South African
Journal *of* Science

volume 115
number 7/8

Cardioprotection conferred by rooibos?

Evaluation of research: relevance of metrics

Corrosion map of South Africa's macro atmosphere

Progressive delays in the timing of sardine migration

Challenges and solutions in citizen science projects

ASSAf
ACADEMY OF SCIENCE OF SOUTH AFRICA

Volume 115
Number 7/8
July/August 2019

eISSN: 1996-7489

Published by
the Academy of Science of South Africa (www.assaf.org.za) with financial assistance from the Department of Science & Technology.

Design and layout
SUN MeDIA Bloemfontein
T: 051 444 2552
E: publish@sunbloem.co.za

Correspondence and enquiries
sajs@assaf.org.za

Submissions
Submissions should be made at www.sajs.co.za

Cover caption
The iconic sardine.
In an article on page 61, Fitchett and colleagues examine the progressive delay in the timing of South Africa's annual sardine migration.

The Anthropocene

The concept of the Anthropocene has been buzzing around for nearly two decades. The first reference to the Anthropocene as a name for the current geological epoch arose in February 2000 during a meeting of the International Geosphere-Biosphere Programme (IGBP) in Cuernavaca, Mexico. On that occasion, Paul J. Crutzen, the Dutch, Nobel Prize-winning atmospheric chemist, and then Vice-Chair of the IGPB, had become increasingly impatient with his colleagues' repetitive use of the word 'Holocene' and exclaimed, 'Stop using the word Holocene. We're not in the Holocene any more. We're in the…the…the…[searching for the right word]…the Anthropocene!'[1] Later that year, Crutzen (b.1933) and Eugene F. Stoermer (1934–2012), limnologist at the University of Michigan who had originally coined the term in the 1980s (in a different context), co-authored the initial scientific publication on the topic in the *IGBP Newsletter*. In it, the authors noted prior recognition of the damage that humans were inflicting on the planet. In 1864, for example, American diplomat and thinker George Perkins Marsh (1801–1882) published his groundbreaking *Man and Nature*; in 1873 Antonio Stoppani (1824–1891), geologist and palaeontologist, referred to the 'anthropozoic' era; while in 1926 Russian geologist Vladimir I. Vernadsky (1863–1945) took note of the 'noosphere', the growing human power over the total biosphere.[2] But Crutzen and Stoermer concluded that the impact had reached geological proportions.

As a new epoch, the notion of the Anthropocene intrigued geologists. In 2009, Jan Zalasiewicz and Mark Williams of the University of Leicester formed the Anthropocene Working Group (AWG) in the Subcommission on Quaternary Stratigraphy within the International Union of Geological Sciences. The AWG comprised almost 40 members, among whom at the time was a South African, Professor Mary Scholes. The aim was to succeed Sir Charles Lyell's Holocene ('recent whole'), suggested in 1833 and formalised in 1885, with the Anthropocene. Numerous meetings and publications aroused considerable excitement as well as debate. Anticipation grew when South Africa hosted the International Geological Congress in Cape Town in August 2016 at which the issue would be discussed. Many believed that the entire geological community would then accept the 'Anthropocene' for the modern geological epoch.

That did not happen. There was not, apparently, sufficient consensus on the markers of the Anthropocene and its commencement date. As Waters et al.[3] explained, 'To constrain the Anthropocene as a potential formal unit within the Geological Time Scale, a spectrum of indicators of anthropogenically induced environmental change' must be present and must include signals that are stratigraphical and include the lithostratigraphical and the biostratigraphical.

By 2019 the matter was no closer to resolution and in May this year, the AWG voted whether to disband because of irreconcilable disagreements within the group, or to proceed with formal recommendation for the Anthropocene with required markers and date. A majority favoured the second option. Thus, the AWG will continue to hunt for a Global Boundary Stratotype Section and Point in the mid-20th century that will pass stratigraphical muster for an interval of geological time.[4] As AWG member, environmental historian John McNeill, observed in a personal email (21 May 2019), it will be a slow process.

However, as a metaphor, the Anthropocene has fired the imagination of people well beyond the geological community. The multidisciplinary literature is large and growing, except, perhaps (regrettably) in and from South Africa where the Anthropocene has a low profile. There have been no themed museum exhibits, art exhibitions, readings, theatre and other cultural engagements to inform South Africans through other disciplines of the many human-induced permanent changes to the earth. In addition to the geological and chemical, these are the multiple aspects of global and climate change, enduring pollution, species mega-extinctions and landscape-scale transformations. The establishment in 2014 of the scholarly journal, *The Anthropocene Review*, led the way for a transdisciplinary conversation. Sociologists, philosophers, environmentalists and historians elsewhere have also written about many of these issues. The Anthropocene has been dissected as a 'capitalocene' and a 'plantationocene', linked to justice and equity as well as to geology.[5]

Not everyone is pleased to have the Anthropocene so widely interpreted in this manner.[6] AWG secretary Colin Waters was concerned that '… the term has come to mean different things as it has spread to different groups, a situation that can only end in headaches … We need a common understanding'[7]. Nonetheless, together with museum displays in Europe, Australia and the USA, there have been multidisciplinary readings and writings, workshops and conferences that have enabled citizens in those places to conceptualise and better understand the era in which we live and also to envision the future. Doing so requires no official scientific approval, and total engagement with the Anthropocene as a whole may become a tool for common action, not solely a description of the state of the planet.[8]

References

1. Steffen W. The Anthropocene. In: Robin L, Sörlin S, Warde P, editors. The future of nature: Documents of global change. New Haven, CT: Yale University Press; 2013. p. 486. https://doi.org/10.1558/jsrnc.v10i4.31456
2. Crutzen PJ, Stoermer EF. The 'Anthropocene'. IGBP Newsletter. 2000 May; 41:17–18. Available from: http://www.igbp.net/download/18.316f18321323470177580001401/1376383088452/NL41.pdf
3. Waters CN, Zalasiewicz JA, Williams M, Snelling AM. A stratigraphical basis for the Anthropocene? Special publication 395 Geological Society of London. London: Geological Society of London; 2014. https://doi.org/10.1144/sp395.18
4. Anthropocene Working Group. Results of binding vote by AWG released 21st May 2019 [document on the Internet]. c2019 [cited 2019 Jul 10]. Available from: http://quaternary.stratigraphy.org/working-groups/anthropocene/
5. Davis J, Moulton AA, Van Sant L, Williams B. Anthropocene, Capitalocene, … Plantationocene?: A manifesto for ecological justice in an age of global crises. Geogr Compass. 2019;13(5), e12438. https://doi.org/10.1111/gec3.12438
6. Zalasiewicz J, Waters CN, Head MJ, Poirier C, Summerhayes CP, Leinfelder R, et al. A formal Anthropocene is compatible with but distinct from its diachronous anthropogenic counterparts: A response to W.F. Ruddiman's 'Three-flaws in defining a formal Anthropocene'. Prog Phys Geog. 2019;43(3):319–333. https://doi.org/10.1177/0309133319832607
7. Waters C in Sample I. Anthropocene: Is this the new epoch of humans? The Guardian. 2014 October 16;Geology [updated 2014 Oct 28; cited 2019 Jul 10]. Available from: https://www.theguardian.com/science/2014/oct/16/-sp-scientists-gather-talks-rename-human-age-anthropocene-holocene
8. Robin L. Environmental humanities and climate change: Understanding humans geological and other life forms ethically. WIREs Clim Change. 2018;9(1), e499, 18 pages. https://doi.org/10.1002/wcc.499

HOW TO CITE:
Carruthers J. The Anthropocene. S Afr J Sci. 2019;115(7/8), Art. #6428, 1 page. https://doi.org/10.17159/sajs.2019/6428

AUTHOR:
Michèle Ramsay[1]

AFFILIATION:
[1]Sydney Brenner Institute for Molecular Bioscience, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

CORRESPONDENCE TO:
Michèle Ramsay

EMAIL:
Michele.Ramsay@wits.ac.za

HOW TO CITE:
Sydney Brenner (1927–2019): The opening game. S Afr J Sci. 2019;115(7/8), Art. #a0311, 1 page. https://doi.org/10.17159/sajs.2019/a0311

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

PUBLISHED:
30 July 2019

Sydney Brenner (1927–2019): The opening game

In his memoire, *My Life in Science* (BioMed Central Limited; 2001), Sydney Brenner described his greatest skill as 'getting things started'. Throughout his life, he inspired breathtaking research projects and ambitious scientific institutes that are thriving today across several continents.

Brenner was born in Germiston on 13 January 1927. His curiosity and quest for knowledge was apparent at an early age, and led to him being awarded a scholarship to study medicine at the University of the Witwatersrand at the age of 15. He was a pioneer and explorer at heart and did not seriously consider a medical career. Thus, as a young man, he left South Africa for the UK to pursue scientific ideas, and joined the laboratory of Cyril Hinshelwood (a future Nobel laureate) and completed a DPhil at the University of Oxford in 1954.

His first view of the structure of the DNA model built by Jim Watson and Francis Crick at Cavendish Laboratories (Cambridge, UK) had a profound effect on his career. In 1956, he moved to Cambridge where he shared an office with Francis Crick, during which time they, together with many collaborators, contributed groundbreaking work towards elucidating the triplet code and the role of mRNA in protein synthesis, resulting in seminal publications from 1961 to 1965.

Seeking the challenge of working with whole organisms, Brenner chose the transparent fast-growing nematode worm, *Caenorhabditis elegans*, and started the work in the mid-1960s. Much of his research was done at the UK Medical Research Council's famous Laboratory of Molecular Biology at the University of Cambridge. Here he worked closely with John Sulston to map the entire nervous system and the development of each of the cells of *C. elegans* from fertilised egg to 959-cell adult; and with Robert Horvitz to identify the genes for programmed cell death – which led to the three of them sharing the 2002 Nobel Prize in Physiology and Medicine.

Brenner thought deeply about the impact of research on society and the responsibility of scientists at different levels: informing the public, protecting the public, sharing resources and developing guidelines to promote scientific discovery. During the Asilomar conference on recombinant DNA (California, 1975), he took the lead in discussions on the ethics and appropriate use of these technologies. He was a proponent of the Human Genome Project and the need for more inclusive participation in this international project, and was a founding member of the Human Genome Organisation (HUGO).

In 1989, he initiated the Fugu Genome Project, having long known that the genome of this fish (the puffer fish) was about an eighth the size of the human genome. After an initial slow start, the project came to rapid fruition – and therein lies a tale. The complete sequence of the genome was published in 2002 in *Science* and a woodcut sketch of *Fugu rubripes* appeared on the cover.

Brenner garnered respect and admiration from influential people in the governments of Singapore and Japan, which led to his 'institution-building years'. When invited to meet with the Prime Minister of Singapore in 1983, Brenner urged him to get involved in cutting-edge research in biotechnology and presented a half-page vision. The government of Singapore promptly funded the establishment of the Institute of Molecular and Cell Biology at Singapore National University. When invited to become its director, Brenner suggested that it would be preferable to have a well-respected Singaporean leader. And when the Institute officially opened in 1987, Brenner had a laboratory in which he pursued the *Fugu* research. In 2003, he became an honorary citizen of Singapore in recognition for his critical role in the inspiration and planning of the Agency for Science, Technology and Research for the promotion, funding and oversight of all biomedical research in the country.

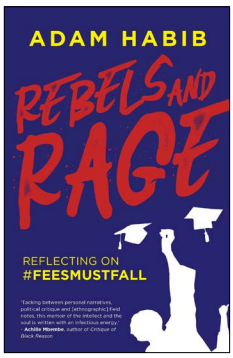
In 1992, Brenner was invited to take part in an international review of the University of Tokyo to explore educational and research reform in Japan. Following much debate and planning, he became the Founding President of the Okinawa Institute of Science and Technology (OIST) in 2005 and then handed over the reins in 2007 to local leadership. The OIST has developed into a thriving English-language institution with well over half its staff and students recruited from outside Japan. OIST paid tribute to Brenner at a Memorial on 26 May 2019.

In 2004, South Africa bestowed on Brenner the Order of Mapungubwe (Gold). Also in 2004, Brenner established the Sydney Brenner Postdoctoral Fellowship, administered by the Academy of Science of South Africa. On 28 March 2008, he agreed to the use of his name for the Sydney Brenner Institute for Molecular Bioscience at his alma mater, the University of the Witwatersrand, to establish a research hub for genomics and bioinformatics studies in African populations. Brenner aptly referred to African genomes as a treasure trove. When meeting with him in April 2011, I asked him what was occupying his mind and he proceeded to explain that he was trying to figure out what came first – the ability to smell or the ability to taste. A vexing conundrum, indeed.

Brenner married May Covitz Balkind, a student of psychology at Wits where they met, and together they raised four children. May died in 2010 and her son Jonathan in 2018. Brenner spent his last years in Singapore, still exploring the mysteries of life, and recently bringing together a stellar cast for *Sydney Brenner's 10-on-10: The Chronicles of Evolution,* published in 2019 (Wildtype Books).

His mischievous wit, razor-sharp intellect, edgy commentary and relish for ruffling feathers will be missed. To echo the words of Alan Christoffels (who worked with Brenner in Singapore before returning to South Africa): 'A baobab has fallen'. Brenner's memory lives on in all the people he inspired and challenged over his lifetime and in the research institutions he 'got started' and nurtured.

BOOK TITLE:
Rebels and rage: Reflecting on #FeesMustFall



AUTHOR:
Adam Habib

ISBN:
978186428960 (softcover)

PUBLISHER:
Jonathan Ball, Johannesburg; ZAR275

PUBLISHED:
2018

REVIEWER:
Stuart T. Saunders

AFFILIATION:
Emeritus Professor, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Stuart Saunders

EMAIL:
stuarts@iafrica.com

HOW TO CITE:
Saunders ST. Rebels and rage: Reflecting on #FeesMustFall – A review. S Afr J Sci. 2019;115(7/8), Art. #6234, 2 pages. http://doi.org/10.17159/sajs.2019/6234

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

PUBLISHED:
30 July 2019

Rebels and rage: Reflecting on #FeesMustFall – A review

I understand the challenges faced by vice-chancellors as a consequence of student protests, whether they occur under an apartheid government – as was the case when I was Vice-Chancellor of the University of Cape Town (UCT) from 1981 to 1996 – or during a democracy. The issues usually are different, but the tensions are the same.

