination of qualitative and quantitative approaches enhances the study of relatively complex processes of communication.<sup>12</sup> A country dictionary was also created in WordStat.

#### Corpus construction

A total of 4201 articles from 17 newspapers published in 12 African countries were downloaded from NEXIS UK in June 2015 using the keyword 'Ebola' and the index for African newspapers (Table 2). The articles spanned 29 months from January 2013 to May 2015. We

created variables to filter for country and relevance. 'Relevance three' are those articles with at least three mentions of Ebola and one newspaper per country.

**Table 2:** Newspaper and frequency of occurrence of the keyword 'Ebola'

	2013	2014	2015	Total	Relevance three
<b>West Africa</b>					
<i>This Day</i> (Nigeria)		804	112	916	
<i>Vanguard</i> (Nigeria)		699	102	801	438
<i>The Inquirer</i> (Liberia)		559	221	780	566
<i>Concord Times</i> (Sierra Leone)		85	349	434	282
<i>The Analyst</i> (Liberia)		237	3	240	
<i>Daily Observer</i> (The Gambia)		130	24	154	92
<i>FOROYAA</i> (The Gambia)		44	22	66	
<i>Cameroon Tribune</i> (Cameroon)		34	15	49	15
<i>Ghanaian Chronicle</i> (Ghana)		20	16	36	12
<b>East/Southern Africa</b>					
<i>The Star</i> (Kenya)		191	51	242	111
<i>The New Times</i> (Rwanda)	3	121	32	156	83
<i>The Herald</i> (Zimbabwe)		101	32	133	60
<i>The Times of Zambia</i> (Zambia)		55	18	73	35
<i>New Era</i> (Namibia)	1	44	6	51	31
<i>The Namibian</i> (Namibia)	3	31	6	40	
<i>The Independent</i> (Uganda)	6	10	7	23	10
<i>Zimbabwe Independent</i> (Zimbabwe)		4	3	7	
Total	13	3169	1019	4201	1735

We observed that between September and November 2014, no articles were available for the *Concord Times* of Sierra Leone. We are, however, of the opinion that this does not have a significant influence on the findings. Also, the user-defined dictionary approach does not recognise context, metaphors, etc. Its use in the thematic analysis was limited to extraction and weighting of keywords.

## Findings

### *Intensity of coverage as a measure of public anxiety*

Figure 1 shows that coverage peaked in August 2014 for Nigeria's *Vanguard* newspaper while for Liberia's *The Inquirer*, the crest was in September 2014. The virus was transmitted to Nigeria on 20 July 2014 and the country was declared free on 20 October 2014. The *Vanguard* peak thus reflects the period of extreme anxiety in Nigeria. The reported deaths from Liberia, Sierra Leone and Guinea combined<sup>3</sup> peaked in October 2014, followed by a second peak in December 2014.

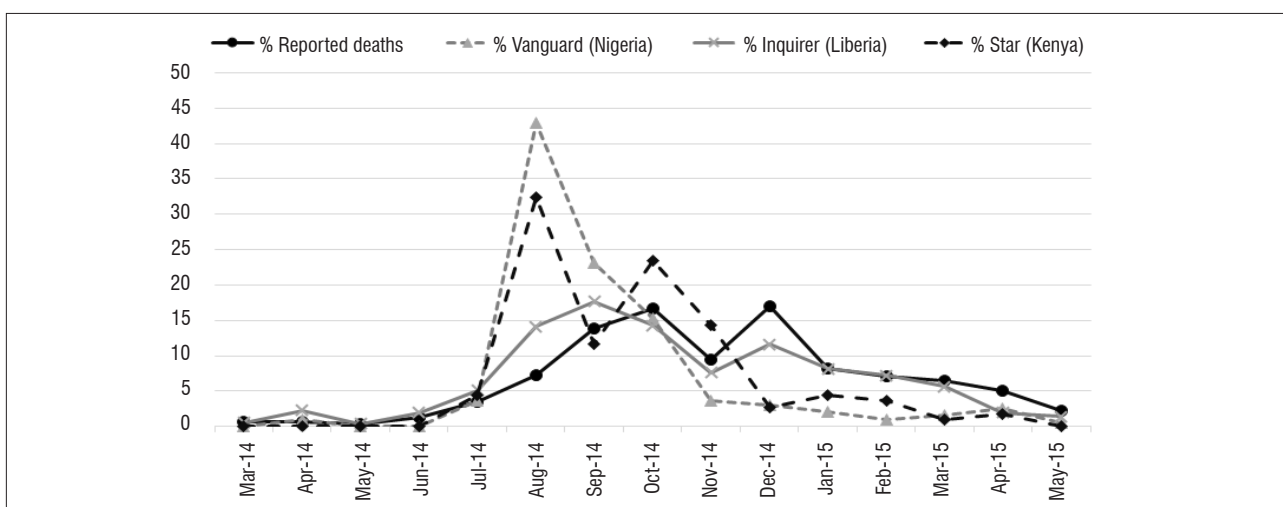
The Kendall's tau<sub>b</sub> correlation coefficient shows significant correlations between recorded deaths and coverage statistics between March 2014 and May 2015. The correlation (*r*) between deaths and *Vanguard* coverage was 0.545 at a 0.5 level of significance; *The Star* 0.615 at 0.01; *The Inquirer* 0.760 at 0.01; the *n*=1735 sub-sample 0.823 at 0.01 and the entire corpus of 4201 was 0.804 at 0.01. We can thus confirm a significant association between coverage and the number of recorded deaths and make reasonable conclusions that the African media mirrored public anxiety over the outbreak.

### *Actors and countries*

The actors were categorised based on their social functions as follows:

- Science actors: doctors, nurses, researchers, UNICEF, Doctors Without Borders, World Health Organization, pharmaceutical companies, scientists
- Cultural actors: bishops, church leaders, community leaders, elders, herbalists, imams, pastors, religious leaders, reverends, spiritual healers, traditional chiefs, traditional healers, traditional rulers, traditional leaders
- Government actors: commissioners, government officials, governors, ministers, presidents, senators

We report the term 'frequency-inverse document frequency' (tf-idf) – a weighted measure of the statistical relevance of words, which represents a fair balance between popularity and specificity.<sup>39</sup> For the 1735 sub-corpus ('relevance three'), government actors appear in 58% of articles with a tf-idf of 957; scientists in 40% of articles with a tf-idf of 798 and cultural actors in 10% of articles with a tf-idf of 392.



Coverage/reported deaths for the month was divided by the total coverage for the period.

**Figure 1:** Newspaper coverage of Ebola and reported deaths (*n*=1735 articles).

Table 3 shows countries based on a tf-idf (also see the supplementary material). Liberia with a tf-idf of 821 appears in 55% of cases, Sierra Leone with 685 appears in 39% and Nigeria with 999 appears in 28%. Nigeria is the regional power in West Africa and has been actively involved in Sierra Leone and Liberia for many years helping to quell gruesome civil wars, and again intervened significantly in the Ebola crisis with finance and equipment. Gambia is geographically close to Liberia and Sierra Leone while Kenya Airways operates regular flights to West African countries. The USA with the highest td-idf for non-African countries appears in 15.6% of cases, China in 5% and the UK in 3.6%. Liberia is a previous settlement of the American Colonization Society. The late response of the USA was not lost on the public, nor was the early response of China. Alfred Sirleaf's *The Daily Talk*, depicted the score line as 'China 2: US/West 1'<sup>40</sup>.

**Table 3:** Countries and number of articles ( $n=1735$ )

Africa (infected)	tf-idf	Africa (non-infected)	tf-idf	Non-African	tf-idf
Nigeria	999.9	Gambia	455.8	USA	376.6
Liberia	821.1	Kenya	420.1	China	356.2
Sierra Leone*	685.6	Zimbabwe	305.5	UK	127.3
Guinea	515.9	Zambia	273.4	India	102.4
Mali	89	Rwanda	272.8	France	98.5
		Namibia	230.6	Spain	79.3
		Uganda	210.1	Iran	77.3
		Ghana	199.9	Cuba	67.2

tf-idf, term frequency-inverse document frequency  
\*Some missing data.  
See supplementary material for more details.

### Categorisation

The categorisation combines theory with automated text analysis. The theoretical approach (top-down) divides the issues into risk and non-risk information, while bottom-up looks at the 'keywords in context' for interpretational frames. The researchers worked together to agree on the meaning units and frames. We used the 1735 sub-corpus and discussed each group in turn, citing text from articles. Religious beliefs were separated from traditional and spiritual beliefs because the latter are often associated with ritualistic practices of sacrifice to appease gods and spirits while the former, of the Abrahamic faith, generally do not involve rituals but do include a belief in spirits. Table 4 shows the framework of the analysis. (See the supplementary material for more detail.)