Adam Habib, Vice-Chancellor of the University of the Witwatersrand (Wits) has made an important contribution to our understanding of the #FeesMustFall movement in *Rebels and Rage*. It is a frank account of the events at Wits during the protests. The payment of fees by students to universities has been a major inhibitor of access to higher education for thousands of poor (mainly black) students. Fees have steadily increased because of the government's annual lowering of its subsidies to universities. As Habib points out, the university system expanded from 420 000 students in 1994 to 1.1 million in 2014, without any concomitant increase in university subsidies. The increases in fees were higher at research-intensive universities as their running costs are higher.

Habib forcefully and correctly emphasises the importance of research universities in ensuring that South Africa's development does not become dependent on that from the developed world, and he recognises the tension between this imperative and ensuring access to those universities. There is no doubt that the lack of adequate university funding by government was responsible for the precipitation of this crisis. The student call for free education is a just one, but the methods used by the #FeesMustFall movement were frequently violent and unacceptable, and thus poses a serious threat. Habib claims that students and their supporters in the faculties were often problematic in the attitudes they adopted, and that the African National Congress and Economic Freedom Fighters were regularly involved. Political populism was often at play.

Habib was determined that Wits would not close, and a poll in this regard showed that he had the support of the vast majority of staff and students. Closing the university would have threatened the future careers of large numbers of students. In order to ensure that Wits remained open, Habib employed independent security services which were not allowed to carry guns or dangerous weaponry. When necessary, he called in the police, but he did so reluctantly, because although Wits was in control of the actions of the private security personnel, they had no control over the police. Habib was criticised for using private security companies, but he was absolutely correct in doing so, as Wits was able to remain open. Claims against the security services for initiating violence were usually false – the violence was initiated by the protestors who often acted unlawfully and irresponsibly and thus, regrettably, undermined their cause, which was a just one.

In addition, most universities had outsourced many of their non-academic staff duties, such as maintenance and catering, in order to save money. The campaign to insource these staff was soon linked to the #FeesMustFall protests. The Vice-Chancellors decided to try to act in concert on this issue, as many universities faced serious financial challenges in regard to insourcing. However, UCT broke ranks in the matter and all the universities had to follow. Those employees who were outsourced were often paid lower wages than those within and had no additional privileges such as medical aid and pension schemes. Moreover, outsourcing was difficult to defend on moral grounds. Problems of transformation and sexual harassment, including rape, were soon on the agenda. To exacerbate the situation, Wits had to contend with a media which was often sensationalist and frequently inaccurate. Habib deals with all these matters frankly in the book, sparing no one, including himself. It is refreshing.

In his account, Habib sets out eight possible initiatives to meet the challenges that confront South African universities regarding transformation. First, is a programme to diversify the academy; second, to expand existing curriculum reform activities; third, to initiate a change in student admission policy to strengthen diversity; fourth, to organise student residences to enhance diversity further; fifth, to create an inclusive climate in which all may feel comfortable; sixth, to rename buildings; seventh, to develop indigenous languages among staff and students; and, eighth, to create a partnership with civil society to lobby for resources. In an arena in which discussion and debate are often fuzzy, these are imaginative proposals.

In discussing strategy, Habib was often in contact with Max Price, then Vice-Chancellor of UCT. The situation on each campus was not identical and UCT chose not to bring in security personnel. In the *Daily Maverick* of 12 March 2019 Price challenged some of Habib's analysis of the events at UCT. He disagreed that the UCT executive was less united than its Wits counterpart and that this might have played a role in the decision not to use security. He also challenged the statement that UCT did not complete the 2016 academic year and that UCT faced protests at the end of 2017 while Wits did not. Price also disputed whether the presence or absence of security played a role in how the events on the two campuses played out in different ways.[1] However, it must be remembered – as Habib points out – that the UCT campus is a sprawling one with many access points while Wits is more contained and thus controllable. Price's own book, when published, will be equally important and complementary to Habib's. Those interested in what Habib has to say should also read Jonathan Jansen's *As by Fire: The End of the South African University* (Tafelberg; 2017).

Rebels and Rage has attracted considerable media attention. In an op-ed, entitled 'Resisting university capture: Adam Habib, Wits and Fallism', published in the *Daily Maverick* on 1 April 2019, Robert Morrell, writing in his personal capacity, stresses the dangers facing South African universities. He describes Habib's book as 'compelling and harrowing reading'. Relating how Habib identified a new kind of threat, 'ideologically cloaked' as the 'far left' – which Habib refers to as the 'Pol Pot brigade' – Morrell criticises UCT's ill-conceived Institutional Reconciliation and Transformation Committee.[2] Their report is inadequate and superficial and should be rejected. It is difficult to accept that arsonists should be given amnesty. Education at a university goes beyond formal academic studies and should also prepare graduates to be good citizens; that goal is not achieved by such amnesties.

Critique of *Rebels and Rage* has also come from a number of members of Wits in an open letter to the *Mail and Guardian* (1 April 2019). The authors question whether Habib had permission to publish certain names and designate people (perhaps unfairly) as the 'far left', and they claim factual errors in the book.[3]

Jacob Zuma, then President, and some of his Cabinet Ministers attended meetings with Vice-Chancellors and with students during the periods of protest. After declaring that the state would cover the fee increase in 2016, he unexpectedly announced that students from families earning less than ZAR350 000 p.a. would receive free higher education. The financial costs of this decision were met in part by an increase in VAT. More recently, the Higher Education Minister at the time, Naledi Pandor, allocated ZAR967 million to eliminate the debts of National Student Financial Aid Scheme **(**NSFAS) students. The 'missing middle', i.e. those whose families earn in excess of the limit but that nonetheless are unable to afford university fees, remain a major concern. The Commission of Inquiry into Higher Education and Training (the Heher Commission) recommended that these students' fees might be covered by an income-dependent loan scheme. In any event, students from families with means would have to pay full fees.[4]

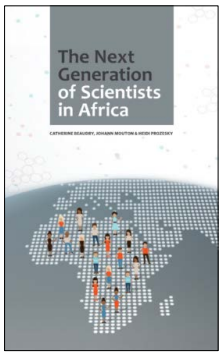
It must be remembered that entering a university for the first time is an enormous challenge for any young person. This is especially the case for young black students who are generally from impoverished families and who face the tension of receiving financial aid for their studies which is in excess of the annual family income. The culture of most universities is alien to them. They realise that their schooling has usually been inadequate and has put them at a disadvantage to their white contemporaries. Into this mix must go the problems of finding accommodation, of debt to the institution, and of upfront payments which are required to secure registration. The last two are now often waived, but the other challenges result in anger and frustration and must be dealt with by government and by the institutions. The government must recognise the vital autonomy of universities, while institutions need to take steps to deal with the difficulties that students face. One such action is the provision of an academic development programme to help students bridge the gap resulting from their poor schooling.

Protests at universities are a global phenomenon. It is to be hoped that Habib's contribution will be followed by others that cast light on the causes and dynamics of such protests in South Africa and suggest ways of remediation and address.

References

1. Price M. The UCT and Wits strategies on #FeesMustFall were different for good reasons. Daily Maverick. 2019 March 12 [cited 2019 Apr 10]. Available from: https://www.dailymaverick.co.za/article/2019-03-12-the-uct-and-wits-strategies-on-feesmustfall-were-different-for-good-reasons/
2. Morrell R. Resisting university capture: Adam Habib, Wits and Fallism. Daily Maverick. 2019 April 01 [cited 2019 Apr 10]. Available from: https://www.dailymaverick.co.za/article/2019-04-01-resisting-university-capture-adam-habib-wits-and-fallism/
3. Ally S, Baro G, Bradbury J, Canham H, Cock J, Dube S, et al. An open letter to the readers of Adam Habib's 'Rebels and Rage'. Mail & Guardian. 2019 April 01 [cited 2019 Apr 10]. Available from: https://mg.co.za/article/2019-04-01-an-open-letter-to-the-readers-of-adam-habibs-rebels-and-rage
4. Report of the Commission of Inquiry into Higher Education and Training to the President of the Republic of South Africa [document on the Internet]. No date [cited 2019 Apr 10]. Available from: http://www.thepresidency.gov.za/sites/default/files/Commission%20of%20Inquiry%20into%20Higher%20Education%20Report.pdf

BOOK TITLE:
The next generation of scientists in Africa



EDITORS:
Catherine Beaudry, Johann Mouton and Heidi Prozesky

ISBN:
9781928331940 (ebook);
9781928331933 (softcover)

PUBLISHER:
African Minds, Cape Town; ZAR299 (softcover), open access (ebook)

PUBLISHED:
2018

REVIEWER:
Renfrew Christie[1,2]

AFFILIATIONS:
[1]Fellow of the Royal Society of South Africa, Cape Town, South Africa
[2]Member of the Academy of Science of South Africa, Pretoria, South Africa

CORRESPONDENCE TO:
Renfrew Christie

EMAIL:
renfrew.christie@gmail.com

HOW TO CITE:
Christie R. African science: Better but still inadequate. S Afr J Sci. 2019;115(7/8), Art. #6233, 2 pages. https://doi.org/10.17159/sajs.2019/6233

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

PUBLISHED:
30 July 2019

African science: Better but still inadequate

This book is excellent. It should be read by every scholar, funder and policymaker in the field. The authors set out the state of science in Africa and the labour conditions of Africa's young scientists. Their rigorous data collection included a very-large-sample survey questionnaire, bibliometrics and interviews. The book reports an improvement in the state of African science (p.177), compared to the previous millennium's woeful picture; but this step forward is not normalised against the rapid population expansion on the continent. African science may be better in quantity and quality, but still is sadly inadequate to serve the needs of a continent expected to double in population size within 30 years.[1]

Fortunately, science has never been national or continental. Insofar as science and the resulting technologies are essential to the well-being and prosperity of 2.5 billion Africans in 2050, they will largely have been drawn from global knowledge and best practice. Nonetheless, context is vital to the use of new discoveries; and there are matters crucial to Africa, which are seldom studied globally. We therefore need all the new young African scientists we can get; and a much more positive structure for their work.

The book has four parts and nine chapters. The first part, on the state of science in Africa, has chapters on whether African science is rising; a bibliometric analysis of African science; and a view of funders and funding. The second, on the challenges, gives a profile of the African young scientist; depicts a lack of funding, mentorship and support; and sets out the benefits of international mobility against a lack of opportunity. The third, on research performance, describes publication and citation counts, as well as enablers of and barriers to publishing. The fourth part, a conclusion, summates that although African science has improved, this improvement is in no part due to African governments and domestic funders: the money largely comes from the obvious sources outside the continent; and scientists in Africa work in weak institutions without support, while facing numerous unnecessary frustrations and negative experiences.

Finally, there are four pages of recommendations (p. 178–181), which I found to be regrettably imprecise and woolly. The recommendations lack the punch of those of a good commission of inquiry. Lenin's 'What is to be done?' or 'Who, whom?' are missing.

Instead we read: seniors 'need to be more approachable, less domineering, and more trusting and encouraging of their younger colleagues' research aspirations' (p.178). And:

> *There seems to be a lack of recognition, at institutional level, of the extremely time consuming nature of teaching large, undergraduate classes. An increase in marking and administrative teaching assistance is therefore strongly recommended.*
>
> *A strong emphasis on quantifiable research outputs is often out of touch with the daily realities with which lecturers and senior lecturers are faced.*
>
> *It should also be recognised, especially by higher education institutions, that many young scientists may be first-generation academics, for whom the expectations and roles associated with their positions are unclear.*

Really? These are things known to all but the least progressive deans, university presidents and even ministers of higher education across the continent. In cultures where age means power and deference, and with other large demands on funding, acquiring the cash and the cultural capital to change these things could be impossible. For example, if the tradition of treating professors like gods is still dying hard in Germany, it will die equally hard in Africa. We live worldwide in a time of Procrustean key performance indicators and blind, managerialist short-term targets. African institutions are not exempt from these follies; and so the young up and coming suffer in ways that their ageing mentors did not. Whether in Oxford or in Africa, it is plain that young scientists must work much harder and wiser than their forebears. The book's recommendations take us little further.

Although the recommendations are limp, the hard research findings are cogent, if somewhat dense and difficult to summarise. And if you want what used to be called 'facts', there are many.

An interesting finding is that the Tunisian output of publications (200–300), normalised for population size, beats that of South Africa (at 100–200) in the 2011–2015 period (p.16). Another is that African papers reflected in the Web of Science more than doubled from 1.5% of world output in 2005 to 3.2% in 2015 (p.13).

Africa is strongest in the fields of 'tropical medicine; parasitology; infectious diseases; public, environmental and occupational health; water resources; ecology; immunology; zoology; and plant sciences' (p.16), all of which are fields in which Africa produced over 5000 papers between 2005 and 2015; and contributed over 4% of the world total in 2015.

Disappointingly, the new generation of African academics has almost exactly the same gender distribution as its forebears: only 33% of under 39s are women; 30% of those between 40 and 50 are women; and 28% of those over 50 are women (p.48). This is glacial gender progress.

Above all, respondents felt that there are simply not nearly enough African scientists:

> *They would have to hire more people. Especially the young universities that have just started up, they have very few PhDs in every department, so the PhDs that are there have to do the admin as the others are probably doing their studies, trying to get PhD or masters or other degrees. So, in my department there's just two PhDs, so one is the Dean and then I'm the Chairman, so everybody's doing admin. So, the only thing they can do is more people. (33-year-old male from Kenya)* (p.62)

Soon after I was born, Kenya had six million people in 1950. In 2020, it will have 53 million people. If I live to be 100, in 2050, I will see a Kenya of 95 million people.[1] **Kenya will be sixteen times more populous in 2050 than in 1950.**

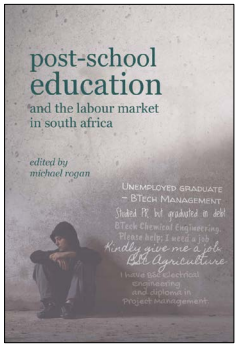
If that Kenyan population has been properly educated, with its universities strongly underpinned by advanced research, the Kenya of 2050 will be 'healthy, wealthy and wise'. If not, life will be 'nasty, brutish and short'.