The category of keywords with the strongest relevance was 'religious belief' with a tf-idf of 716 appearing in 18% of cases. This category was followed by 'rumours and conspiracy theories' with a td-idf of 456 from 15% of cases; 'risk information' with 400 from 93% and the lowest was 'traditions' with a score of 259 from 8%. At the level of the two communicative modalities, the universe of risk information was less discriminating overall with a td-idf of 400 from 93% of cases while the non-risk consensual discourse was more important with a td-idf of 848 from 33%. Also, we found a significant correlation between scientific and non-scientific information in the same newspaper: Nigeria's *Vanguard* newspaper ( $r=0.86$ ;  $p<0.001$ ;  $n=801$ ), Liberia's *The Inquirer* ( $r=0.84$ ;  $p<0.001$ ;  $n=780$ ) and Kenya's *Star* ( $r=0.73$ ;  $p<0.003$ ;  $n=242$ ). There was also a significant association for the 'relevance three' corpus ( $r=0.91$ ;  $p<0.001$ ;  $n=1735$ ) and the full corpus comprising all African dailies ( $r=0.96$ ;  $p<0.001$ ;  $n=4201$ ).

**Table 4:** Content categorisation from keywords to scientific and non-scientific information

Keywords	Bottom-up		Top-down	
	Meaning units	Interpretation/frame	Theory	
Contracted, disease, infection, risk, transmit, vaccine, virus, viral disease	Ebola symptoms: fever, vomiting, headache, muscle pain, diarrhoea, nausea, bleeding, etc. Hygiene measures	Containment/ diffusion	Risk information 93% cases tf-idf = 400	Risk information 93% cases tf-idf = 400
	The 'uneducated' vs inadequate government responses	Obstacle		
	Dengue, Lassa, malaria symptoms: fever, vomiting, headache, muscle pain, diarrhoea, nausea, bleeding	Obstacle		
Tradition, mourning, mats, traditional healers, spiritual healers	Mourning, hugging, washing	Obstacle	Traditions 7.7% cases tf-idf = 259	
	Claims to cure			
Christian, religion, church, mosque, Muslim, prayer, spirit	Suspension of mourning, hugging, etc.	Containment/accommodation	Religious belief 17.8% cases tf-idf = 716	Non-risk information 33% cases tf-idf = 848
	Laying of hands, praying for healing	Obstacle		
	Religious beliefs and gatherings	Paradoxical accommodation		
Rumour, corruption	Care for the sick	Containment/accommodation	Rumours and conspiracy theories 15% cases tf-idf = 456	
	Suspension of shaking hands, touching			
Conspiracy, depopulation, racism, racist, stigma, terrorist, New World Order	Corruption, diversion, accountability	Obstacle		
	Local remedy			
	Rumours of spread of disease	Accommodation/ stigma/ revolt		
	Conspiracy theories about disease spread			
	Economics of an African disease	Obstacle/rejection		
	Viral terrorism			
	Bioterrorism, depopulation, New World Order, racist and racism			

tf-idf, term frequency-inverse document frequency  
See supplementary material for more details.

### Risk information

Several articles provided detailed descriptions of EVD: mode of transmission, symptoms and preventive measures. In the early months, such descriptions often used emotive language: 'The Ebola virus can kill its victims within days, causing severe fever and muscle pain, weakness, vomiting and diarrhoea – in some cases shutting down organs and causing unstoppable bleeding'<sup>41</sup>. The public were asked to avoid shaking hands, to wash hands frequently and avoid bush meat such as bats and monkeys – the vectors of the disease. National government representatives positioned uneducated families and communities as the greatest obstacle. Drawing on metaphors from deficit-knowledge frames, they called on people to take responsibility for educating others and to join the fight against the virus.

However, risk information was not unproblematic because of the similarity of symptoms with Lassa and dengue fevers which also cause fever, body aches, vomiting, diarrhoea, bleeding, etc.; malaria also causes high fevers and vomiting, and cholera causes vomiting and diarrhoea – all are diseases which are common in Africa. The similarity confused the public and medical personnel, which lead to panic in several countries, even as far away as Zimbabwe.<sup>42</sup>

Also, understanding the need for and wearing of protective clothing was not enough to be protected, as 120 of the 240 healthcare workers who contracted the disease from patients died (as at August 2014).<sup>43</sup>

### Religious beliefs and science

The roles played by religious institutions and actors were distinguishable as three sub-categories: those that presented obstacles by upholding the sanctity of faith in God to cure all ailments (rejection of science); the paradoxical which gave conflicting directives on science and religion (accommodation); and those activities that aided its containment (diffusion). Accommodation of science by religion indicates cognitive polyphasia – the coexistence of different forms of knowing.

#### 'Ebola the evil spirit'

Liberia's *The Inquirer* cites the story of a church in Monrovia<sup>44</sup> where pastors were laying hands on the sick to cure them of 'spiritual attacks', following which four people died, including a pastor's wife, and the pastor himself was later admitted to the Ebola Treatment Unit. Another church leader in Nigeria told his followers that Ebola is not a disease but an evil spirit.

#### Paradoxical accommodations and 'tangled hierarchies'

A church leader told pastors<sup>45</sup> that all those who had fasted for 100 days should have no fear of Ebola, but he also warned them to avoid laying hands on anybody they suspected of having the disease. In Sierra Leone, a Muslim argued that believers can only be infected if God permits but warned them to avoid contact<sup>46</sup>:

*The Prophet said: (There is no 'Adwa') i.e. transfer of a disease by itself, but with the permission of Allah ... we must keep away from Ebola as we do from a lion.*

#### Accommodation of science by religion

Many churches ordered the suspension of the practice of shaking hands as a sign of peace and the serving of Holy Communion in the mouth. A religious leader in Liberia<sup>47</sup> called on fellow men of God to stop laying hands as a means of healing persons and imams to stop bathing dead bodies:

*I beg you in the Name of Jesus ... please stop laying hands on people in order to cure them of Ebola. To our venerable imams, I respectfully appeal to you in the name of Allah ... please stop bathing dead bodies.*

The church was also a source of medical aid. Several religious institutions in Sierra Leone, including the United Brethren in Christ Church Conference, received funds from abroad for medical equipment

and the Abundant Life Chapel Home in Liberia served as an orphanage for children who lost their parents to the disease.

### Traditional and spiritual practices

The West African crisis, according to WHO<sup>48</sup>, may have started in Guinea following the burial of a young boy, from whom it spread to family members, as it is customary to embrace the body of the deceased as a sign of love and affection. So was a chain reaction of cases sparked, which spread to neighbouring countries. In many communities it is tradition to wash the body of the dead and to sit on mats to mourn<sup>48</sup>:

*Bassonians, like other Kwa-speaking groups including Kru and Grebo, are better known for spending time on mats to mourn their dead ones. They are also known for bathing (washing) dead bodies as part of traditional rites which were long practised by their ancestors.*

Liberia's Ministry of Information<sup>49</sup> describes how Ebola changed their way of life:

*We who are afforded divine blessings by caring for our elderly ... and believe our duties to each other extend to burying our dearly departed through traditional rituals and religious practices ... were often limited to watching and restricted from touching, as our forefathers taught us to do.*

Some traditional secret societies believed that a dead member's ghost will torment others if they failed to observe the traditional rites of passage.<sup>50</sup>

Some traditional healers also placed advertisements on radio and television announcing their capability to cure the disease.

Some Nigerians<sup>51</sup> did not believe that bats transmit the virus, as they had hunted them for generations for their meat, and, in some cultures, hunting bats was a requirement to 'move up an age group':

*If you want to graduate from that [age] group, you...go into the forest to find a very special kind of bat and kill it...if you can do it, you bring the carcass and the elders share the meat, you'll be promoted.*

#### Accommodation of science by traditions

At the peak of the outbreak in September 2014, Liberia's President, Ellen Johnson-Sirleaf, made a passionate plea<sup>48</sup> to the public to 'stop the mat business'. Sierra Leone's Vice President, Samuel Sam-Sumana, also called for the suspension of traditional practices<sup>52</sup>: '... [A]t this moment, all cultural and traditional practices are suspended until we are declared Ebola free; then and only then can we go back.'

The need to show love for lost family members, friends and associates by mourning as dictated by traditions aided the spread of the disease. Ebola thus qualifies as the plague of love and traditions. The accommodation of science by traditions also indicates the coexistence of different forms of knowledge.

#### Rumours, stigma, revolt and conspiracies

There were rumours that drinking and bathing in salt water or eating bitter kola can prevent the disease.<sup>53</sup> These rumours were informed by preconceptions about the efficacy of traditional medicine among a public confronted with the failure of its Western counterpart. Rumours of corruption and the disbursement of funds were also common. The *Wall Street Journal*<sup>54</sup> also reported that some body collectors collected bribes instead of corpses. A community outreach worker said:

*They say ... 'we can give you a certificate from the Ministry of Health that it wasn't Ebola.' Sometimes it is \$40. Sometimes it is \$50. Then, they offer bags to them and [the family] carry on their own thing.*

West Point, one of Liberia's slums, was engulfed in a revolt during which a treatment centre was ransacked. Some residents<sup>55</sup> were said to be opposed to the influx of patients from other places out of fear they would spread the disease in the area. In some parts of Guinea, eight awareness officials were killed by villagers who accused them of spreading the disease.<sup>56</sup> These actions evolved from the tying together of 'errant data'<sup>23</sup> and represent the negative effects of stigmatisation. Economic factors may have also contributed to the looting and revolt as residents criticised government's actions which restricted people's movement as a containment measure, but which also left many with few survival options.