It is, literally, *vital* that the quantity and quality of Africa's cohort of young scientists be radically increased; and that their working conditions are dramatically improved. This fine book gives extensive, reliable data, in detail, on which to base the policy argument.

Reference

1. United Nations, Department of Economic and Social Affairs, Population Division. World population prospects: The 2017 revision. Volume I: Comprehensive tables (ST/ESA/SER.A/399). New York: United Nations Population Division; 2017. Available from: https://population.un.org/wpp/Publications/Files/WPP2017_Volume-I_Comprehensive-Tables.pdf

BOOK TITLE:
Post-school education and the labour market in South Africa



EDITOR:
Michael Rogan

ISBN:
9780796924636 (paperback);
9780796924605 (PDF)

PUBLISHER:
HSRC Press, Cape Town; ZAR250

PUBLISHED:
2018

REVIEWER:
Jenny Grice[1,2]

AFFILIATIONS:
[1]Freelance editor, Johannesburg, South Africa
[2]Former official of the National Union of Metalworkers of South Africa (Numsa), Johannesburg, South Africa

EMAIL:
Jennygrice1957@gmail.com

HOW TO CITE:
Grice J. Why are so many young people NEETs? S Afr J Sci 2019;115(7/8), Art. #6462, 1 page. https://dx.doi.org/10.17159/sajs.2019/6462

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

PUBLISHED:
30 July 2019

Why are so many young people NEETs?

Post-school Education and the Labour Market in South Africa, edited by Michael Rogan, makes the bold claim that 'it offers the most detailed examination of the SA PSET (post-school education and training) to date'.

In the foreword, then Minister of Higher Education and Training, Naledi Pandor, explains that its 13 chapters derive from Theme 5 of the government's Labour Market Intelligence Partnership's (LMIP) six-themed project. LMIP is researching and analysing skills supply and demand to improve planning of the human resources development needs in the country.

The major task of Theme 5 is to answer two key questions that continue to beset our society: (1) why some young South Africans who have completed school are unable to access any kind of post-school education and training (PSET) and (2) why others, despite some tertiary education, find themselves in the same predicament. Researchers have labelled this category of people as NEETs – youth who are not in employment, education or training. South Africa has more than 6 million NEETs, only 6% of whom have some type of tertiary education.

According to the Organisation for Economic Co-operation and Development (OECD)[1], in 2017 South Africa led the 'NEET' pack of more than 40 countries from developed and developing countries with 37.2% of youth categorised as NEETs. This book breaks down this figure further to claim that 50.7% of 23–24-year olds are NEETs. A distant second was Turkey at 27.2%. As the OECD states, NEETs 'are at risk of becoming socially excluded – individuals with income below the poverty-line and lacking the skills to improve their economic situation'[1].

Given this backdrop, any book that takes on the challenge of exposing the detailed ramifications of learners' pathways through the education system, post-school and into (or 'not into') the labour market is to be welcomed.

The book has three main sections and each of its 13 chapters has been written by 20 recognised experts in their fields. The first section explores how learners progress through and from school into higher education. The link between study choices at tertiary level and employment follows in the second section, while the third examines whether learners become employed after completing technical and vocational education and training (TVET) and workplace-based training.

Rogan excels in giving an overall outline of the different sections in the book and their purpose. Chapters are well structured, each with an introduction setting out the intention and concluding with a summary of the findings. Complex data are appended at the end of the chapter to prevent readers from getting bogged down in figures and tables and losing track of the argument. All these techniques will help busy readers skim through the key findings if pressed for time. Each chapter is data-rich, relying on largely quantitative data to inform the authors' analyses. Rogan's concluding chapter expertly draws the findings of the different chapters and sections together.

Within the first section, researchers found that poor basic education continues to impact negatively on learners in moving successfully through school into PSET and completing PSET. However, the NEET problem could not simply be explained as 'school drop-outs'. Surprisingly, data showed that many NEETs had passed through school smoothly, some even achieving university entrance at matric, but were not entering university.

Funding was posited as a major reason for this, with writers urging that unless there is a substantial change to the current funding model, government's enrolment targets for PSET will not be met. On another surprising note, 'A' students from disadvantaged backgrounds are more likely to attend universities than their counterparts from advantaged backgrounds because current funding models favour top-performing disadvantaged students.

Poor awareness of options post school, particularly regarding workplace-based training and TVET Colleges, was another reason posited for low participation in PSET.

On paper, TVET colleges should provide a route into the labour market for those who leave school in Grade 9. In practice, however, researchers found that TVET colleges were full of matric students. The authors of the chapter were unable to give reasons. Was it due to lack of places, and/or funding for universities? Or perhaps that TVETs themselves were targeting matrics to raise their pass rates?

Given poor basic education, adult education programmes could provide much needed education and skills for those who failed at school in order to link them with the labour market. Instead, researchers found a disjuncture between these programmes and skills needed for the workplace or to enter PSET, leaving these students stranded in NEET-land yet again. By contrast, work-based learning programmes seem more successful in placing completers in jobs although there is poor uptake of younger learners in these programmes. Once again the authors were unable to explain why.

The sphere of vocational training has seen massive policy changes over the last 20 years. Researchers were cautious (largely because of their small sample of learners) in pronouncing on whether the new National Certificate (Vocational) is succeeding in improving the link between education and work.

Readers should not expect to find definitive solutions to the NEET problem. Many chapters conclude with unanswered questions and recommend further research to explore these unknowns. Nevertheless, the findings do reveal much-needed details of the PSET sector that the reader is unlikely to find elsewhere.

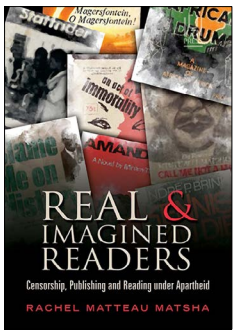
I felt the researchers' frustration in being unable to answer all the questions raised by their research. I would have liked to have the quantitative data balanced with more qualitative investigations that allowed for more nuanced explanations that addressed some of these issues, but perhaps this is the meat of another book.

Nonetheless, this is a very useful volume that researchers, students and policymakers in the education field will welcome as a reference work and as an indicator of government policy.

Reference

1. Organisation for Economic Co-operation and Development (OECD). Youth not in employment, education or training (NEET) (indicator). c2019 [cited 2019 May 22]. https://doi.org/10.1787/72d1033a-en

BOOK TITLE:
Real and imagined readers: Censorship, publishing and reading under apartheid



AUTHOR:
Rachel Matteau Matsha

ISBN:
978186914402 (paperback)

PUBLISHER:
UKZN Press, Pietermaritzburg; ZAR325

PUBLISHED:
2018

REVIEWER:
Keyan G. Tomaselli

AFFILIATION:
Department of Communication Studies, University of Johannesburg, Johannesburg, South Africa

EMAIL:
Keyant@uj.ac.za

HOW TO CITE:
Tomaselli KG. The power of books and their censorship in South Africa. S Afr J Sci 2019;115(7/8), Art. #a0313, 1 page. https://doi.org/10.17159/sajs.2019/a0313

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

PUBLISHED:
30 July 2019

The power of books and their censorship in South Africa

When I was a lecturer at the University of the Witwatersrand (Wits) during the late 1970s, De Jong's Bookshop, easily accessible across Jan Smuts Avenue, became one of the clandestine centres that sold banned books in Johannesburg. 'A new consignment is in' was the rallying cry for the Left who immediately descended on the bookshop to obtain their purchases – handed over in brown paper bags. *Real & Imagined Readers* sketches this period most evocatively: it was a time of rampant censorship, book bannings and book burnings. But it was also the era of critical student newspapers, alternative publishers and of student and activist resistance to apartheid. For readers of my vintage, Matsha's story was not an imagined experience. For us it was real.

The value of this book, comprising five chapters and a conclusion, is in the way that its author recreates a sense of 'being there', illustrating the experience, the period, the publishers, authors and readers. The contents deal with book and magazine censorship, censors versus publishers, librarians and booksellers, readers and their roles, and how readers were imagined under the various censorship regimes that spanned over a century.

The reference to 'imagined' relates to the ways in which the changing censorship apparatus constructed readers during different periods – from the impressionable and naïve, the average, the good reader, and from the likely to the probable reader. As fresh legislation was enacted, new literary influences informed concepts of censorship, although such influences waxed and waned according to the political climate.

What is also revealed in Matsha's compelling narrative is the complexity, nuance and contradictions that characterised the 20th century. Censorship was never total, although one startling passage reveals how thousands of banned books were incinerated in a massive oven managed by the then-state-owned Iron and Steel Corporation (ISCOR). The scale of book banning was extraordinary, but so were the struggles against censorship that included many Afrikaans-language novelists, poets and academics, whose books were routinely banned. Alternative externally funded publishing houses were established, and innovative ways of distributing books were devised to counter censorship. We learn here of the inspector from the Publication Control Board who toured the country, infiltrating bookshops and examining shelves for 'undesirable' material.

Notwithstanding such close surveillance, alternative bookstores in the big cities, alternative groups of reading communities and other forms of clandestine distribution and discussion took place. Independent publishers found ways of distributing their 'undesirable' titles before the censors discovered them. Dissemination occurred no matter how many books were banned, burned and confiscated. Banned books migrated between individuals and reading groups, and books were found by activists and writers in old boxes in storerooms belonging to family members who had somehow appropriated them. The narrative on readers' roles, examined in Chapter 4, aroused my many memories on how crucial reading was in cultural mobilisation; how reading-as-subversion was in the air; how reading beyond educational courses was a pre-requisite; and how literacy was a social practice as an indicator of oppositional identity formation. Matsha brings these remembered and lived relations to life. Clandestine networks overcame official censorship and these included authors, multiracial all, and courageous publishers who contested the repressive hegemony.

Real & Imagined Readers ends with a nuanced discussion of the changing censorship legislation in South Africa since 1892 (obscene materials), the *Customs Management Act of 1913*, the *Suppression of Communism Act (1950)*, the *Publication and Entertainment Act of 1963* and the *Publications Act of 1974*.

Matsha examines the philosophies and assumptions that shaped the censors' decisions during these different periods and legislative regimes. After 1963, the reader of the material, rather than the producer, became increasingly important because sceptical Afrikaner intellectuals, who wanted to be flexible in retaining their right to social critique, became involved. The 1974 Act took no account of their literary expertise and moved from the more discriminatory 'likely reader' to the mundane, easily led-astray 'average man'. This regressive political shift of category from assumed intelligent readers to susceptible readers split the Afrikaner intelligentsia, but the reintroduction of the imaginary 'likely reader' as a measure of literary reflection occurred nonetheless. This shift was especially evident in the establishment of a more open-minded Appeal Board that overturned many of the censors' bannings.

What I also appreciated in this immensely readable book was its implicit conceptual framework that never intruded on the narrative, and the implication that when citizens do not read they cannot engage adequately in civic organisation or in the public sphere. Currently, in this age of social media, anything goes, fake news predominates, and logic and evidence are no longer valued by individuals who seek only scapegoats on whom to vent their rage. From *Real & Imagined Readers* we learn how much the anti-apartheid struggle owed to the literati of all ethnic groups and persuasions, including authors, discerning readers and political activists who analysed conditions through reading voraciously, circulating that reading and intelligently acting on it.

AUTHOR:
Casparus J. Crous[1,2]

AFFILIATIONS:
[1]Department of Conservation Ecology and Entomology, Stellenbosch University, Stellenbosch, South Africa
[2]Previous: South African Environmental Observation Network, Arid Lands Node, Kimberley, South Africa

CORRESPONDENCE TO:
Casparus Crous

EMAIL:
cjcrous@gmail.com

HOW TO CITE:
Crous CJ. The darker side of quantitative academic performance metrics. S Afr J Sci. 2019;115(7/8), Art. #5785, 3 pages. https://doi.org/10.17159/sajs.2019/5785

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
economic incentives; hypercompetitive academia; productivity ratings; publishing behaviour; unethical practices

PUBLISHED:
30 July 2019

The darker side of quantitative academic performance metrics

The economy of knowledge

Scientific information can be considered an economic commodity.[1] Authors produce papers as currency to acquire research employment, and, in turn, publishers sell these papers for profit. The appropriateness of monetising knowledge, and the sustainability of such business models, remains contentious.[2-4] But I do not wish to embroider on science economics per se. Instead I highlight here how current publishing behaviour has been influenced by economic incentives – behaviour that can now be predicted by basic economic models.[5] Understanding such behavioural changes in science culture will become helpful to identify potentially unethical publishing practices.[6,7]

The use of quantitative academic performance metrics

Eligibility criteria to secure employment or grants are generally based on quantitative academic performance indices, for example, number of papers, the *h*-index[8,9], or citations per paper[10]. Science metrics have greatly advanced our understanding of publishing trends among authors, but are clearly also not without critique.[11] I have previously commented on the pitfalls of unsophisticated performance measures in evaluating academic success among scholars from developed and developing nations.[12] Current literature is filled with similar polemical opinions, where even choosing a journal to publish in has become an awkward affair.[13] Yet for administrators these records remain helpful to initially separate the wheat from the chaff, and are easy and free to obtain online.[14]

Despite progress on reforming performance evaluations, such as the Leiden Manifesto[15], it will take some time for the playing field to level out. The scene is therefore set for a new science culture of winners and losers. Aspiring academics will thus most likely have to actively manage their research productivity and performance[5], more aggressively so than ever before in this hypercompetitive academic environment[6,16].

The rise of unethical citation practices

A healthy economy is related to having greater productivity (e.g. exports) than consumption (e.g. imports). To maintain this healthy economy, it is crucial to predict future shortfalls in productivity that might lead to *catastrophic* losses in revenue. With millions of academic papers in circulation these days, predicting future citation yield, and thereby personal performance, might prove to be extremely difficult for scholars.[5] Fears of disadvantage thus arise in especially aspiring academics, prompting collusive and coercive citation practices to reduce productivity uncertainty.[5,6,17,18]

Haley[5] subsequently put forward three likely responses by academic authors facing metric performance uncertainty: (1) do nothing, thus relying on natural accumulation of citations from the wider science community; (2) switch research fields, perhaps to those more topical at the moment, aiding a rapid and steady citation accumulation; or (3) artificially inflate citations.