The public revolts have been attributed to a denial of the existence of the disease. We argue that revolts may have been informed by economic factors, fear<sup>30</sup> and stigmatisation<sup>27</sup> of the infected and treatment centres and not from ignoring risk information. The public were acting on risk information, albeit in their own way, by distancing themselves from all persons and institutions associated with the virus. A homeless man<sup>57</sup> said his friends drove him away when he was sick fearing he might have been infected with EVD and still refused to admit him even when his health improved.

### Conspiracy against Africa

A writer argues that it is not in the business interest of Western pharmaceutical conglomerates to have a simple solution such as bitter kola produced locally in Africa. Gambia's president, Yahya Jammeh<sup>58</sup>, describes the treatment of Westerners with new drugs and the neglect of Africans as racism:

*The same thing was also done for HIV/AIDS ...  
Then who created the virus. They have now  
treated four Westerners who contracted this  
virus, why can't they use the same treatment  
for Africans?*

Patrick Sawyer – Nigeria's index case – was a Liberian-American who attended his sister's burial ceremony after she died from Ebola in Liberia but told doctors in Nigeria that he had had no previous contact with EVD. Hospital management described him as a bioterrorist and the Nigerian authorities said the import of Ebola to Nigeria was 'viral terrorism'.<sup>59</sup> A newspaper columnist argues that Sawyer did not work alone and was sent to prepare grounds for a new wonder drug for massive profits and to establish a New World Order.

A street vendor<sup>40</sup> argues that Western powers created Ebola to fight China out of Africa. An article describes Ebola as a grand conspiracy against Africa<sup>60</sup>, like HIV/AIDS, citing trials on humans which started a few weeks before the outbreak in Guinea and Sierra Leone. Another article<sup>61</sup> cites health workers as saying that the most serious impediment to containing the virus is the depth of scepticism about the disease and its origins:

*Africans are whispering that it is a disease made  
in the laboratory for depopulation and control.  
The most colourful yet is that Ebola and the  
militarization of America's health intervention  
gives the US leverage to establish its military bases  
through the backdoor.*

The conspiratorial arguments above were informed by errant scientific data, thus the non-scientific information was not completely devoid of reification.<sup>13</sup>

### Limitations of content analysis

The content analysis allows the researcher to identify the different stories told about EVD and chart their relationships with the theoretical model. It does not indicate how many in the public share these views or if they acted on them. Such analysis will require surveys of the communities in West Africa, which was not covered by this research.

## Conclusions

We conclude that media coverage is a good measure of public anxiety about the spread and containment of Ebola in West Africa, as shown by the intensity and disease fatalities graph in which the trough and peak show similar patterns; and the debate was not by health agencies and national government officials alone, as cultural and religious actors, international governments and non-governmental organisations played significant roles. Also, non-scientific discourse showed very strong relevance in the debate and was significantly associated with risk information in the newspapers.

Risk information about EVD was not simple to understand as it could be easily confused with symptoms of dengue, Lassa and malaria fevers or cholera. Even when understood, the disease claimed many lives – including those of trained medical staff. Its assimilation<sup>12</sup> into common sense led to stigmatisation<sup>27</sup> and the distancing of sick and recovered patients, by both medical staff in hospitals and laypeople on the streets. The ensuing crises peaked in revolts, leading to the killing of members of an Ebola response team in Guinea and the looting of a treatment unit at West Point in Monrovia, Liberia.

The cultural expression of love – deep-seated in traditions which encourage mourners to embrace and wash corpses of relatives – provided a stream of new hosts for the virus to propagate itself. Ebola can thus be referred to as a disease of love and traditions in West Africa. Also, religion was both a constraint and a facilitator to containment and posed a paradox to believers between their faith in God and scientific advice. Some pastors described EVD as a 'spiritual attack' while imams argued that diseases come from God. Religious groups deployed the three communication strategies: rejection, accommodation and diffusion.<sup>12</sup> In accommodation, believers were told they cannot be infected, yet at the same time were told to avoid contact with others and to pray against the disease. The accommodation of risk information by religion and tradition shows strong evidence of cognitive polyphasia as scientific information coexisted with other forms of knowledge.

Rumours of Ebola as 'man-made' and a 'Western conspiracy' – a rejection<sup>12</sup> of scientific explanation – were rife and some medical workers confirmed that these rumours were an obstacle to their work in the field. Experience with Western countries on drug trials, rumours of unethical vaccine trials and the spread of the virus to Nigeria by a Liberian-American, Patrick Sawyer, provided errant data to claims of bioterrorism. The lack of a cure led to allegations of racism and there were also suspicions about the economic interests of Western governments and pharmaceutical companies. These arguments also show that non-scientific discourse is not devoid of scientific arguments and that the reified and consensual universes are not sharply differentiated.<sup>13</sup>

Thus, our conceptual approach, premised on behaviour being informed by a host of social psychological factors in addition to scientific information, has provided a platform to examine public debate about the spread and containment of Ebola in Africa. From our findings, our recommendations for the planning and execution of future health intervention projects are as follows.

1. Science communication needs to evolve processes of engagement with experiential knowledge forms, particularly in emergency settings in which fear is expected and/or normalised practices and values are a risk factor.
2. In settings in which there is long-held distrust between communities and scientists and/or Western donor agencies (such as is the case in many African contexts), active efforts of trust-building need to be built into communication activities.
3. More pre-emptive engagement needs to occur between global health agencies and at-risk communities so that emergency preparedness structures of communication can be established.



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## Authors' contributions

B.A.F. was responsible for the study conception and design and the collection of data; B.A.F. and C.J.C. were responsible the analysis and interpretation of data; and writing and revising the manuscript.

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# Women's representation in national science academies: An unsettling narrative

Science academies are well placed to contribute towards strengthening of national systems of innovation through advocating for an increased participation of girls and women in science. To successfully do so, academies would need to overcome challenges faced with regard to women's representation in their own ranks and women's resultant full participation in the activities of national science academies. We collected baseline data on the representation of women scientists in the membership and governance structures of national science academies that are affiliated with IAP: the Global Network of Science Academies. Women academy members remained far below parity with men, given that women's membership was typically about 12%. Women members were better represented in the social sciences, humanities and arts but the corresponding shares rarely exceeded 20%. In the natural sciences and engineering, women's membership remained well below 10%. On average, the largest share of women members (17%) was associated with academies in Latin America and the Caribbean. The average share of women serving on governing bodies was 20%. To change this unsettling narrative, the importance of academies of science annually collecting, analysing and reporting gender-disaggregated data on membership and activities is highlighted as a key recommendation. Several aspects of women's representation and participation in national science academies are highlighted for further investigation.

**Significance:**

- Demonstrates under-representation of women in national science academies.
- Reports on results of the first gender-disaggregated survey on membership and governance of national science academies, globally.
- Underscores the importance of regular collection, analysis and reporting of gender-disaggregated data in the science sector.

## Introduction

The participation of women in science has attracted significant attention in recent decades, as evidenced by the growing number of policy-oriented studies on the topic<sup>1-6</sup> and the many scholarly studies in the academic literature<sup>7-9</sup>. Typical themes include the participation of the girl-child in science, technology, engineering and mathematics (STEM)<sup>10-12</sup>, women scientists' representation and performance in STEM occupations<sup>13-16</sup>, gender differences with regard to remuneration and promotion practices<sup>17,18</sup>, and women's access to technologies<sup>19,20</sup>, to mention a few.

Up to now the available studies, with the exception of one<sup>21</sup>, have remained silent on the representation of women in the activities of national science academies. This silence is ironic as science academies – in addition to honouring scientific excellence by means of electing eminent scientists into membership – also operate as change catalysts by virtue of their participation in scientific agenda setting, science advice in support of policy development and, in some cases, the management of research activities. It could therefore be argued that national science academies are well placed to contribute towards strengthening of national systems of innovation through advocating for increased participation of girls and women in STEM, and by gendering science policies and applying the gender lens in research and innovation. However, to do so successfully, academies would need to overcome challenges faced with regard to women's representation in their own ranks, for instance, in academy membership and governance. It also means that reliable gender-disaggregated baseline information and appropriate international benchmarks would need to be collected, analysed and reported in order to enable academies to regularly monitor and compare progress.

It is against this background that we undertook the current study to collect baseline data on the representation of women scientists in the membership and governance structures of national science academies affiliated with an international umbrella body of academies, namely IAP: the Global Network of Science Academies (now known as the InterAcademy Partnership). IAP is a global network of science academies that was launched in 1993, and whose primary goal is 'to help member academies work together to advise citizens and public officials on the scientific aspects of critical global issues'<sup>22</sup>. It represents over 110 national academies of science in both the global North and South. IAP considers progress towards women's full participation in science a critical issue of global importance. The results represented here follow recommendations, in 2006, by another academy umbrella body, the InterAcademy Council (IAC) that academies should regularly report on women's representation and participation within their ranks.<sup>23</sup>

## Method

The Academy of Science of South Africa (ASSAf) and the InterAmerican Network of Academies of Sciences (IANAS) executed the study as two separate but related online surveys during the period 2014–2015.

IANAS surveyed the 19 national science academies of IAP in North America and Latin America and the Caribbean. ASSAf surveyed the 84 academies of IAP in the other world regions. The other regions comprised Africa; the Middle East and Central Asia; South Asia; South East Asia and the Pacific; Western and Northern Europe; South Eastern Europe; and Central and Eastern Europe. A number of regional networks of science academies are affiliated to the IAP as observers and carry out the IAP mandate within the regions. They represent the Association of Academies and Societies of Sciences in Asia (AASSA), the Euro-Mediterranean Academic Network (EMAN), the European Academies' Science Advisory Council (EASAC), IANAS, the Network of Academies of Science of the Organisation of Islamic Conference (NASIC), and the Network of African Science Academies (NASAC). It is in this context that IANAS' involvement in the survey should be viewed.

For both surveys, data were collected on women's share of national academy membership, their representation in academy governance structures and whether the academy had a committee in place to advise on gender and/or diversity issues. A 'member' was taken to mean any person elected into the academy. Academies use different names to refer to those elected into their ranks, for example, member or fellow. In some instances, disparate categories distinguish membership (e.g. affiliate, honorary or even patron), with specific limitations of participation in academy activities placed in alignment to these categories. For example, affiliate members may not be eligible to vote in academy leadership elections. The reference year for membership figures was 2013/2014, as academies could use one of two sets of figures: the 2013 intake of members in cases in which elections for the 2014 intake had not yet occurred, or the 2014 member intake in those cases in which the relevant elections had already occurred.

Respondents in the ASSAf survey were asked to specify the number of academy members in nine broad discipline groups and to indicate the number of women members in those groups. An 'all other' option was included to cater for a situation in which the academy's discipline did not match any of the nine groups provided. The IANAS survey used 10 broad disciplinary groups, together with an 'other' option. For consistency, the broad disciplines in the IANAS survey were mapped onto those in the ASSAf survey. It should be noted here that science academies vary regarding their definition of disciplines and which of the latter are eligible for elections. For example, some academies do not elect into membership scientists in the humanities, arts and social sciences.

The survey was completed by a variety of individuals within academies, who included the presidents of academies and other office bearers, executive officers and the academy secretariat. IANAS focal points on gender at each of the North and Latin American, and Caribbean academies, also assisted some academies in that region in completing the questionnaire. A total of 69 national science academies provided information. The number of 'unique' academies was 65, given that the Swiss Academies of Arts and Sciences and its four constituency academies participated individually. The eventual response rate was 63% (i.e. 65 out of 103 national academies). It should be noted that many of the IAP member academies, at the time of the survey, might not have gathered the requested gender-disaggregated statistics, or had limited staffing capacity to answer extensive requests.

## Results

### *Academy membership*

The science academies reported on the total number of academy members together with the number of women academy members. Table 1 reports the share of women members for the 63 national science academies that provided data. The two academies ranked highest are both IANAS members: the Cuban Academy of Sciences (27%) and the Caribbean Academy of Sciences (26%). The national science academies of Mexico, Nicaragua, Peru, Uruguay, Honduras and Canada – all IANAS members – also feature on the list of the top 10 academies with the largest shares of women members (between 16% and 23%). In terms

of organisations ranked lowest, for 30 of the 63 science academies in Table 1 the share of women members is 10% or less. ASSAf is the only African academy that ranks among the top five organisations as far as women membership is concerned (24%). The Uganda National Academy of Sciences occupies the second position on the African continent (13%), followed by the academies of Ghana and Cameroon (both 11%). The average share of women members, across all 63 national science academies, is 12% (median = 11%).

Table 2 compares the mean share of women academy members in each world region. The largest mean share (17%) is associated with Latin America and the Caribbean. Because the mean is sensitive to outliers, it is advisable to also focus on the median shares. In terms of the median shares of women academy members, North America occupies the first place (15%), with Latin America and the Caribbean in close second place (14%). However, the North American region includes only two national science academies with exceptionally large membership figures (Table 1): the Royal Society of Canada (with 2108 members, of which 16% are women) and the United States National Academy of Sciences (with 2252 members, of which 13% are women). In Africa, women comprise on average 10% of academy members.

Figure 1 shows, for each of the nine broad disciplines, the mean share of women members across all the science academies that completed the relevant items in the survey. The figure ranges from as high as 22% (biological sciences) to as low as 5% (engineering sciences). However, given that there are size differences between the individual science academies as far as the share of women members is concerned (Table 1), it would be more appropriate to report the median share. Following this suggestion, we witness three broad disciplines for which the median share of women members per science academy equals zero: computer sciences/ICT, mathematical sciences and engineering sciences. This trend is also indicative of academic reflections on the representation of women in these fields.<sup>24-26</sup>

### *Academy governance*

The average share of women serving on the governing bodies of national science academies (20%, Table 1) is markedly higher than the share of women in the academy membership (12%). The corresponding median shares are 18% and 11%. Further investigation is required to uncover the reasons for this apparent difference. At this stage one can only speculate on possible reasons. For instance, it could point to the fact that there is a general recognition among academies that women need greater representation and a logical first step would be to include those already elected into the academy in the governing body. An equally plausible hypothesis is that women volunteer their time more readily than men do and hence are better represented in the governance of academies. According to Table 1, the US National Academy of Sciences (47%), together with two European academies (in Switzerland and Sweden, both 47%), have the best representation of women as members of the governing body. Outside Europe, three IANAS members are also noteworthy: Cuba (40%), Canada (38%) and Panama (38%). Relatively high shares are also recorded for three other European academies: the Netherlands (43%), the United Kingdom (40%) and Ireland (36%). In Africa, ASSAf recorded the largest share of women in academy governance (31%).

Lastly, the ASSAf survey enquired about the existence of an academy committee to address gender and/or diversity issues, or at the least someone to advise the academy on such issues. Of the 51 responding academies, 31 (61%) had no such committee or advisor. A third of academies (33%; 17 academies) had an established infrastructure (i.e. a dedicated committee) while the remainder (6%; 3 academies) relied on the input and guidance of individuals. Typically, academies with a larger share of women in their membership, specifically in Latin America, also reported having some infrastructure to address gender or diversity issues. On a regional level, IANAS has established a women in science working group comprising members of academies who are national focal points, and who act as strategic advisers to academies.

**Table 1:** Percentage of women members of national science academies and their governing bodies, by individual academy

Academy	Country	Academy membership			Academy governance		
		Total members	Women members	% Women	Total members	Women members	% Women
Cuban Academy of Sciences	Cuba	313	85	27%	10	4	40%
Caribbean Academy of Sciences	Caribbean	223	57	26%	7	2	29%
Academy of Sciences of the Czech Republic	Czech Republic	250	60	24%	17	4	24%
Academy of Science of South Africa	South Africa	423	101	24%	13	4	31%
Mexican Academy of Sciences	Mexico	2499	587	23%	10	3	30%
Nicaraguan Academy of Sciences	Nicaragua	30	7	23%	30	7	23%
National Academy of Sciences of Peru	Peru	114	23	20%	See table notes <sup>a</sup>		
National Academy of Sciences of Uruguay	Uruguay	26	5	19%	5	1	20%
National Academy of Sciences of Sri Lanka	Sri Lanka	136	25	18%	17	4	24%
Latvian Academy of Sciences	Latvia	393	70	18%	30	7	23%
National Academy of Sciences of Honduras	Honduras	29	5	17%	3	1	33%
Finnish Academy of Science and Letters	Finland	715	123	17%	10	3	30%
Science Council of Japan	Japan	2101	361	17%	16	4	25%
Swiss Academy of Medical Sciences	Switzerland	222	38	17%	14	4	29%
Royal Society of Canada	Canada	2108	346	16%	16	6	38%
Academy of Sciences Malaysia	Malaysia	265	41	15%	16	4	25%
Academy of Sciences and Arts of Bosnia and Herzegovina	Bosnia and Herzegovina	55	8	15%	16	3	19%
Royal Irish Academy	Ireland	480	69	14%	22	8	36%
Venezuelan Academy of Physical, Mathematical and Natural Sciences	Venezuela	50	7	14%	6	1	17%
National Academy of Sciences of Costa Rica	Costa Rica	43	6	14%	8	1	13%
Royal Netherlands Academy of Arts and Sciences	Netherlands	547	74	14%	7	3	43%
Colombian Academy of Exact, Physical and Natural Sciences	Colombia	190	26	14%	7	2	29%
Austrian Academy of Sciences	Austria	790	105	13%	4	1	25%
Academy of Sciences of the Dominican Republic	Dominican Republic	168	22	13%	17	5	29%
Brazilian Academy of Sciences	Brazil	506	64	13%	13	1	8%
Uganda National Academy of Sciences	Uganda	56	7	13%	11	1	9%
Royal Swedish Academy of Sciences	Sweden	624	78	13%	15	7	47%
US National Academy of Sciences	United States of America	2252	294	13%	17	8	47%
Academy of Medical, Physical and Natural Sciences	Guatemala	68	8	12%	6	1	17%
Chilean Academy of Sciences	Chile	75	9	12%	6	1	17%
National Academy of Exact, Physical and Natural Sciences	Argentina	34	4	12%	7	2	29%
Ghana Academy of Arts and Sciences	Ghana	105	12	11%	11	2	18%
Cameroon Academy of Sciences	Cameroon	83	9	11%	9	0	0%
Academy of Sciences of Albania	Albania	39	4	10%	7	1	14%
Croatian Academy of Sciences and Arts	Croatia	150	15	10%	5	1	20%
German National Academy of Sciences Leopoldina	Germany	1534	152	10%	12	2	17%