Examples of artificial inflation are in fact seen among authors, editors, reviewers and publishers. Authors may premeditate plans to cite underrepresented papers in their following works, regardless of true applicability to the current message at hand.[17] Using coercive citation practices, reviewers may request authors to cite their papers, directly relevant or not, or editors may request authors to include more papers from their journal to improve journal impact factor.[18] In turn, collusive citation practices, although less common, occur when two or more journals conspire to primarily cite papers found in each other's issues, and in this way boost performance enormously[19] – also termed 'citation stacking', this is certainly one of the most concerning consequences of quantitative performance metrics. But perhaps the worst consequence of citation-based performance metrics, is the possibility to directly manipulate citation scores by creating fake publications riddled with self-citations.[20]

Too many tactics, too little science?

Using Haley's[5] three likely responses by authors to achieve metric success, I drew a three-bubble Venn diagram to conceptualise situations in which authors might use a *combination* of responses to mitigate citation uncertainty (Figure 1). I imagined four scenarios:

- *The Desperate* signifies authors who generally allow for the natural accumulation of citations of their papers, but sooner or later they realise that they are falling behind and start to actively manage ways to increase scores.
- *The Schemer* is primarily looking for ways to artificially inflate citations while simultaneously switching to more popular research topics whenever possible and/or joining larger groups of collaborators to share in their productivity. Doing nothing is beyond the realm of *The Schemer* as they know the current publishing game fortunes the connected, e.g. providing more opportunities to place papers while editing manuscripts.
- *The Survivor* is an author who generally allows for the natural accumulation of citations of their papers, like *The Desperate*. But instead of artificially trying to inflate scores when realising slow accumulation, this author increases citation probability by constantly switching to hot, citable topics or more innovative fields.
- *The Abyss* represents the point at which scholars utilise all three tactics. They can switch to popular or innovative fields, although often away from their expertise, thereby eventually creating a wide network of collaborations to share in the larger citation economy. These authors might also downplay ethically blurry citation practices, such as artificial inflation, as they also allow for natural accumulation and might resort

to playing the whole game. *The Abyss* is therefore the bottomless pit where mishmashes between intellectual and moral standards capture the minds of young academics.

Should the status quo in current scientific culture be maintained (where citations are seen as currency), then desperate and scheming authors would increasingly be found. Haley[5] explained this to be the case as artificially inflated citations might require the least amount of effort or funds to increase visibility. *The Survivor* perhaps represents the least frowned-upon scenario to increase performance metrics. However, Haley[5] mentioned such strategies could lead to decreased publication quality, and citations are not necessarily guaranteed when shifting to more popular science avenues. Ultimately, even though some scholars will remain honest and open, the evolution of citation behaviour due to ill-advised incentives would eventually lead to great confusion among those that need it least – aspiring scientists. Too many tactics with too little science can potentially devastate the scientific endeavour as we know it.[6,7]

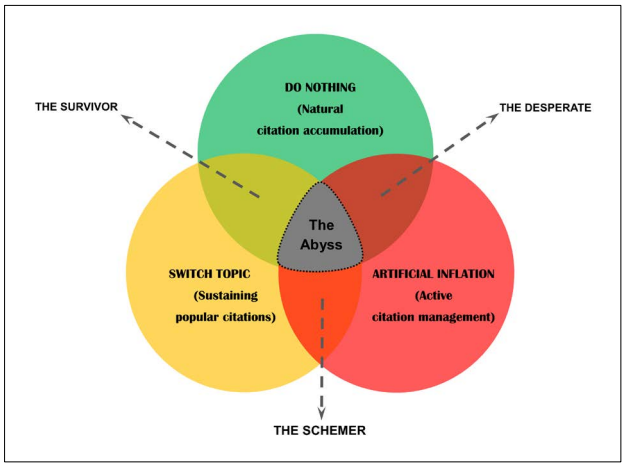


Figure 1: Four hypothetical scenarios that might arise when aspiring academics use combinations of tactics to increase quantitative performance metrics (adapted from concepts in Haley[5]).

Collateral damage of unethical publishing to science culture

The collateral damage of self-interested publishing games is becoming more visible. Peer reviewers are growing increasingly scant.[21] This fact is tough to believe given the staggering increase in published papers over the past few years – estimated at >2 million a year. Clearly, some reviewers are working more than others. In this era of paper gluttony and highly competitive scientific employment[22], it is perhaps unsurprising that young, contract-based researchers might regard peer reviewing as belonging to more comfortable, permanent employees. This way they can write and cross-cite many papers. On the other hand, some might choose to review a lot to aid citation of their work. The spirit of peer reviewing is threatened.[7]

Lawrence[16] summarised the dangers of an increasing 'aggression factor' on the psychology of people in a hypercompetitive science environment, where the battle for superiority may weaken the spirits of more gentle scholars to pursue academic careers. This way many brilliant minds, who became desperate or troubled, would leave. Who knows what wonderful discoveries have been and will be lost in the future.

Lighting-up academia's darker side

Emerging economies need to be attractive to heighten interest from investors. So too needs to be the performance of aspiring academics. There are thus incentives to perform, and to perform well more often. No wonder economists can now describe how young researchers could behave to increase their chances of being spotted in the vast universe of academia. I wanted to highlight that behavioural changes in citation practices by authors facing performance uncertainty will become commonplace[5] and will likely further evolve.[6,7] It is crucial that more mature academics and administrators acknowledge the existence of these patterns so that those in charge can help manage younger academics to avoid becoming desperate and scheming, and finally getting lost in the moral abyss.

Torch-bearing policies are therefore urgently needed to light the way forward. Lane[23] drew attention to the fact that if incentives are used to push productivity and performance in academia, then economists and social scientists must help reform the applications of purely number-based metrics. It is high time we re-visit extant and useful guidelines, such as the Leiden Manifesto, to better understand the limitations of available science metrics and how to apply them when evaluating personal excellence in complex academic environments.[15,24]

And while we are counting beans, the sixth mass extinction event has dawned.[25] The idea of an inclusive, noble science environment should be alive and kicking to protect our vulnerable planet.[6,26] To remain focused, we should consider eliminating quantitative performance measures altogether.

References

1. Stephan PE. How economics shapes science. Cambridge, MA: Harvard University Press; 2012.
2. Young NS, Ioannidis JP, Al-Ubaydli O. Why current publication practices may distort science. PLoS Med. 2008;5(10), e201, 5 pages. https://doi.org/10.1371/journal.pmed.0050201
3. Van Noorden R. Open access: The true cost of science publishing. Nature. 2013;495(7442):426. https://doi:10.1038/495426a
4. Bergstrom TC, Courant PN, McAfee RP, Williams MA. Evaluating big deal journal bundles. Proc Natl Acad Sci USA. 2014;111(26):9425–9430. https://doi.org/10.1073/pnas.1403006111
5. Haley MR. On the inauspicious incentives of the scholar-level h-index: An economist's take on collusive and coercive citation. Appl Econ Lett. 2017;24(2):85–89. https://doi.org/10.1080/13504851.2016.1164812
6. Edwards MA, Roy S. Academic research in the 21st century: Maintaining scientific integrity in a climate of perverse incentives and hypercompetition. Environ Eng Sci. 2017;34(1):51–61. https://doi.org/10.1089/ees.2016.0223
7. Grant DB, Kovács G, Spens K. Questionable research practices in academia: Antecedents and consequences. Eur Bus Rev. 2018;30(2):101–127. https://doi.org/10.1108/EBR-12-2016-0155
8. Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci. 2005;102(46):16569–16572. https://doi.org/10.1073/pnas.0507655102
9. Hirsch JE. Does the *h* index have predictive power? Proc Natl Acad Sci USA. 2007;104(49):19193–19198. https://doi.org/10.1073/pnas.0707962104
10. Lehmann S, Jackson AD, Lautrup BE. Measures for measures. Nature. 2006;444(7122):1003. https://doi.org/10.1038/4441003a
11. Costas R, Bordons M. The *h*-index: Advantages, limitations and its relation with other bibliometric indicators at the micro level. J Informetr. 2007;1(3):193–203. https://doi.org/10.1016/j.joi.2007.02.001
12. Crous CJ. Judge research impact on a local scale. Nature. 2014;513(7516):7. https://doi.org/10.1038/513007a
13. Lee AT, Simon CA. Publication incentives based on journal rankings disadvantage local publications. S Afr J Sci. 2018;114(9–10), Art. #a0289, 3 pages. http://dx.doi.org/10.17159/sajs.2018/a0289
14. Harzing AW, Van der Wal R. Google Scholar as a new source for citation analysis. Ethics Sci Environ Polit. 2008;8(1):61–73. https://doi.org/10.3354/esep00076
15. Hicks D, Wouters P, Waltman L, Rijcke SD, Rafols I. Bibliometrics: The Leiden Manifesto for research metrics. Nature. 2015;520(7548):429. https://doi.org/10.1038/520429a
16. Lawrence PA. The mismeasurement of science. Curr Biol. 2007;17(15):R583–R585. https://doi.org/10.1016/j.cub.2007.06.014
17. Van Raan AF. Comparison of the Hirsch-index with standard bibliometric indicators and with peer judgment for 147 chemistry research groups. Scientometrics. 2006;67(3):491–502. https://doi.org/10.1556/Scient.67.2006.3.10
18. Wilhite AW, Fong EA. Coercive citation in academic publishing. Science. 2012;335(6068):542–543. https://doi.org/10.1126/science.1212540

19. Van Noorden R. Brazilian citation scheme outed. Nature. 2013;500(7464):510–511. https://doi.org/10.1038/500510a

20. Delgado López-Cózar E, Robinson-García N, Torres-Salinas D. The Google Scholar experiment: How to index false papers and manipulate bibliometric indicators. J Assoc Inf Sci Technol. 2014;65(3):446–454. https://doi.org/10.1002/asi.23056

21. Lajtha K, Baveye PC. How should we deal with the growing peer-review problem? Biogeochemistry. 2010;101:1–3. https://doi.org/10.1007/s10533-010-9530-6

22. Siegel D, Baveye P. Battling the paper glut. Science. 2010;329(5998):1466. https://doi.org/10.1126/science.329.5998.1466-a

23. Lane J. Let's make science metrics more scientific. Nature. 2010;464(7288):488. https://doi.org/10.1038/464488a

24. Braun T, Bergstrom CT, Frey BS, Osterloh M, West JD, Pendlebury D, et al. How to improve the use of metrics. Nature. 2010;465(17):870–872. https://doi.org/10.1038/465870a

25. Ceballos G, Ehrlich PR, Dirzo R. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proc Natl Acad Sci USA. 2017;114(30):E6089–E6096. https://doi.org/10.1073/pnas.1704949114

26. Lawrence PA. The politics of publication. Nature. 2003;422(6929):259. https://doi.org/10.1038/422259a.

AUTHOR:
Camilla Adelle[1]

AFFILIATION:
[1]Centre for the Study of Governance Innovation, University of Pretoria, Pretoria, South Africa

CORRESPONDENCE TO:
Camilla Adelle

EMAIL:
cadelleup@gmail.com

HOW TO CITE:
Adelle C. Creating knowledge democracy in South Africa: The role of communities of practice. S Afr J Sci. 2019;115(7/8), Art. #5888, 3 pages. https://doi.org/10.17159/sajs.2019/5888

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
cognitive justice; research partnerships; science–policy–practice interface; research collaboration

PUBLISHED:
30 July 2019

Creating knowledge democracy in South Africa: The role of communities of practice

In our pursuit of a more equitable, just and sustainable society, we must examine not only who makes decisions, but also on whose evidence these decisions are made. The question of whose knowledge is to be recognised, translated and incorporated into action[1] is especially important in South Africa as universities attempt to respond to calls to decolonise the curricula. In this Commentary, I argue that widening the scope of knowledge production is an essential role that universities can play in creating knowledge democracy. Communities of practice are presented as a way in which scientists can cultivate research partnerships with stakeholders outside of science to co-produce knowledge needed to solve society's current complex challenges.

The concept of knowledge democracy 'respects multiple modes, forms, sources and idioms of knowledge production, representation and dissemination'[2]. According to Hall and Tandon[3], what is generally understood as knowledge in universities represents only a very small proportion of the global treasury of knowledge.

> *Knowledge is created through research, through the experience of the wise, through the act of surviving in the world, and is represented in text, poetry, music, political discourse, social media, speeches, drama and storytelling. Knowledge is linked to practical skills, to our working lives and to universal and abstract thought. Knowledge is created every day by each one of us and is central to who we are as human beings.*[4]

However, these other ways of knowing are relegated by modern science to the realm of beliefs, opinions and intuitive or subjective understandings, which at best may become objects for scientific inquiry.[3]

The separation between lay and scientific knowledge dates to the creation of Oxford University and other early tertiary education institutions in Europe some 500 years ago. This act had the effect of

> [E]*nclosing knowledge, limiting access to knowledge, exerting a form of control over knowledge and providing a means for a small elite to acquire this knowledge for the purposes of leadership of a spiritual, governance or cultural nature.*[3]

The walls of the universities quite literally came to demark the 'knowers' on the inside and the 'non-knowers' on the outside.[3]

As university knowledge systems around the world are today based not only on this Western model of academic enclosure but also on the Western cannon of literature, philosophy and culture that it has produced,[3] it is perhaps not surprising that in South Africa we see both: a continued separation between lay or indigenous and university knowledge systems; and, at the same time, calls by our students for the decolonisation of universities. The epistemologies of most peoples of the world, whether indigenous or excluded on the basis of race, gender or socio-economic status, are missing.