Table 1 continued

Academy	Country	Academy membership			Academy governance		
		Total members	Women members	% Women	Total members	Women members	% Women
Hassan II Academy of Science and Technology	Morocco	71	7	10%	6	1	17%
Australian Academy of Science	Australia	479	46	10%	17	5	29%
Swiss Academy of Engineering Sciences	Switzerland	263	25	10%	11	4	36%
Serbian Academy of Sciences and Arts	Serbia	141	13	9%	13	1	8%
Montenegrin Academy of Sciences and Arts	Montenegro	44	4	9%	7	0	0%
Nigerian Academy of Science	Nigeria	160	14	9%	See table notes <sup>b</sup>		
Royal Society of New Zealand	New Zealand	446	39	9%	7	1	14%
Turkish Academy of Sciences	Turkey	197	17	9%	11	0	0%
National Academy of Sciences of Bolivia	Bolivia	47	4	9%	9	1	11%
Royal Academy of Exact, Physical and Natural Sciences	Spain	49	4	8%	6	1	17%
French Academy of Sciences – Institute of France	France	485	38	8%	7	1	14%
Pakistan Academy of Sciences	Pakistan	90	7	8%	17	2	12%
Georgian National Academy of Sciences	Georgia	103	8	8%	20	1	5%
Bangladesh Academy of Sciences	Bangladesh	85	6	7%	13	2	15%
Kenya National Academy of Sciences	Kenya	146	10	7%	14	2	14%
Palestine Academy for Science and Technology	Palestine	75	5	7%	6	1	17%
The Royal Society	United Kingdom	1419	92	6%	20	8	40%
Sudanese National Academy of Sciences	Sudan	78	5	6%	5	1	20%
Indian National Science Academy	India	864	52	6%	31	0	0%
Chinese Academy of Sciences	China	741	42	6%	16	1	6%
National Academy of Lincei	Italy	530	28	5%	8	0	0%
Slovenian Academy of Sciences and Arts	Slovenia	95	5	5%	13	0	0%
Hungarian Academy of Sciences	Hungary	776	39	5%	33	1	3%
Ethiopian Academy of Sciences	Ethiopia	102	5	5%	11	1	9%
Mongolian Academy of Sciences	Mongolia	63	3	5%	17	1	6%
Polish Academy of Sciences	Poland	533	22	4%	24	1	4%
Tanzania Academy of Sciences	Tanzania	130	5	4%	6	1	17%
Academy of Scientific Research and Technology	Egypt	See table notes <sup>c</sup>			27	2	7%
Union of the German Academies of Sciences and Humanities	Germany	See table notes <sup>c</sup>			8	0	0%
Swiss Academies of Arts and Sciences	Switzerland	See table notes <sup>c</sup>			19	9	47%
Swiss Academy of Humanities and Social Sciences	Switzerland	See table notes <sup>c</sup>			18	5	28%
Swiss Academy of Sciences	Switzerland	See table notes <sup>c</sup>			7	2	29%
National Academy of Sciences of Panama	Panama	See table notes <sup>d</sup>			8	3	38%

<sup>a</sup>The National Academy of Sciences of Peru did not provide information on the composition of its governing council.

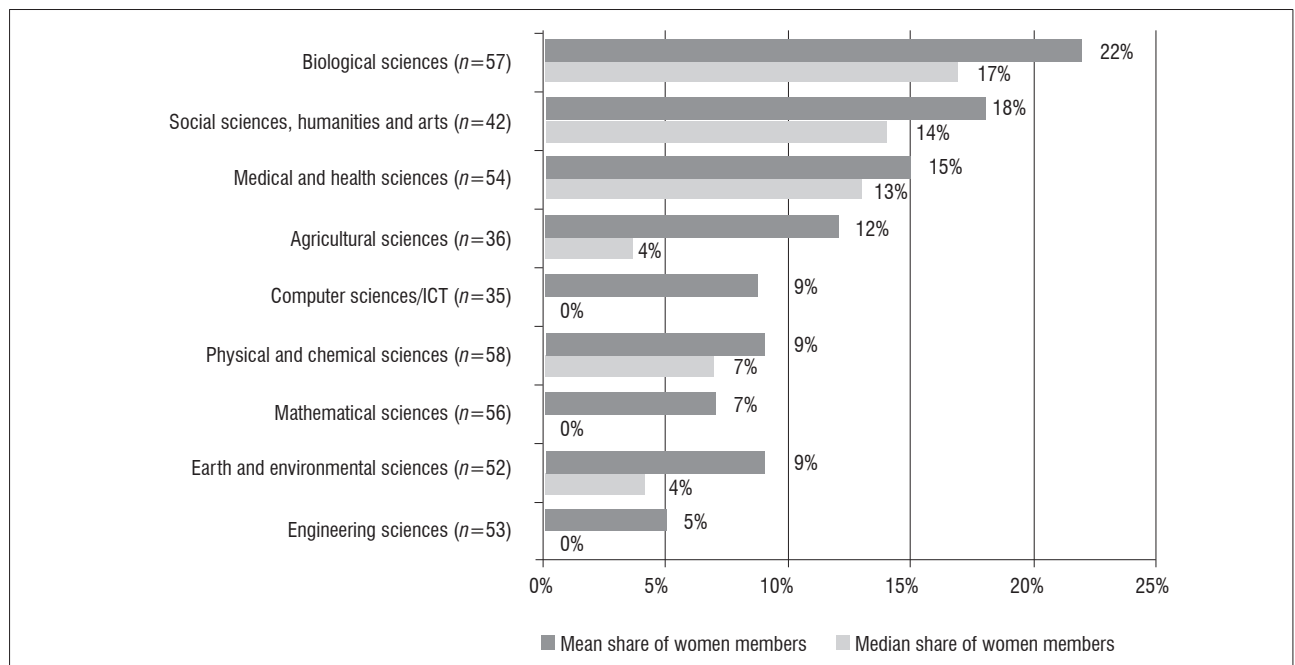
<sup>b</sup>The Nigerian Academy of Science reported that only one person (a woman) sits on the governing body.

<sup>c</sup>Five national academies did not provide any statistics to calculate the share of women academy members: the Academy of Scientific Research and Technology in Egypt, the Union of the German Academies of Sciences and Humanities, and the Swiss Academies of Arts and Sciences and two of its four constituent members (the Swiss Academy of Humanities and Social Sciences [SAHS] and the Swiss Academy of Sciences [SCNAT]). In the case of the Swiss Academies of Arts and Sciences, the SAHS and SCNAT do not have a system of individual members – their members are scientific unions with individuals from the relevant disciplines.

<sup>d</sup>Although the National Academy of Sciences of Panama participated in the IANAS survey, its statistic for members is not included in the table. The membership entry process for this science academy in Latin America is by application rather than election. Its relatively high share of women members (40%) is thus not comparable to figures for other academies.

**Table 2:** Percentage of women members of national science academies, by IAP world region

IAP world region	Number of academies	% Women				
		Mean	Median	Standard deviation	Minimum	Maximum
Africa	10	10%	10%	6%	4%	24%
Central and Eastern Europe	4	13%	12%	10%	4%	24%
Latin America and the Caribbean	16	17%	14%	5%	9%	27%
Middle East and Central Asia	3	8%	8%	1%	7%	9%
North America	2	15%	15%	2%	13%	16%
South Asia	4	10%	8%	6%	6%	18%
South East Asia and the Pacific	6	10%	10%	5%	5%	17%
South Eastern Europe	6	10%	10%	3%	5%	15%
Western and Northern Europe	12	11%	12%	4%	5%	17%
<b>Total</b>	<b>63</b>	<b>12%</b>	<b>11%</b>	<b>6%</b>	<b>4%</b>	<b>27%</b>



**Figure 1:** Percentage of women members of national science academies, expressed as both mean and median shares, by broad discipline group.

## Conclusion and recommendations

Although not optimal, the number and spread of participating academies provide a good base for future surveys. Large response variations were observed among the IAP member academies with regard to women's representation in membership and governance. Still, a common message emerged that needs to be acted upon. Elements of this rather familiar message include the following: women academy members remain far below parity with men given that women's membership is typically about 12%; in the natural sciences and engineering, women's membership remains well below 10%; and women members are better represented in the social sciences, humanities and arts, but rarely at over 20%.