Universities themselves have perpetuated this injustice. Gaventa and Bivens[5] argue that 'universities [need] to think not only about justice in the larger world, but also about their own distinctive role in shaping cognitive justice and knowledge democracy'. We need to reflect on how inequalities in the production of knowledge contribute to other types of inequalities (including those that we seek to address through research): 'In a world in which knowledge shapes power and voice, and vice versa, the fundamental inequality in the production of knowledge about inequality itself must be addressed.'[6]

The idea of knowledge democracy and cognitive justice not only recognises that different forms of knowledge exist, but argues that this plurality must to go beyond tolerance to actively recognising the need for diversity:

> *The idea of cognitive justice…sensitizes us not only to forms of knowledge but* [also] *to the diverse communities of problem solving. What one offers then is a democratic imagination…where conversation, reciprocity, translation create knowledge not as an expert, almost zero-sum view of the world but as a collaboration of memories, legacies, heritages, a manifold heuristics of problem solving.*[7]

From the perspective of cognitive justice, therefore, the integration of different types of knowledge is not only a moral necessity, but also a pragmatic one. Multiple perspectives can contribute to our capacity to find workable solutions to some of our society's most complex problems. In addition, knowledge created with the involvement of the likely users of that knowledge is more likely to be seen by these potential users as relevant and legitimate and hence more likely to be used.

Post-positivist critics of the linear understanding of science–society relations, in which knowledge production and use remain separate processes, have long argued that science alone cannot solve these types of complex issues.[8] In these circumstances, cause and effect may not be easily identifiable and uncertainty is inherently present. Rather than searching for a single 'right' answer, the intention of scientists should be to arrive at '"reasonable" decisions [that are] "appropriate" to situations that are both morally and factually ambiguous'[9(p.71)]. Nowotny et al.[8] describe this as a shift from generating 'merely' scientifically reliable knowledge towards more 'socially robust' knowledge. It is for these types of complex, cross-cutting problems, therefore, that universities can most contribute to creating knowledge democracy through the co-generation or co-production of knowledge.

Defined as the 'collaborative process of knowledge production that involves multiple disciplines and stakeholders of other sectors of society'[10], the co-production of knowledge should ideally be based on a dialogue on equal terms between groups of stakeholders with shared styles of thinking. However, accepting the diversity of knowledges on equal terms, and embarking on the co-production of knowledge, means letting go of assumptions about the primacy of science and recognising other ways of knowing beyond the university's gates.

> *The research process can no longer be characterized as an 'objective' investigation of the natural (or social) world. …Instead, it has become a dialogic process, an intense (and perhaps endless) 'conversation' between research actors and research subjects…*[11(p.187)]

Facilitating these conversations requires creating a 'new architecture of knowledge'[12] that makes spaces to shift accepted ways of knowing and acting and embrace new knowledge partnerships as being at the heart of our universities' contribution to nurturing a knowledge democracy and cognitive justice.

So how can universities and research institutes bring about this shift towards a more pluralistic regime of knowledge? How can they provide spaces and intellectual resources to complement and build on the enormous knowledges that exist in our communities and society more broadly?[13] What role can we as individual scientists play? Oswald[14] argues:

> *We as researchers are in a privileged position where we can set research agendas, ask certain questions, involve certain people – we are gatekeepers for what counts as valid knowledge and evidence.*

One approach that we have been piloting in our work – in the DST/NRF Centre of Excellence for Food Security jointly hosted by the University of the Western Cape and the University of Pretoria – is to build research partnerships through communities of practice. A community of practice (CoP) is a group of people who share a common interest or concern and who deepen their knowledge and expertise in this area by interacting on an ongoing basis.[15] CoPs can fulfill a variety of related functions. They can connect people who might not otherwise have the opportunity to interact; provide an opportunity to share information; help people organise around purposeful action; stimulate learning through the transfer of knowledge from one member to another; and generate new shared knowledge that helps people transform their practice.[16]

It is this latter function, as sites of social learning, which is of most interest for the co-production of knowledge. The concept of the 'agora' has been used to characterise this problem-generating and problem-solving environment in which actors and knowledge from inside and outside of science meet and the co-production of knowledge takes place.[1] It is populated not only by arrays of competing 'experts' and the organisations and institutions through which they bring their knowledge and experience to bear on decisions taken, but also by variously jostling 'publics'.[1] The 'agora' is in its own right a domain of primary knowledge production, through which people enter the research process and where knowledge is embodied in people, processes and projects.

Communities of practice were originally developed as an analytical concept by Wenger and Lave in the 1990s to study learning by apprentices through participation in networks. Lave and Wenger[17] argued that learning is not an individual process, but a social process situated in a cultural and historical context. However, the concept was quickly taken up by organisational and management studies which presented CoPs as vehicles to promote intra-institutional learning. A myriad of articles now aim to guide the reader on how to cultivate, nurture or steward a CoP. For example, Cambridge et al.[16] set out design principles in the form of a set of key questions to be considered when setting up a CoP. These questions include: For whom is the community? What are the key issues for this group? What is the primary purpose of the group? What kind of activities will the CoP undertake? Numerous articles also depict CoPs as dynamic structures that constantly evolve and whose life cycle can be mapped out over time into several phases. For example, Wenger et al.[15] describe five phases: realising potential, coalescing, maturing, stewardship and transformation. Other articles also set out a dazzling array of reasons for the failures of CoPs, such as a lack of identification with the CoP from members, lack of a core group, and low-level one-on-one interaction between members.[18]

While CoPs are often portrayed in the literature as harmonious and based on trust and shared values, our experience in nurturing a CoP on local food governance in the Western Cape supports recent arguments that not all CoPs are the same.[19] In contrast to the traditional conception of CoPs as intradisciplinary, CoPs can also transcend different disciplines and organisations. These transdisciplinary CoPs bring together actors from across the knowledge–policy–practice interface and are much more likely to include individuals with very different viewpoints, and 'ways of knowing'.[20] While inevitably difficult to negotiate, these are precisely the spaces where co-production of knowledge is most needed to tackle complex societal problems.

Issues of power, including open disagreement and conflict, are often overlooked in the literature on CoPs, and especially in the 'how to' guides. By focusing mainly on the more harmonious and homogeneous intradisciplinary CoPs rather than transdisciplinary CoPs, the literature can obscure the degree to which CoPs are influenced and shaped by their context, which includes the institutional, political and cultural context. From our experiences in the Western Cape, we have found that asymmetries of power within a transdisciplinary CoP can result in some stakeholders hesitating to speak up within what can be perceived as an expert-dominated space. This is particularly the case for more vulnerable, but nevertheless knowledgeable, stakeholders who are closer in nature to the wider citizenry than to traditionally recognised experts.

Conversely, these same pressures can lead certain stakeholders to 'come out fighting' if collectively agreed codes of interaction are not in place. Unmanaged, these tensions can escalate to a level of conflict that some CoP members find uncomfortable. Differences in institutional culture and practice of CoP members can also lead to disagreement on whether the CoP should focus on 'talking' or 'doing', 'top-down' or 'bottom-up' approaches, and to what extent certain stakeholders such as 'big business' should be included (or not). While issues of power, conflict and disagreement have been underplayed in the literature, our experience indicates that these need careful reflection to be better understood, managed and harnessed. The co-production of knowledge requires multiple perspectives and, in the sense that social learning is 'negotiated meaning' in a 'push pull' process,[19] it would not be feasible to expect these power relationships and tensions to be absent. Indeed, it could be argued that they are the essence of co-production. If we are all experts now, the ordering of this brave new world of pluralistic expertise is being played out and negotiated in these spaces.[1]

Communities of practice are not the only way in which to create such shared spaces for the co-production of knowledge with stakeholders from outside of science. These spaces can be created through scenario exercises, deliberative stakeholder workshops, learning journeys or digital storytelling, to name but a few other approaches. These approaches are also not new, especially not in South Africa where research is often driven by the need to solve real-world policy problems rooted in specific places and communities. However, this type of co-production of knowledge is not ubiquitous or even the norm in many disciplines and fields of research.

But perhaps this situation is not surprising considering that the co-production of knowledge takes time, resources and a willingness to step outside of 'our comfort zone'. It also requires certain skills and an attitude that we may need to strive hard to obtain. More fundamentally, it requires embarking on triple loop learning (learning how to learn) because it shifts our understanding of how we create knowledge and learn as scientists – or how we 'do science'. However, the scientific system is not set up for enabling and encouraging this type of transdisciplinary work. When the career incentives are weighted in favour of publications in high-impact (disciplinary) journals and funding proposals require a detailed road map of the anticipated research, including expected outputs, it is hard

to fully engage in potentially resource-intensive and unpredictable knowledge partnerships.

Crucially, however, if we are to move beyond creating fragmented and unused (or 'orphan') solutions to complex problems in our society, universities must act to widen the scope of recognised knowledge and move towards nurturing knowledge democracy. This requires universities to openly and actively engage with stakeholders and citizenry as a whole in the co-production of knowledge. We must also reflect on our own individual roles as scientists in creating knowledge. Establishing CoPs around existing research themes and teams is one practical way many of us at (South) African universities can begin to construct a new architecture of knowledge, one knowledge partnership at a time.

Acknowledgements

This article was funded by the DST-NRF Centre of Excellence for Food Security. I thank members of the Western Cape Food Governance Community of Practice as well as my colleagues Bruno Losch and Florian Kroll for their enthusiasm and dedication to our joint endeavour.

References

1. Nowotny H. Democratising expertise and socially robust knowledge. Sci Public Policy. 2003;30(3):151–156. https://doi.org/10.3152/147154303781780461
2. Tandon R. Global democracy requires knowledge democracy [webpage on the Internet]. c2013 [cited 2018 Dec 11]. Available from: http://unescochair-cbrsr.org/index.php/2013/09/15/global-democracy-requires-knowledge-democracy/
3. Hall BL, Tandon R. Decolonization of knowledge, epistemicide, participatory research and higher education. Research for All. 2017;1(1):6–19. https://doi.org/10.18546/rfa.01.1.02
4. Escrigas C, Sanchez JG, Hal B, Tandon R. Editor's introduction. In: GUNi, editor. Knowledge, engagement and higher education: contributing to social change. Hampshire, NY: Palgrave Macmillan; 2014. p. xxxiii.
5. Gaventa J, Bivens F. Co-constructing democratic knowledge for social justice: Lessons from an International Research Collaboration. In: Shefner J, Dahms HF, Jones RE, Jalata A, editors. Social justice and the university: Globalisation, human rights and the future of democracy. London: Palgrave Macmillan; 2014. p. 149–174. https://doi.org/10.1057/9781137289384_8
6. ISSC, IDS, UNESCO. World social science report 2016. Challenging inequalities: Pathways to a just world. Paris: UNESCO Publishing; 2016.
7. Visvanathan S. The search for cognitive justice [webpage on the Internet]. c2009 [cited 2018 Mar 29]. Available from: http://www.india-seminar.com/2009/597/597_shiv_visvanathan.htm
8. Nowotny H, Scott P, Gibbons M. Re-thinking science: Knowledge and the public in an age of uncertainty. Cambridge: Polity Press; 2001.
9. Sanderson I. Making sense of 'what works': Evidence based policy making as instrumental rationality? Public Policy Admin. 2002;17(3):62–75. https://doi.org/10.1177/095207670201700305
10. Pohl C, Van Kerkhoff L, Hirsch Hardorn G, Bammer G. Integration. In: Hirsch Hardorn G, Hoffman-Reim H, Biber-Klemm S, Grossenbacher-Mansuy W, Joye D, Pohl C, et al., editors. Handbook of transdisciplinary research. Berne: Springer; 2008. p. 411–424.
11. Nowotny H, Scott P, Gibbons M. Introduction: 'Mode 2' revisited: The new production of knowledge. Minerva. 2003;41(3):179–194.
12. Dolan C, Shahrokh T, Edström J, Kabafunzaki DJ, Maganya D, Moninga A, et al. Engaged excellence or excellent engagement? Collaborating critically to amplify the voices of male survivors of conflict-related sexual violence. IDS Bulletin. 2016;47(6)37–54. https://doi.org/10.19088/1968-2016.198
13. Tandon R, Singh W, Clover D, Hall B. Knowledge democracy and excellence in engagement. IDS Bulletin. 2016;47(6):19–36. https://doi.org/10.19088/1968-2016.197
14. Oswald K. Engaged excellence in research…another buzz phrase or an opportunity [webpage on the Internet]. c2017 [cited 2018 Mar 29]. Available from: https://www.ids.ac.uk/opinion/engaged-excellence-in-research-another-buzz-phrase-or-an-opportunity
15. Wenger E, McDermott R, Snyder WM. Cultivating communities of practice. Boston, MA: Harvard Business School Press; 2013.
16. Cambridge D, Kaplan S, Suter V. A community of practice design guide: A step-by-step guide for designing and cultivating communities of practice in higher education [webpage on the Internet]. c2005 [cited 2018 Nov 26]. Available from: https://library.educause.edu/resources/2005/1/community-of-practice-design-guide-a-stepbystep-guide-for-designing-cultivating-communities-of-practice-in-higher-education
17. Lave J, Wenger E. Situated learning: Legitimate peripheral participation. Cambridge, UK: Cambridge University Press; 1991. p. 27–44. https://doi.org/10.1017/cbo9780511815355.003
18. Probst G, Borzillo S. Why communities of practice succeed and why they fail. Eur Manage J. 2008;26:335–347. https://doi.org/10.1016/j.emj.2008.05.003
19. Vincent K, Steynorc A, Waagsaetherc K, Cullan T. Communities of practice: One size does not fit all. Clim Serv. 2018;11:72–77. https://doi.org/10.1016/j.cliser.2018.05.004
20. Cundill G, Roux DJ, Parker JN. Nurturing communities of practice for transdisciplinary research. Ecol Soc. 2015;20(2):22. https://doi.org/10.5751/es-07580-200222

AUTHORS:
Joseph M. Hulbert[1,2,3]
Sophia C. Turner[4]
Samantha L. Scott[5]

AFFILIATIONS:
[1]Cape Citizen Science, Cape Town, South Africa
[2]Forestry and Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa
[3]Department of Conservation Ecology and Entomology, Stellenbosch University, Stellenbosch, South Africa
[4]limbovane Outreach Project, DST-NRF Centre of Excellence for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa
[5]rePhotoSA, Plant Conservation Unit, Department of Biological Sciences, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Joseph Hulbert

EMAIL:
joey.hulbert@fabi.up.ac.za

HOW TO CITE:
Hulbert JM, Turner SC, Scott SL. Challenges and solutions to establishing and sustaining citizen science projects in South Africa. S Afr J Sci. 2019;115(7/8), Art. #5844, 4 pages. https://doi.org/10.17159/sajs.2019/5844

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
public engagement; science outreach; science education; research participation

PUBLISHED:
30 July 2019

Challenges and solutions to establishing and sustaining citizen science projects in South Africa

Citizen science is a term for research that engages non-scientists in the collection and generation of data. Many citizen science projects exist within South Africa and, because of their success, we expect more projects will be initiated. In this Commentary, we discuss three projects based in, but not confined to, the Western Cape Province to provide context for their methods, specific objectives and overall desired impacts. We then identify a few challenges that we have faced from the researcher perspective and we provide recommendations for those interested in initiating a citizen science project in South Africa.

Many projects involve citizen scientists because their participation enhances the breadth of the research through the collection of data over greater spatio-temporal scales.[1-3] However, not all projects in South Africa have purely research objectives, some are education-oriented with the specific objective of empowering the participants. In some cases, the educational objectives may be motivated by the desire to engage local communities or by the understanding of ubuntu wisdom. Citizen science is therefore a powerful approach to address multiple objectives, but there are many challenges to achieving the desired outcomes. We outline these challenges below within the context of an education-oriented project, a research-oriented project and a project that combines the two objectives.

limbovane Outreach Project

The limbovane Outreach Project (http://www0.sun.ac.za/limbovane) is a science education project based in the DST-NRF Centre of Excellence for Invasion Biology at Stellenbosch University. The word 'limbovane', meaning 'ants' in isiXhosa, represents the project's engagement of learners in the collection and identification of ants.[4] The project is primarily education-oriented now, but it has led to advances in knowledge about ant diversity throughout the region since it was initiated in 2005.[4] limbovane supports Grade-10 Life Sciences teachers and students by enhancing educational outcomes through stimulating workshops and activities that provide resources and hands-on learning about the theoretical biodiversity concepts covered in the Life Sciences curriculum. Learners are exposed to the various stages of the scientific method and gain practical experience conducting biodiversity studies, all while advancing knowledge about the diversity of ants in South Africa. limbovane is the longest running citizen science project that specifically engages youth in South Africa. In this time, limbovane has empowered thousands of learners to understand and value the biodiversity of the Western Cape Province.

rePhotoSA

rePhotoSA (http://rephotosa.adu.org.za) is the repeat photography project of southern African landscapes. It is a joint project between the Plant Conservation Unit and the Animal Demography Unit at the University of Cape Town. In contrast to limbovane, this project is mainly research-oriented. rePhotoSA is founded on one of the largest historical landscape photograph collections in Africa, which currently consists of over 20 000 images.[5] Approximately 6000 photographs have been uploaded to an interactive map available online. Citizen scientists can search for and download historical images to find the exact location from where the original photograph was taken. The primary objective is to enhance the understanding of landscape change over time.[5] Ground-based repeat photography has a long history in documenting landscape change and has been used in many research projects to better understand: (1) the drivers of vegetation change in the Karoo[6,7], (2) population changes in plant species, such as the endangered Clanwilliam Cedar[8] and the quiver tree[9], and (3) human impacts on the environment. Contributions to rePhotoSA therefore provide a valuable resource for research and provide a platform to monitor long-term vegetation change into the future.

Cape Citizen Science

Cape Citizen Science (http://citsci.co.za) is a programme co-hosted by the University of Pretoria and Stellenbosch University. The programme receives support from the DST-NRF Centre of Excellence in Tree Health Biotechnology and the Forestry and Agricultural Biotechnology Institute. Cape Citizen Science invites citizens (including school groups) to participate through many methods spanning the gradient of education to pure research. Some citizens have learned through workshops and educational hikes, and others have contributed to advancing knowledge by submitting physical samples or reporting unhealthy plants through online tools.[10] Cape Citizen Science has demonstrated that research projects can provide opportunities for informal education[11] and that citizens can contribute to advancing scientific discovery in South Africa.

Project summary

Together, these initiatives represent some of the diversity of citizen science projects based in southern Africa. Each project has its own objectives and target groups for participation, but they overlap in the overall motivation to engage the public. Each project serves its own niche in the interface between the public and scientists because of the diversity of communities and the availability of resources in South Africa. For these reasons, we suggest that there is great opportunity to establish and sustain citizen science projects in South Africa, but we caution prospective project practitioners to be aware of ongoing projects to avoid duplication. The mixture of available resources and communities provides great opportunities for collaboration on projects, and for the sharing of tools and resources. We therefore encourage support for a network of projects to nurture a dialogue between project leaders. We anticipate that fostering stronger connections between projects will enhance the quality and breadth of opportunities to empower more people to make observations and critical decisions.

Challenges and solutions

The purpose of this Commentary is to identify some of the challenges and potential solutions that we have experienced in South Africa in initiating and maintaining a citizen science project. We outline some of the challenges we have faced below by first reviewing available literature and then providing context within the projects discussed above. Understanding these challenges will prepare future project leaders to overcome barriers and enable their projects to better contribute to advancing knowledge and positively influencing society.

Experimental design

Incorporating effective experimental design can be a major challenge for many citizen science projects. Careful design is critical for collecting adequate sample sizes without fragmentation or sampling bias.[12] One approach to alleviating this challenge is to incorporate a design that targets specific areas for sampling.[13] This design was incorporated in the 'Go Outside for Science' phase of Cape Citizen Science. Participants were asked to physically collect samples in randomly selected sampling locations to avoid sampling bias and ensure strong coverage throughout the region. However, this phase could only be promoted to groups with permission to collect samples in protected areas because South Africa has many protected species. Therefore, the strict sampling permission requirements presented a challenge to the implementation of the experimental design. Cape Citizen Science was able to overcome this challenge by engaging professional staff (e.g. nature reserve managers) in the research.

Data quality

Data quality is central to the immediate and long-term success of any citizen science venture. While volunteer participation can create possibilities for otherwise cost-prohibitive projects, careful attention is needed to ensure the data collected by volunteers are high quality.[14] This challenge can be overcome by providing training for participants[15] and implementing methods of quality assurance or using tools that are monitored by the greater community such as inaturalist.org.[16] Future projects will also need to include efforts towards overcoming data quality skepticism in the greater science community.[17] Training of participants and implementation of targeted sampling designs in combination can result in extensive and useful data sets that will help generate support for future projects.[13] We expect that more support for citizen science projects will become available if it can be demonstrated that the data collected by citizens are valuable and high quality.

Data quality is particularly important for rePhotoSA. For example, photographs need to be taken in the exact same location in order to overlay the images and quantify landscape changes, such as the health of individual trees.[8] To overcome this challenge, rePhotoSA produced a thorough set of instructions for taking repeat photographs. The project team is also currently developing complementary online video tutorials and intends to expand their public engagement to demonstrate how to capture research-grade repeat photographs in the field. Together these resources are examples of methods that can be incorporated into any project to improve data quality.

Project management and sustainability

Another major challenge in South Africa, which may be similar elsewhere, is that many of the citizen science projects are championed by postgraduate students, postdocs, or outreach coordinators who have fixed-term appointments or limited availability. This challenge emphasises the importance of managing expectations and deciding on the appropriate lifetime for a project. For example, Cape Citizen Science was established to facilitate research for one student's project, but has now grown into an umbrella programme for other projects because of shifts in the scientific capacity, the depletion of project funds, or simply because the research was completed for those projects. While only one PhD student is needed to start a citizen science programme, many are needed to keep the programme running. We therefore recommend that the ideal lifetime of future projects be identified early on in the project planning process. The apparent expiration may even motivate participation. An alternative solution, employed by limbovane, is to hire a project coordinator who is solely dedicated to the project. Such a coordinator can relieve pressure on the researcher and dedicate efforts to sustaining the project over the long term. While this capacity may not be financially feasible for most projects initially, it is an approach that would help overcome the challenge of sustaining projects or programmes.

Financial support

Limited funding challenges most research in South Africa. However, this challenge has different implications for citizen science programmes. Establishing a citizen science programme may not require a large investment, but the merit of establishing a programme depends on the availability of sustained funding. For example, one-time small grants from the Table Mountain Fund and the Faculty of Agrisciences at Stellenbosch University have both contributed to citizen science projects in the Western Cape Province, but a different funding structure is needed if the projects are to evolve into sustained programmes that host multiple projects. Most financial support for research is project based; however, establishing a citizen science programme to facilitate a single research project may not be worthwhile unless it is sustained across multiple projects. An ideal funding structure in South Africa would involve longer-term (3–5 years) support for a single laboratory to initiate and sustain a programme that could incorporate multiple short-term projects.

Specific costs of each project vary, but the biggest expenses of the projects mentioned above are the salaries of project coordinators (or bursaries for students) and travel (e.g. transporting youth to nature reserves). Some other costs are hosting and maintaining data sets on servers, sequencing microbial cultures, general laboratory supplies and outreach materials. For example, the limbovane Outreach Project budgets a large amount toward materials such as workbooks, ant identification keys and promotional resources. Similarly, Cape Citizen Science tries to provide awards (e.g. plant identification field guides, biodiversity posters and dissection kits) to youths who successfully answer questions after presentations in outreach activities. In general, the costs of these materials and activities are easy to underestimate.

While securing financial support for research may be difficult in general, citizen science programmes may be able to adopt creative approaches to overcome the challenge. For example, Cape Citizen Science has received public support through two crowdfunding campaigns (Discovering Plant Destroyers in South Africa and Engage Kayamandi Youth in Cape Citizen Science with Vision Afrika) and other projects have generated support as beneficiaries of 'MySchool MyVillage MyPlanet' or through corporate sponsorship. However, even if public or private support is a feasible funding mechanism, connecting with philanthropists in these situations can be challenging. One solution may be to collectively identify the citizen science projects that are present in South Africa and to create a repository of projects open to support from philanthropists. Such a repository could be maintained by a government agency or third party (similar to 'MySchool MyVillage MyPlanet'), but eligibility would need to include small and short-term projects without marketing campaigns or the required designation as a non-profit organisation (NPO).

Project guidance

Alternatively, even if funding is available, some researchers may be uncertain how to use it to achieve educational outcomes. Because citizen science is relatively new in South Africa, universities do not have capacity to guide researchers into the interface between their research programmes and the greater public. A financial incentive (e.g. internal grants) may be the top-down approach to enhancing societal impact, but additional training and guidance is critical for economic efficiency. Enhancing the network between projects, showcasing projects at broader scales, or offering workshops to other faculties interested in initiating projects would increase efficiency. In the meantime, we encourage those in this position to join the online group at https://groups.io/g/CitSciSA to seek guidance.

Attracting and maintaining citizen scientists

The number of registrants or people who express interest in participating in citizen science projects may far exceed the number of actively participating

members. This phenomenon has been described within the social sciences through the theory of planned behaviour: simply, a gap often exists between intention and behaviour.[18] Citizens may intend to participate but there are barriers to the behavioural expression of this intention. Some of the attitudinal barriers we have identified, particularly with rePhotoSA, are impatience or confusion with the technicality of taking and uploading a repeat photograph, ambivalence or indifference as a result of a lack of knowledge of the application of repeat photography, or loss of interest because of an insufficient number of historical images in the participant's area of interest. Citizen scientists who initially struggle to participate in a project are unlikely to try again in the future.[1] This challenge underscores how critical it is to tailor an experience that firstly captures the interest of a potential citizen scientist and then creates a participatory environment that is both intuitive and rewarding.

One approach to recruiting potential participants who may have barriers to getting involved, is to use social media platforms to raise awareness. This approach has been implemented in many citizen science projects where emerging technologies have characterised a new avenue of public engagement.[19] rePhotoSA has observed the advantages of social media in cultivating support from the public, equipping citizens with knowledge of repeat photography protocols, validating citizen repeat photographs, and disseminating the results of scientific studies using repeat photography. Therefore, implementing similar strategies with emerging technologies (such as social media campaigns) should not be overlooked in future projects because it can help overcome challenges in building communities and sharing resources.

Project redundancy

Many citizen science projects can coexist in South Africa without overlap because of the diversity and abundance of communities. For example, Cape Citizen Science and limbovane coexist in the same university and target the same age groups, but work with different communities. Cape Citizen Science has established partnerships with many NPOs and limbovane works directly with schools and schoolteachers. While both projects strive to provide meaningful engagement opportunities for similar age groups, there are many different communities and groups of learners with which to engage.[11]

Conversely, the diversity of communities can also present opportunities for redundancy. For example, there are at least three online tools which citizens can use to report observations of biodiversity.[10] Each of these tools has their own community of participants who may be unaware of the other communities or tools. This might be a consequence of recently emerging technologies and we may see a merger of communities as one tool becomes more popular. However, it is important for projects to take note of and consider using existing tools and platforms rather than creating new ones in the future. In some cases, it may even be feasible to extend an existing tool or project into new communities. Similarly, it is also critical that projects which exist in similar spaces communicate and work together to avoid redundancy and provide diverse opportunities to communities.

Socioeconomic context

The socioeconomic diversity in South Africa provides great opportunity for citizen science projects to coexist and serve separate niches in society, but it can also be a challenge for projects to accommodate multiple groups. For example, projects such as rePhotoSA require access to equipment that can be a barrier to participation for some groups. As an online repeat photography project, citizen scientists need access to a stable Internet connection and at least a smartphone, if not a digital camera and tripod. While an online database may increase accessibility to the project for many,[1] it may also, together with the type of equipment required, actively exclude others. The unique requirement for high-resolution images (≥3 Mb) to be uploaded in this project provides a significant constraint for many participants, even those with Internet connections, as these connections can be slow and unstable, especially in rural southern Africa. Despite the limitations, the online format for disseminating historical photographs and receiving repeats is the most efficient at present, but alternatives have been provided on a case-by-case basis. The smartphone may form a potential avenue for data collection in the future and the development of a 'gamified' repeat photography application is being considered. This development may provide more opportunities for participation by opening the project up to citizens without access to expensive camera equipment or computers and increase participation with entertainment.