In light of the above and other findings derived from this study, a number of recommendations are proposed: (1) IAP member academies should annually collect, analyse and report gender-disaggregated data on their respective membership and activities; (2) the IAP should publish gender-disaggregated data of its member academies in its annual report;

(3) the IAP annual report should report on the gender dimensions of IAP's internal activities; and (4) IAP member academies should establish permanent organisational structures that provide strategic direction and implement the academy's gender mainstreaming activities. Moreover, as it could take time to achieve a significant shift in academy membership, it is recommended that academies report on the 'gender make-up' of each year's election, in order to determine whether there is an overall trajectory of improvement.

There are also several aspects of women's representation in science that we did not explore in the current study. It is not clear what the main criteria for academy member selection or election are: honouring a lifetime body of work, or honouring scientific excellence and achievement even if that has been reached at an earlier career stage. It is often believed that women follow a different age structure within the scientific community; they tend to be younger, having more recently gained access to select science fields and in some cases have gaps in their scientific career as a result of the work-life balance cycle. To the extent that there is reliance on

a body of work as opposed to significant achievement at an earlier career stage, women may be forced to 'wait their turn'. Another pattern we may see for women is one of career interruptions, for example, as a result of family responsibilities, so their record of work is less comprehensive when it comes to consideration for academy membership.<sup>27-29</sup> It is also not clear to what extent the fields are given equal weight or priority when selecting women for academy membership. If there is positive bias towards engineering, computer science or the physical sciences, then fewer women will appear among those nominated as fewer are present among the share of researchers in those fields. If there is negative bias towards the biological, medical, social and behavioural sciences then women's higher representation in those fields will not be reflected in the overall academy representation.

Cultural effects that may affect women's election into science academies were also not addressed through the quantitative findings presented here. An argument could be made that the (mostly) male academy members nominate and elect colleagues from their established professional networks that were formed during past decades<sup>30-31</sup>, based on the academy's membership rules. Also, to what extent is unconscious bias<sup>32</sup> against women shared by both men and women scientists? Many cultures have male and female work spheres, confine girls to less valued 'women's work' and underestimate women's intellectual and technological capacities. This bias can be replicated in the processes of nomination, evaluation and selection of women and men, for example, for science grants, fellowships and prizes<sup>33</sup>, which contribute to the body of evaluation for membership into academies of science. Moreover, a number of questions warrant further investigation to better contextualise the findings of the IAP survey. Five examples will suffice:

- What is the age (mean and median) of women and men at time of election into the academy?
- Are the national governments of the science academies actively addressing gender equality in science?
- Do women researchers in some fields (e.g. social sciences and humanities) have a lower expectation of being nominated into the academy, given historical reasons for how academies are structured?
- Are all members of the science academies amenable to the development and implementation of gender policies to promote fairness in the assessment of women's contributions to the mandates of academies of science? This question should be linked to a greater understanding on male perception regarding the inclusion of women in academies of science.
- In cases in which the proportion of women on the academy governing board is much higher than in the membership, does this 'advantage' translate into actions to change the membership rules in order to improve the gender balance of the membership?

In summary, although the statistics present a picture of the status of women's representation in national science academies, they reveal the importance of further qualitative research to engage the unsettling quantitative narrative concluded by the study. This further research should allow for the design and implementation of appropriate policies to bring about needed changes.

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## Authors' contributions

D.N. was responsible for the conceptualisation, methodology, data collection, data analysis, validation, writing the initial draft, making revisions, project leadership, project management, funding acquisition. N.B. was responsible for the conceptualisation, methodology, data collection, data curation, data analysis, validation, writing the initial draft, making revisions, project management. F.H. was responsible for the conceptualisation, methodology, data collection, data curation, data

analysis, validation, revising the draft, project management. R.D. was responsible for making revisions, project leadership, funding acquisition. S.M. and J.T. were responsible for revising the draft.

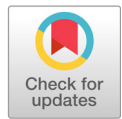
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# Population irruption of the clam *Meretrix morphina* in Lake St Lucia, South Africa

The thick-shelled clam *Meretrix morphina*, previously referred to as *Meretrix meretrix*, now occurs in the west Indian Ocean region, along the eastern seaboard of Africa, from the Red Sea to the Mlalazi Estuary, close to the Tugela River. Its presence in South Africa is only of recent recording. *Meretrix morphina* was detected for the first time in Lake St Lucia in 2000. The population declined and was not detected from 2005 until 2011, most likely as a result of a severe drought that resulted in widespread desiccation and hypersalinity in the lake. The system then experienced increased freshwater input resulting in lower salinities from 2011 until 2014, during which time *M. morphina* reappeared and their population gradually increased. In 2015, *M. morphina* became abundant in St Lucia, attaining unprecedented densities of 447 ind./m<sup>2</sup>. Biomass, expressed as a fresh weight, varied in the different basins of St Lucia, ranging from 195 g/m<sup>2</sup> at Lister's Point to 1909.8 g/m<sup>2</sup> at Catalina Bay. However, in 2016, when drought conditions returned, *M. morphina* disappeared. This species appears to thrive under brackish salinities and high temperatures. It is able to establish large populations with high biomass and can become dominant. However, *M. morphina* is sensitive to desiccation and hypersaline conditions. This clam has substantial commercial value and is exploited along the African east coast, particularly in Mozambique. In future, it may feature more prominently in South African estuaries. However, the ecology of *M. morphina* is still largely unknown.

**Significance:**

- First record of population irruption of *M. morphina* in South Africa.
- Report on the largely unknown ecology of a commercially valuable bivalve.
- Update on the taxonomy and poleward spread of *M. morphina*.

## Introduction

The thick-shelled clam *Meretrix morphina* (Lamarck, 1818) has previously been reported erroneously as *Meretrix meretrix* (Linnaeus, 1758) in the western Indian Ocean<sup>1,2</sup> because of an invalid synonymy which has only recently been rectified<sup>3</sup>. The species is restricted to the shores of the west Indian Ocean, but has occasionally been reported from South African coastal waters, mainly as dead shells.<sup>1</sup> Branch et al.<sup>2</sup> and Kilburn and Rippey<sup>4</sup> have stated that *M. morphina* does not occur naturally south of Maputo Bay, Mozambique; however, this species has recently been recorded in the St Lucia and Mlalazi estuaries. This occurrence represents another case of poleward range expansion, probably in response to global warming, as many such cases have already been documented along the South African coastline.<sup>5</sup> The mode of introduction into Lake St Lucia remains unresolved, but possible means involve either transport of veligers from Maputo Bay via the southward flowing Agulhas Current or human-mediated introduction of adults as bait for recreational fishing.<sup>6</sup>

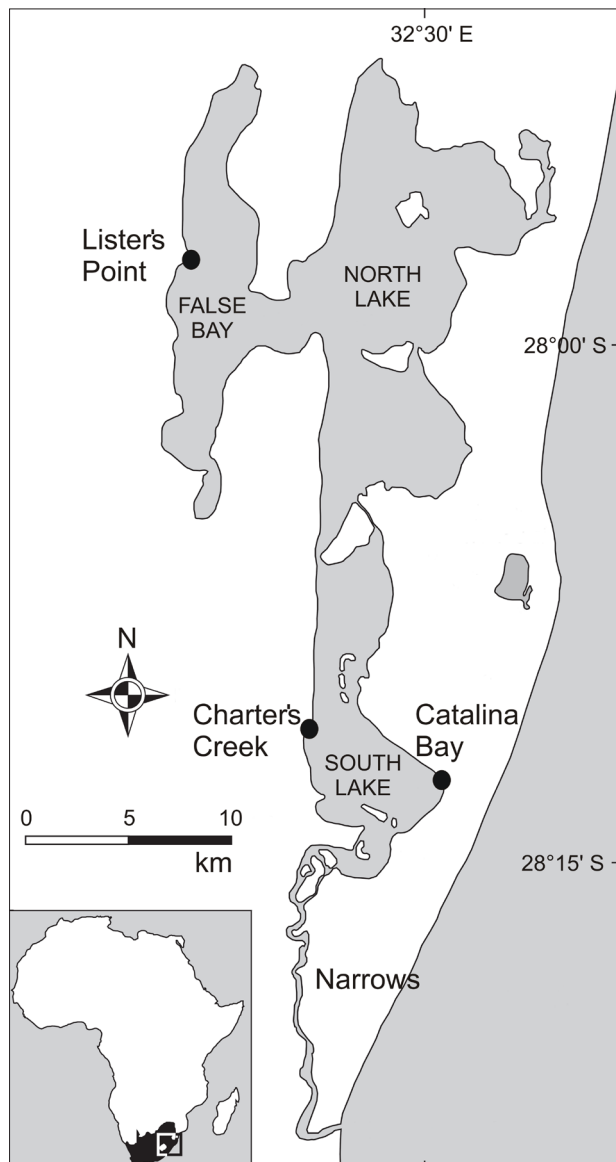
The St Lucia system is Africa's largest estuarine lake, a Ramsar Wetland of International Importance and a crucial part of the iSimangaliso UNESCO World Heritage Site.<sup>7</sup> It represents one of the most important nursery areas for estuarine dependent marine species along the southeast African coast and is regarded as a hotspot of biodiversity and centre of endemism.<sup>8</sup> Historically, this system has undergone cyclical periods of alternating dry and wet conditions, culminating in floods and prolonged droughts.<sup>9</sup> The flow of fresh water into St Lucia is also affected by anthropogenic activities in its catchments and in the mouth region of the estuary.<sup>10,11</sup> The system is presently exposed to desiccation, prolonged mouth closure and the development of hypersalinity during dry phases.<sup>12</sup> For a detailed review of hydrodynamics in St Lucia see Stretch et al.<sup>9</sup> and Lawrie and Stretch<sup>11</sup>.