Conclusion

The objective of this Commentary was to highlight some challenges we have faced as practitioners of citizen science projects in South Africa. We recognise that additional challenges likely exist for citizen engagement outside of the researcher perspective (e.g. the educator perspective), but we suggest that addressing the challenges herein will promote the sustainability of future citizen science projects. Prospective project leaders are encouraged to subscribe to the online group to join a network of projects in South Africa. Although we have identified many challenges, we believe there is ample opportunity to initiate citizen science programmes in South Africa. Cumulatively, our projects demonstrate that the citizen science approach can be applied to achieve many objectives, even simultaneously, across many communities. Although each project serves a distinct niche in society and the research institutes, there are still many communities in which opportunities for engagement from local universities or research agencies do not exist. We therefore encourage increased support for the establishment and sustainability of citizen science projects. Such support would provide more South Africans with opportunities for informal education and enhanced citizenship.

Acknowledgements

We are especially grateful to all the citizens who participated in our projects and provided the experiences discussed above. We acknowledge the citizen science community in South Africa and particularly those responsible for organising the project fair on International Citizen Science Day in 2018 where we met. We also acknowledge support from the DST-Centre of Excellence in Invasion Biology, the DST-Centre of Excellence in Tree Health Biotechnology, the University of Cape Town, Stellenbosch University and the University of Pretoria. rePhotoSA received specific support from the Plant Conservation Unit and the Animal Demography Unit at the University of Cape Town. limbovane receives funding from the Rand Merchant Bank Fund for outreach activities and support from the Western Cape Education Department. We also acknowledge the Forestry and Agricultural Biotechnology Institute and the backers who supported the crowdfunding campaigns for Cape Citizen Science. Sharing of our experiences and recommendations was made possible by many invaluable avenues of support that we are fortunate to have received.

References

1. Delaney DG, Sperling CD, Adams CS, Leung B. Marine invasive species: Validation of citizen science and implications for national monitoring networks. Biol Invasions. 2008;10:117–128. https://doi.org/10.1007/s10530-007-9114-0
2. Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV et al. Citizen science: A developing tool for expanding science knowledge and scientific literacy. BioScience. 2009;59:977–984. https://doi.org/10.1525/bio.2009.59.11.9
3. Dickinson JL, Zuckerberg B, Bonter DN. Citizen science as an ecological research tool: challenges and benefits. Annu Rev Ecol Evol Syst. 2010;41:149–172. https://doi.org/10.1146/annurev-ecolsys-102209-144636
4. Braschler B. Successfully implementing a citizen-scientist approach to insect monitoring in a resource-poor country. BioScience. 2009;59:103–104. https://doi.org/10.1525/bio.2009.59.2.2
5. Scott SL, Rohde RF, Hoffman MT. Repeat landscape photography, historical ecology and the wonder of digital archives in southern Africa. Afr Res Doc. 2018;131:35–47.
6. Masubelele ML, Hoffman MT, Bond WJ. Biome stability and long-term vegetation change in the semi-arid, south-eastern interior of South Africa: A synthesis of repeat photo-monitoring studies. S Afr J Bot. 2015;101:139–147. https://doi.org/10.1016/j.sajb.2015.06.001
7. Masubelele ML, Hoffman MT, Bond WJ. A repeat photograph analysis of long-term vegetation change in semi-arid South Africa in response to land use and climate. J Veg Sci. 2015;26:1013–1023. https://doi.org/10.1111/jvs.12303

8. White JDM, Jack SL, Hoffman MT, Puttick J, Bonora D, Visser V, et al. Collapse of an iconic conifer: Long-term changes in the demography of *Widdringtonia cedarbergensis* using repeat photography. BMC Ecol. 2016;16:53. https://doi.org/10.1186/s12898-016-0108-6

9. Jack SL, Hoffman MT, Rohde RF, Durbach I. Climate change sentinel or false prophet? The case of *Aloe dichotoma*. Divers Distrib. 2016;22:745–757. https://doi.org/10.1111/ddi.12438

10. Hulbert JM. Citizen science tools available for ecological research in South Africa. S Afr J Sci. 2016;112, Art. #a0152, 2 pages. http://dx.doi.org/10.17159/sajs.2016/a0152

11. Hulbert JM, Roets F. Science engagement in South Africa. Science. 2018;361:985. https://doi.org/10.1126/science.aav1499

12. Conrad CC, Hilchey KG. A review of citizen science and community-based environmental monitoring: Issues and opportunities. Environ Monit Assess. 2011;176:273–291. https://doi.org/10.1007/s10661-010-1582-5

13. Meentemeyer RK, Dorning MA, Vogler JB, Schmidt D, Garbelotto M. Citizen science helps predict risk of emerging infectious disease. Front Ecol Environ. 2015;13:189–194. https://doi.org/10.1890/140299

14. Crall AW, Newman GJ, Stohlgren TJ, Holfelder KA, Graham J, Waller DM. Assessing citizen science data quality: An invasive species case study. Conserv Lett. 2011;4:433–442. https://doi.org/10.1111/j.1755-263x.2011.00196.x

15. Gardiner MM, Allee LL, Brown PM, Losey JE, Roy HE, Smyth RR. Lessons from lady beetles: Accuracy of monitoring data from US and UK citizen-science programs. Front Ecol Environ. 2012;10:471–476. https://doi.org/10.1890/110185

16. He Y, Wiggins A. Community-as-a-service: Data validation in citizen science. Paper presented at: 4th International Workshop on Methods for Establishing Trust of (Open) Data; 2015 October 11–12; Bethlehem, PA, USA. https://doi.org/10.13016/M22T76

17. Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, et al. Next steps for citizen science. Science. 2014;343:1436–1437. https://doi.org/10.1126/science.1251554

18. Ajzen I. From intentions to actions: A theory of planned behavior. In: Kuhl J, Beckmann J, editors. Action control: From cognition to behavior. Berlin: Springer; 1985. p. 11–39. https://doi.org/10.1007/978-3-642-69746-3_2

19. Newman G, Zimmerman D, Crall A, Laituri M, Graham J, Stapel L. User-friendly web mapping: Lessons from a citizen science website. Int J Geogr Inf Sci. 2010;24:1851–1869. https://doi.org/10.1080/13658816.2010.490532

AUTHORS:
David Glassom[1]
Ursula M. Scharler[1]
Angus H.H. Macdonald[1]

AFFILIATION:
[1]School of Life Sciences, University of KwaZulu-Natal, Durban, South Africa

CORRESPONDENCE TO:
David Glassom

EMAIL:
glassom@ukzn.ac.za

HOW TO CITE:
Glassom D, Scharler UM, Macdonald AHH. Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019). S Afr J Sci. 2019;115(7/8), Art. #6294, 3 pages. https://doi.org/10.17159/sajs.2019/6294

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
basic research; pure science; actionable research; societal benefit; interdisciplinary

PUBLISHED:
30 July 2019

Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019)

In their article 'Science in the service of society: Is marine and coastal science addressing South Africa's needs', Cochrane et al.[1] express concern, based on an analysis of abstracts from a single South African Marine Science Symposium (SAMSS 2017) that too little research is either interdisciplinary or 'actionable' – defined as science whose results translate easily to policies, management actions or industry.

They argue that science is disconnected from the needs of society, may not adequately benefit society and, therefore, that the science risks losing support and credibility. To remedy such drawbacks, they propose funding actionable science as a priority, including in the tertiary education arena, and emphasising interdisciplinary research. In conclusion, they offer eight recommendations for future funding of marine science. Because their article may substantially influence the policies of funding agencies and thus the trajectory of marine science in South Africa, it is important that their claims are examined in the wider context of how science benefits society.

Cochrane et al.[1]'s arguments are built on four premises which do not stand up to scrutiny. Firstly, they assume a clear distinction between pure, basic and applied (or actionable) research. Secondly, they underestimate, to the point of discounting, the value of 'pure' science in advancing the goals and imperatives that, in their opinion, should be urgently addressed. Thirdly, they assume an unrealistic linearity in the way that science translates to policy and management. Finally, they do not account for the manner in which the funding system already addresses many of their concerns.

Pure versus applied science

The distinction between pure and applied science has always been vague, notwithstanding more than a century of debate – for example in the second volume of the journal *Science* published in 1883.[2]

Louis Pasteur wrote:

> *No category of sciences exists to which one could give the name of applied sciences. There are science and the applications of science, linked together as fruit is to the tree that has borne it.*[3]

Even if we disagree with Pasteur, the distinction between the spheres is much less clear than Cochrane et al.[1] assume, with a case being made for a continuum from pure to applied research[4-6], for example, with the idea of 'Pasteur's quadrant' (Figure 1).[4] Interestingly, Bohr was chosen as an example of a pure scientist in the quadrant, yet his work on quantum physics is universally applied in modern electronics, emphasising the merging of the boundaries. On such boundaries, Marie Curie was explicit:

> *We must not forget that when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it.*

It is now widely acknowledged that the differences between pure and applied science and the various other formulations (such as fundamental research and basic research) are political and social constructs that are not philosophically justifiable as much as they are actual distinctions.[5,6] The superiority of pure over applied science thus cannot be considered a widely held contemporary view, as claimed by Cochrane et al.[1], although this may have been so in the past.[5]

Should basic (or pure) research be curtailed?

There is strong evidence that basic science makes large contributions to societal well-being almost irrespective of its subject matter. However, the magnitude of the contributions is often underestimated. Basic research may provide a return on investment of 20–60% per year, because it benefits from a positive feedback loop – research creates knowledge, leading to wealth, leading to more investment in research and more wealth.[7] Thus, while Cochrane et al.[1] refer to the Department of Science and Technology (DST)'s mission of 'increased well-being and prosperity through science, technology and innovation', innovation is far more likely to come from basic research than from applied or actionable research.[8] The benefits of basic research are more objective, less politicised and less focused on specific stakeholders than those arising from targeted research. They are thus less ephemeral and wider ranging.

We have cited the example of quantum physics, which led to the invention of all of modern electronics[9] over the following century. Similarly, MRI scanners would not exist today without previous pure research into superconducting magnets.[10] Examples from biology also abound. Watson and Crick could hardly have imagined the application of genomics to personalised medicine when they described the DNA double helix.[11] The evolutionary history of coral species is emerging as a major influence on their resilience to climate change and this information is being used to 'enhance' evolution of corals in the face of climate change. Thus research on evolution, typically considered a field of pure science, may have practical outcomes for species conservation.

The notion that basic research should be eliminated or substantially curtailed is thus untenable. Ignoring the likely return on investment in basic research risks trapping South African science and the economy in a quagmire of low innovation and growth. Because the benefit of basic science is not directly appropriable by industry, investment from industry is low and governments traditionally have to provide it.[7]

Actionable science is inextricably linked to basic science

The use of conference abstracts by Cochrane et al.[1] to assess the 'actionability' of South African marine science, provides, by their own admission, a limited view. However, even then, the results may be misleading because there is no assessment of whether such actionability was successful. This assessment requires a retroactive view of whether science funded at some time in the past turned out to be actionable or not, and conference abstracts do not provide such information.

In fact, the notion of actionable science implies a linearity between the goals, execution and implementation of scientific research that seldom exists, partly because research outcomes are often unpredictable. Even with positive outcomes, successful management and adequate policies are not guaranteed. While there are, no doubt, examples of directed, actionable science producing usable results, there are also many examples of where such results have not been achieved. Further, actionable science is invariably based on results emerging from basic science. Lewis Thomas[12] wrote:

> *When you are organized to apply knowledge, set up targets, produce a usable product, you require a high degree of certainty from the outset. All the facts on which you base protocols must be reasonably hard facts with unambiguous meaning .... But most of all you need the intelligible basic facts to begin with, and these must come from basic research. There is no other source.*

Fisheries science is surely considered actionable research. Yet for more than half a century it failed to substantially improve management of fish stocks.[13] A recent bitter dispute between two globally renowned fisheries scientists on the state and management of the world's fisheries[14] illustrates the point. Examples of the failure of actionable science from fields as varied as aquaculture, conservation and nutrition are numerous.

Additionally, while Cochrane et al.[1] argue that research priorities should be stakeholder-driven, undue prominence given to stakeholder interests may be a major problem, again evident in fisheries management.[13] This conflict is to some extent intuitive. Stakeholders are, by definition, self-interested. The scope and scale of the research driven by them is likely to reflect this self-interest. It seems to have eluded Cochrane et al.[1] that stakeholders effectively constitute 'sectoral and vested interests' whose influence their eighth recommendation calls for government to renounce.

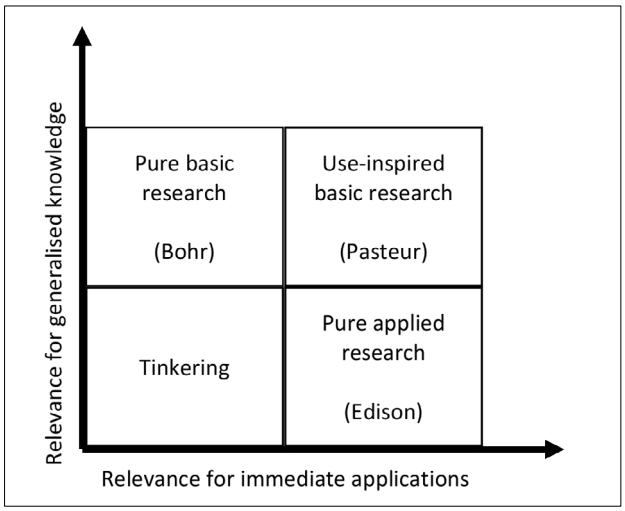


Figure 1: Pasteur's quadrant (from Stokes[4]).