In Lake St Lucia, a viable *M. morphina* population was recorded for the first time in July 2000.<sup>5</sup> The population then declined and was not detected in the lake, most likely because of a severe drought that caused widespread desiccation and hypersalinity in the region from 2005 until 2011.<sup>5</sup> The system then experienced increased freshwater input, resulting in lower salinities from 2011 until 2014, during which time live *M. morphina* reappeared and their population gradually increased. In 2015, *M. morphina* became overwhelmingly abundant in St Lucia. As *M. morphina* is likely to have a major ecological impact when it occurs in such large numbers, information is needed on its biology and ecology in order to fully understand its role in the system. The aim of this study was to document the unprecedented population irruption of *M. morphina* in Lake St Lucia, as well as to identify some possible implications of its presence on the ecology of the system.

## Materials and methods

Lake St Lucia consists of three lake basins, known as South Lake, North Lake and False Bay. Sampling sites were selected to represent the South Lake (Catalina Bay and Charter's Creek) and False Bay/North Lake (Lister's Point) (Figure 1). Routine measurements of physico-chemical parameters (temperature, salinity, O<sub>2</sub> concentration, turbidity, pH) were taken using a YSI 6600V2 multiprobe. In addition, total suspended solids (TSS, mg/L) were determined by gravimetric analysis and chlorophyll-*a* concentrations (mg/L) were determined fluorometrically during quarterly surveys, conducted in January/February, April/May, July/August and November/December of

each year at the representative stations from 2008 to 2015 (for more details refer to Pillay and Perissinotto<sup>13</sup>). Salinity and water level data were obtained from Ezemvelo KZN Wildlife.



**Figure 1:** Map of Lake St Lucia. Black dots indicate dedicated sampling sites.

Benthic macrofaunal collections were undertaken on each occasion using a Zabalocki-type Ekman grab (sampling area = 0.0236 m<sup>2</sup>, depth = 150 mm). At each visit, three replicate samples per site were collected, with each sample comprising the content of three grabs pooled together. After a thorough extraction process, involving repeat stirring and filtration, each macrofaunal sample was preserved using 4% formalin.<sup>13</sup> A survey was also undertaken in November 2015 to assess the prevailing ecological conditions and the densities of the *Meretrix morphina* population during its irruption. Two 1x1-m quadrants were randomly positioned at Catalina Bay, Charter's Creek and Lister's Point. The sediment within each quadrant was extracted to a depth of 150 mm and passed through a 1000- $\mu$ m sieve. All bivalves collected on the sieve were preserved in 10% formalin and taken to the laboratory for identification, enumeration and measurement. The dominant species collected were *Brachidontes virgiliae*, *Dosinia hepatica*, *Salmacoma litoralis*, *Solen cylindraceus* and *Tellinides kilburni*.<sup>6</sup> For each species, individuals of various shell lengths were weighed to determine total fresh weight (shell and wet tissue, g). This measure was used to determine biomass per square metre. Only fresh weight biomass and shell length is reported here to allow for direct preliminary comparisons with previous studies.<sup>14,15</sup>

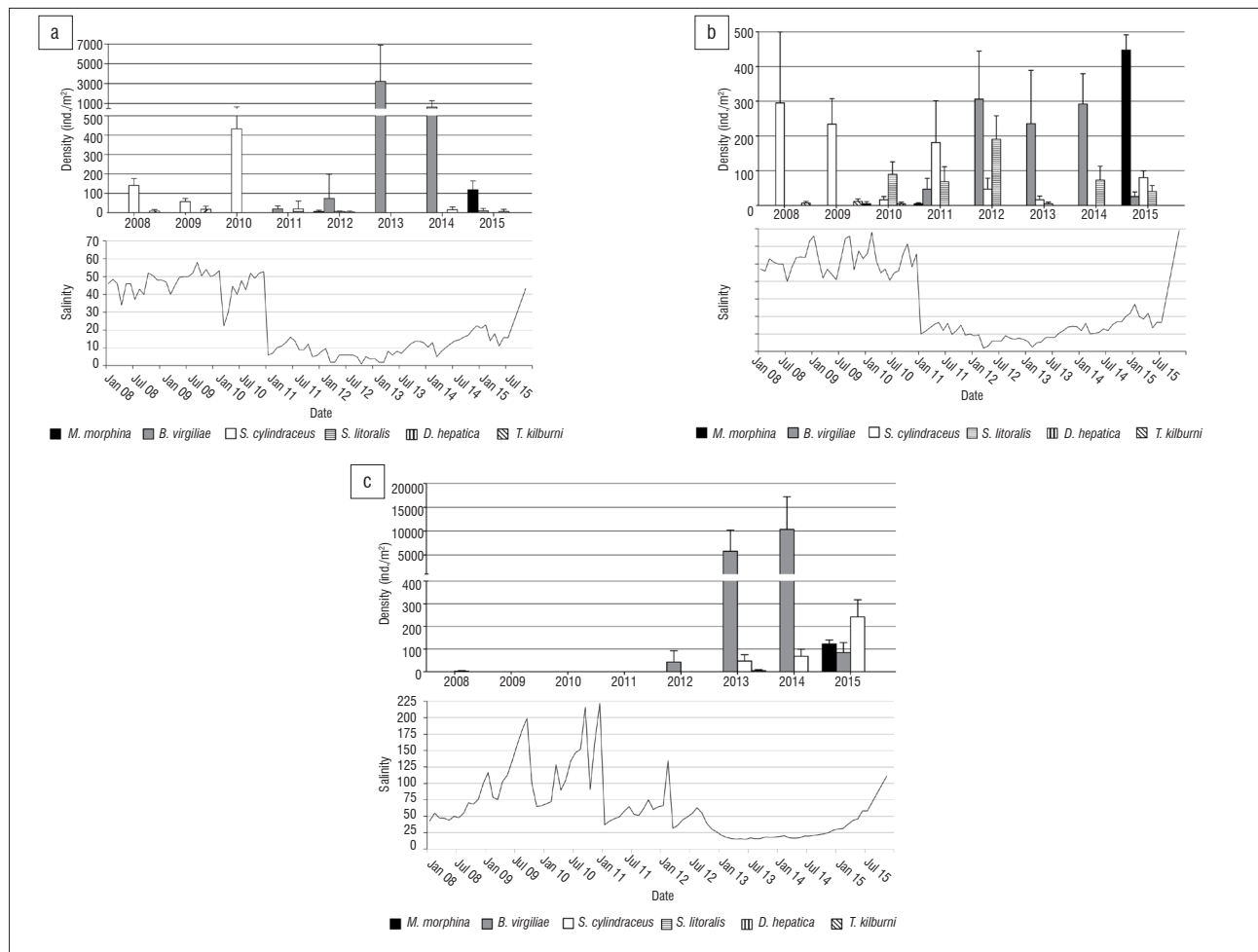
Distance-based linear modelling (DISTLM<sup>16,17,18</sup>) was run in the PERMANOVA package of PRIMER v. 6. This program was used to perform permutational regression (9999 random permutations) to test for linear relationships between *M. morphina* abundance (response) and key environmental variables (temperature, salinity, dissolved O<sub>2</sub> concentration, turbidity, pH, chlorophyll-a, TSS concentrations, lake water level and year – predictors). Data collected when *M. morphina* were present during the years 2010–2015, in the three sampling sites, were included (21 sample points). The response variable (*M. morphina* density) was first converted to a Euclidean distance matrix. A stepwise selection procedure was used, incorporating the corrected Akaike Information Criterion (AICc)<sup>19</sup> as the selection criterion to measure the relative goodness of fit for each model.

## Results and discussion

The presence of *M. morphina* in Lake St Lucia and Mlalazi Estuary adds to the growing record of species displaying a poleward migration in South Africa.<sup>5,20</sup> The southernmost distribution of *M. morphina* was previously recorded as Maputo Bay and Inhaca Island (25°57'S). The new records from St Lucia (28°13'S) and Mlalazi (28°57'S) have now substantially extended this distribution southwards.

Bivalve dominance shifts were previously recorded from St Lucia.<sup>6</sup> These shifts appear to be related to flood and drought states of the system, more specifically, its associated salinity regime.<sup>21</sup> St Lucia was previously dominated by *B. virgiliae* during wet phases and by *S. cylindraceus* during the preceding drought phase<sup>22</sup> (Figure 2). However, during 2015, instead of the expected irruption of *S. cylindraceus*, *M. morphina* dominated (Figure 2, Table 1). The salinity tolerance range of *S. cylindraceus* is 15–65<sup>23</sup>, whereas *M. morphina* was recorded in salinities of 7.5–58.2 during the current study (see also<sup>24–27</sup>). Both species are euryhaline, but *M. morphina* may have established itself ahead of *S. cylindraceus* during low salinity conditions prevailing during the few years leading up to 2015. Whereas *B. virgiliae* has a sedentary habit and *S. cylindraceus* tends to burrow vertically in the substrate, *M. morphina* burrows vertically and horizontally. The more dynamic burrowing behaviour of *M. morphina* may allow it to better avoid predation, optimise foraging and escape unfavourable environmental conditions.<sup>28</sup> The stepwise AICc analysis selected water temperature, salinity, turbidity and total suspended solids as the most parsimonious model explaining a high percentage (80.3%) of the variation in *M. morphina* density (Table 2). Although *M. morphina* can tolerate high salinity, the model indicates that it performs better at lower salinity. An increase in water temperature is expected to raise the metabolism of bivalves, thus influencing activities such as feeding and burrowing. A combination of salinity and temperature affects the growth of *M. morphina*. Thanh and Thung<sup>29</sup> reported an optimal combination with salinity of 20 and temperature of 27 °C for the growth of *M. meretrix* juveniles. The highest average biomass of *M. morphina* was recorded at Catalina Bay in 2015, at an average salinity of 24 and temperature of 26 °C (Table 1).

St Lucia *M. morphina* appear to attain greater density and biomass compared with other populations along the African coast.<sup>13,14</sup> The size and biomass of Maputo Bay populations may be depressed by human harvesting and high pollution levels<sup>14</sup>, whereas the St Lucia populations are not harvested and reside within a protected area. Predation pressure may also have been lower in St Lucia as a result of the adverse effect of the drought on fish populations.<sup>30</sup> Molluscivorous fish, crustaceans and birds are present in both areas, but their comparative impact on bivalve populations is unknown. Notably, *M. morphina* has a strong shell that is thicker than that of most other bivalves in St Lucia, which may also give it an advantage against certain predators. However, *M. morphina* can reach larger sizes and greater biomass than other dominant bivalves in Lake St Lucia (Figures 3 and 4). The maximum densities attained by *B. virgiliae* were >10 000 ind./m<sup>2</sup>, two orders of magnitude higher than those of *S. cylindraceus* or *M. morphina*. The maximum shell length of *B. virgiliae*<sup>21</sup> was 25 mm while *S. cylindraceus*<sup>31</sup> and *M. morphina*<sup>6</sup> reached lengths of 95 mm and 70 mm, respectively. Based on estimated values, *M. morphina* fresh weight biomass during 2015 was 1909.8 g/m<sup>2</sup> at Catalina Bay (Table 1).



**Figure 2:** Population density (ind./m<sup>2</sup>) of bivalves (*Meretrix morphina*, *Brachidontes virgiliae*, *Dosinia hepatica*, *Salmacoma litoralis*, *Solen cylindraceus* and *Tellinides kilburni*) and average salinity at (a) Catalina Bay, (b) Charter's Creek and (c) Lister's Point from 2008 to 2015. Error bars show s.e. Samples were collected by Ekman grab.

**Table 1:** The estimated density, shell length and fresh weight biomass (mean±s.d.) of *Meretrix morphina* at three sites within Lake St Lucia in 2015

	Temperature (°C)	Salinity	Turbidity (NTU)	Total suspended solids (mg/L)	Density (ind./m <sup>2</sup> )	Shell length (mm)	Biomass (g/m <sup>2</sup> )
Catalina Bay	26.39	23.59	3.73	93.6 ± 3.8	117.8 ± 46.1	38 ± 11	1909.8 ± 1037.5
Charter's Creek	24.97	30.94	16.42	102.5 ± 26.9	447.3 ± 106.9	29 ± 15	215.5 ± 263.0
Lister's Point	23.82	61.47	206.325	229.3 ± 119.4	122.4 ± 43.2	20 ± 10	195.5 ± 27.0

**Table 2:** Distance-based linear model of *Meretrix morphina* abundance (response) against environmental variables (predictors) measured in Lake St Lucia from 2010 to 2015. Sequential tests for stepwise model ( $r^2 = 0.80$ ), and percentage of multivariate flux variation explained by the model are presented. The most parsimonious model includes water temperature (°C), salinity, turbidity (NTU) and total suspended solids (TSS, mg/L).

Model	AICc	SS (trace)	Pseudo - F	P	Prop.	Cumul.	res. df
Temperature	210.8	1.25650	6.20	0.021	0.246	0.2460	19
Temperature + TSS	207.56	95381	5.93	0.028	0.187	0.433	18
Temperature + TSS + Salinity	206.43	52677	3.78	0.068	0.103	0.536	17
Temperature + TSS + Salinity + Turbidity	191.95	1.36200	21.68	0.001	0.267	0.803	16

Relationship between dbRDA coordinate axes and orthonormal X variables (multiple partial correlations)

Axis	Explained variation out of fitted model (%)	Explained variation out of total variation (%)	Temperature	TSS	Salinity	Turbidity
1	100	80.3	0.649	0.631	-0.338	0.257

Recruits, juveniles and large *M. morphina* adults were present in 2015 (Figure 3), indicating that the population was healthy and growing. However, at the end of 2015, as lake levels dropped and hypersaline conditions developed, the population was stranded and exposed to sudden desiccation. Thus, there was mass mortality of *M. morphina* (Figure 5). During this time, large flocks of birds, including seagulls and cormorants, were seen feeding on stranded *M. morphina* (personal observation). In 2016, this species was not detected in St Lucia. However, *M. morphina* may irrupt again in future.

High densities of *M. morphina* can play an important ecological role in becoming major consumers of suspended organic matter<sup>15</sup> and their presence may be correlated with patterns of suspended particle loads and turbidity (Tables 1 and 2). However, the feeding behaviour of these clams is influenced by time of day, habitat type, food concentration,

salinity and body size, among other factors.<sup>15,32</sup> Further studies, including comparative feeding analyses among different bivalve species, are needed to accurately address the effects of *M. morphina* on resident taxa and the environment.

While *M. meretrix* has been studied because of its commercial value<sup>32,33</sup>, there is a substantial lack of knowledge regarding the ecology of *M. morphina*. In Lake St Lucia, *M. morphina* appears to thrive under brackish salinities and high temperatures. It is able to establish large populations with high biomass and can become one of the most dominant bivalve species in the system. However, like many other sympatric bivalves, *M. morphina* is sensitive to exposure to desiccation and hypersaline conditions. As the distribution range of *M. morphina* expands, further studies are needed to assess its ecological interactions in new habitats.

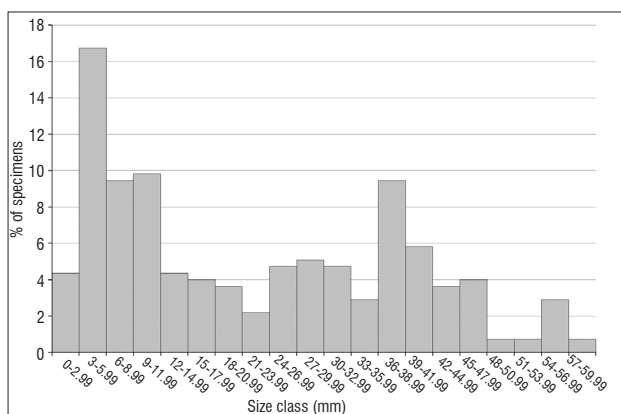


Figure 3: Size class distribution (n=275) of *Meretrix morphina* in Lake St Lucia in November 2015.

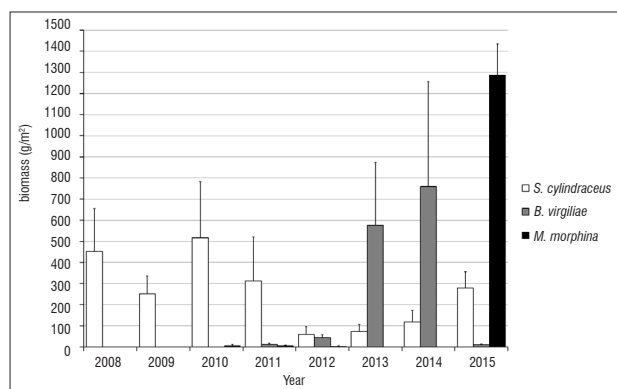


Figure 4: Estimated average biomass (fresh weight, g/m<sup>2</sup>) of *Solen cylindraceus*, *Brachidontes virgilliae* and *Meretrix morphina* in Lake St Lucia between 2008 and 2015. Error bars show s.e.



Photo: Lynette Clennell

Figure 5: Dense aggregations of exposed and dying *Meretrix morphina* clams, while water levels receded and hypersaline conditions became re-established around Catalina Bay, Lake St Lucia, in November 2015.

## Acknowledgements

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## Authors' contributions

N.A.F.M., N.P., R.P. and N.K.C. were the project initiators and coordinators and were responsible for sampling design, compilation of data and the manuscript write-up; R.P., N.A.F.M., N.P., N.K.C., S.J., R.H.T. and C.F. were responsible for sample collection and analysis and the manuscript write-up.

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