Inter- and transdisciplinarity

Cochrane et al.[1] consider that 'reductionist' science cannot consider the full scope of complex socio-ecological problems. However, it is difficult to see how stakeholder-driven, interdisciplinary science can address complex challenges without a solid foundation of discipline-based, basic research. The knowledge which constitutes the building blocks for inter- and transdisciplinary applicable science must originate from discipline-specific basic research. Reductionist science is inextricably linked to the modern scientific method, and provides many benefits to society. For example, the success of molecular and genetic research and their societal benefits rest on a foundation of reductionist biology at the cellular and molecular level.[15] Although we strive to understand systems as a whole, the benefits of 'reductionist' science can thus not be discounted. Although Cochrane et al.[1] affirm that basic research or 'reductionist' science still has a role to play in South African marine science, the general gist of their article largely negates this sentiment, sometimes to the extent of misquoting other views on the subject. For example, they cite McQuaid[16] in support of their view that more science in South Africa should be 'actionable'. But although McQuaid[16] did allow that society is entitled to make demands of science, the point of his paper, stated in the conclusion, was that 'over-managing science in the interests of political imperatives, past or present, can be detrimental to both the science and eventually to society at large'. The recommendations by Cochrane et al.[1] fall squarely into the category of over-management and should be repudiated.

We agree on the need for scientists of different disciplines to work together. However, not all research is interdisciplinary, and not all interdisciplinary research need involve the humanities. It makes no sense to sacrifice strong disciplinary research because of a perceived imperative for interdisciplinary work[15], particularly that involving the social sciences. Where natural scientists do engage with social scientists, methodological differences need to be reconciled. This process is not as simple as Cochrane et al.[1] imply. Twenty years of structured interactions achieved only incomplete integration of natural and human sciences in climate change programmes[17] and a Rural Economy and Land Use programme showed similar difficulties[18], leading a participant to comment:

> *Often it is assumed that interdisciplinarity will simply happen if you put enough motivated people from different disciplines in the same project together. In reality, there are many barriers . . . and successful interdisciplinary collaboration must be planned for explicitly to overcome these barriers.*

Rather than demanding interdisciplinarity as a condition of funding, South African science would therefore do well to develop appropriate collaborations through structured, extended interactions that reconcile different research methods, ideologies and epistemologies among research fields.

Predicting and restricting research

Cochrane et al.[1] advise that the National Research Foundation (NRF) and DST should assess 'the current *and future* needs for scientific research' (our italics). It is difficult to conceive of a reliable model for predicting future research needs, as the future itself is increasingly unpredictable, with emergent problems arising more quickly than ever before. However, they go further, recommending that all tertiary education and research agencies should review their teaching and research in the context of the identified societal needs. It is short-sighted to suggest that the fundamentals of science taught at universities in South Africa should be revised to provide students with skills applicable only to perceived contemporary societal priorities.

Tertiary education is vital to ensure that foundational knowledge and a range of research skills are retained in the research community.[19] The restructuring of both teaching and research proposed by Cochrane et al.[1] would almost certainly hinder this goal. Further, a few highly cited papers, generated by a relatively small proportion of scientists, drive scientific innovation, progress and productivity.[20] However, because it cannot be known which scientists or papers will form the nucleus of progress, a 'surplus' of both is necessary to retain and increase the number of students and scientists the country needs for scientific innovation.

Constraining research and teaching to conform to a narrow, short-term political or social agenda will result in the loss of much foundational

knowledge and important skills, and risk degrading scientific capacity to address the problems that Cochrane et al.[1] say should be prioritised. Such constraints on research and teaching are characteristic of autocratic and closed societies and should not be embraced in South Africa. Whether changes proposed by Cochrane et al.[1] will bring about societal benefits (Recommendation 5), given increased funding for actionable research, is dubious. It has been recently demonstrated, for example by the partial opening of the Tsitsikamma National Park to fishing, and by failed conservation efforts[21] as well as examples in Cochrane et al.[1], that there is a considerable gap between actionable research, sensible policy and effective management, especially where political considerations come into play. One of the reasons that there is a cry for more actionable science in South Africa is because of political interference, inefficient management, and poor skill sets within the implementing agencies to deal with complex governance problems, rather than too much basic science.

The conclusions of Cochrane et al.[1] are thus almost entirely unjustified. But even if we agreed with the conclusions, their recommendations are largely redundant. They failed to note conditions already imposed on funding applications. In the scoring system by which the NRF adjudicates funding applications, 10% is allocated to 'the wider impact of the study on society', 10% to collaborations among institutions and 5% to scientific engagement (informing the public, managers or policymakers about the significance of your work). The scoring system implies that a 'pure' or basic research application outside of the Blue Skies funding call must demonstrate considerably more scientific merit than an 'actionable' application to be competitive for funding. Thus, despite statements to the contrary by Cochrane et al.[1], the requirement for research, including in the marine sciences, to be interdisciplinary and 'actionable' is already well embedded in the funding system. It should concern all marine scientists if a scientifically sound proposal can be rejected unless the social aspects score well, especially if, as argued above, reducing basic research in favour of actionable research impedes economic development and the societal goals that government funding of research is meant to promote.

The model for funding marine science in South Africa should be constantly debated and updated. Unfortunately, this has rarely happened, with many marine scientists willing to tailor their research to the priorities of the NRF and government departments. This approach, along with the inclination of governments to view issues over short terms of office, may impede South African science and the benefits it brings to the population. Any changes should be made following a deeper and less subjective analysis than is contained in Cochrane et al.[1] We should bear in mind this dictum:

> *To feed applied science by starving basic science is like economising on the foundations of a building so that it may be built higher. It is only a matter of time before the whole edifice crumbles.*[22]

In this light, we urge that the debate around science in South Africa and its funding model should centre around how the benefits of local research**,** applied or basic, can accrue to South Africans, rather than about constraining the nature of research that is conducted.

We agree with Cochrane et al.[1] on some points, particularly that more collaboration among disciplines would yield benefits. We concur increased funding is needed for marine science, but not only for actionable science. We note that there are already several national research organisations, facilities and government departments devoted entirely or primarily to applied or actionable research. There are, however, few refugia for basic research.

We propose a comprehensive discussion among marine scientists and government funders to refine recommendations for future marine and coastal research to avoid potential damage to marine science for years to come. As Cochrane et al.[1] began their critique with an assessment of presentations at SAMSS 2017, perhaps a suitable forum for a full and structured discussion would be the upcoming SAMSS 2020.

References

1. Cochrane KL, Sauer WHH, Aswani S. Science in the service of society: Is marine and coastal science addressing South Africa's needs? S Afr J Sci. 2019;115(1/2), Art. #4418, 7 pages. https://doi.org/10.17159/sajs.2019/4418
2. Rowland HA. A plea for pure science. Science Proceedings of Section B: Physics. 1883;2(29):242.
3. Murray JE Organ transplantation and the revitalization of immunology. In: Gallagher RB, Gilder J, Salvatore G, Nossal G, editors. Immunology: The making of a modern science. Cambridge, MA: Academic Press; 1995. p. 179–190.
4. Stokes DE. Pasteur's quadrant: Basic science and technological innovation. Washington DC: Brookings Institution Press; 1997. p. 196.
5. Kaldewey D, Schauz D. "The Politics of Pure Science" Revisited. Science and public policy. 2017;44(6):883–886. https://doi.org/10.1093/scipol/scx060
6. Douglas H. Pure science and the problem of progress. Stud Hist Philos Sci. 2014;46:55–63. http://dx.doi.org/10.1016/j.shpsa.2014.02.001
7. Press WH. What's so special about science (and how much should we spend on it?). Science. 2013;342:817–822. https://doi.org/10.1126/science.342.6160.817
8. Rayleigh RJS. The life of Sir JJ Thomson: Sometime master of Trinity College. Cambridge: Cambridge University Press; 1942.
9. Pripstein M, Trilling G. The power of basic science. Symmetry. 2013 February 07. Available from: https://www.symmetrymagazine.org/article/february-2013/the-power-of-basic-science
10. Womersly J. Being unreasonable: The value of pure science. Symmetry. 2013 February 21. Available from: https://www.symmetrymagazine.org/article/february-2013/being-unreasonable-the-value-of-pure-science
11. Doble B, Schofield DJ, Roscioli T, Mattick JS. The promise of personalised medicine. The Lancet. 2016;387(10017):433–434. https://doi.org/10.1016/S0140-6736(16)00176-8
12. Thomas L. The lives of a cell: Notes of a biology watcher. New York: Viking Press; 1974. p. 147.
13. Longhurst A. The sustainability myth. Fish Res. 2006;81:107–112.
14. Hilborn R. Faith-based fisheries. Fisheries. 2006;31:554.
15. Metzger N, Zare RN. Interdisciplinary research: From belief to reality. Science. 1999;283:642–643. https://doi.org/10.1126/science.283.5402.642
16. McQuaid CD. Balancing science and politics in South African marine biology. S Afr J Sci. 2010;106(11/12), Art. #467, 6 pages. https://doi.org/10.4102/sajs.v106i11/12.467
17. Mooney HA, Duraiappah A, Larigauderie A. Evolution of natural and social science interactions in global change research programs. Proc Natl Acad Sci USA. 2013;110(suppl. 1):3665–3672. https://doi.org/10.1073/pnas.1107484110
18. Lowe P, Phillipson J, Wilkinson K. Why social scientists should engage with natural scientists. Contemp Soc Sci. 2013;8:207–222. https://doi.org/10.1080/21582041.2013.769617
19. Rull V. The most important application of science. EMBO Rep. 2014;15(9):919–922.
20. Philander SG. How many scientists does a country need? [document on the Internet]. c2008 [cited 2019 Apr 29]. Available from: https://www.access.ac.za/wp-content/uploads/2013/09/How-Many-Scientists-Does-South-Africa-Need.pdf
21. Kerwath SE, Parker D, Winker H, Potts W, Mann B, Wilke C, et al. Tracking the decline of the world's largest seabream against policy adjustments. Mar Ecol Prog Ser. 2019;610:163–173. https://doi.org/10.3354/meps12853
22. Porter G. Lest the edifice of science crumble. New Scientist. 1986;111(1574):16.

AUTHORS:
Kevern L. Cochrane[1]
Warwick H.H. Sauer[1]
Shankar Aswani[1,2]

AFFILIATIONS:
[1]Department of Ichthyology and Fisheries Science, Rhodes University, Makhanda, South Africa
[2]Department of Anthropology, Rhodes University, Makhanda, South Africa

CORRESPONDENCE TO:
Kevern Cochrane

EMAIL:
k.cochrane@ru.ac.za

HOW TO CITE:
Cochrane KL, Sauer WHH, Aswani S. Reply to 'Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019)'. S Afr J Sci. 2019;115(7/8), Art. #6415, 2 pages. https://doi.org/10.17159/sajs.2019/6415

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
marine and coastal science

PUBLISHED:
30 July 2019

Reply to 'Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019)'

We welcome discussion on our paper on science in the service of society[1] but find the response by Glassom et al.[2] to be weak and frequently flawed. We can only cover some of the more important disagreements we have in the words available to us.

Glassom et al.[2] misinterpret our paper in their title: 'Society's needs cannot be met by applied science alone': a statement of the obvious and unrelated to any of our arguments. Another misinterpretation occurs in their comment: 'It makes no sense to sacrifice strong disciplinary research because of a perceived imperative for interdisciplinary work'. We actually wrote that 'Disciplinary science should therefore not be discouraged but much greater emphasis must be placed on….interdisciplinary science' and other statements recognising the role of disciplinary science. They wrote 'they assume an unrealistic linearity in the way that science translates to policy and management'. We make no such assumption and the stakeholder model, our recommended scientific approach, encourages an interactive, evolutionary and non-linear approach in addressing problems and searching for understanding and solutions.

They argue that there is no real difference between pure and applied science and that pure cannot be considered superior but elsewhere indicate that they, erroneously, indeed consider actionable science to be inferior, claiming that curtailing basic science would trap science in a 'quagmire of low innovation' and that a focus on actionable science would 'result in the loss of much foundational knowledge and important skills, and risk degrading scientific capacity'. Statements such as these are incorrect and demonstrate their limited knowledge of the scope and nature of actionable science.

Glassom et al.'s statement 'Constraining research and teaching to conform to a narrow, short-term political or social agenda …' is also misleading. Actionable science presents opportunities to engage in a vast and complex realm, requiring not only standard skills of basic science but new, evolving skills and practices (see for example Moore et al.[3] and Palmer[4]). The only fundamental difference between actionable science and basic science is intention: the former is designed to be directly relevant to pressing societal needs. In the South African small pelagic fishery, for example, actionable science ranges from genetics and parasitology to socio-economic conditions of seasonal workers.

We do not dispute that basic science can sometimes lead to societal benefits but the cherry-picking of examples by Glassom et al. is unconvincing, as is their emphatic statement that 'innovation is far more likely to come from basic research than from applied or actionable research', referring to a 1942 biography of J.J. Thompson. They report that basic research may provide an annual 20–60% return on investment, referring to a paper by Press.[5] Those estimates originate from a paper by Salter and Martin[6] in which these authors criticised such quantitative estimates, reporting that estimating the true benefits is very difficult. The authors concluded that basic research, which they define broadly, can lead to significant benefits but the manner in which this occurs, and the extent and conditions for benefits to be achieved, are far from straightforward. Salter and Martin[6] raise many issues relevant to an assessment of the optimal use of public funds for research.

Glassom et al. also argue that actionable science will frequently not have the desired impacts because of vested interests, and that interdisciplinary science will be difficult. We do not disagree, but these arguments simply reinforce the need for actionable science, with ongoing innovation to strengthen its impacts. High-quality actionable science is not sufficient to achieve society's goals, but is an essential requirement. It is precisely because of vested interests that scientific rigour and objectivity remain paramount, which engagement with stakeholders should never compromise. Research capacity is known to be stagnating or declining in several key South African government departments because of budget constraints – the potential implications of which are alarming. Surely, all public implementers and sponsors of science need to consider how they are currently contributing to sustaining national capacity for actionable science, and where they can improve to avoid those likely dire consequences?

Finally, Glassom et al. refer to the National Research Foundation (NRF) scoring system for funding applications. We criticised NRF's criteria used to rate scientists, not necessarily those for other funding opportunities; however, a 10% allocation to 'impact on society' is nevertheless woefully inadequate given the enormous challenges to be addressed in South Africa.

Conclusions

There are other areas where we disagree. We conclude that nothing in Glassom et al.'s response justifies significant changes to the conclusions and recommendations in our paper. Prospect theory tells us that humans tend to prefer the status quo rather than risks of change, but our recommendation to scientists who are not already there, and to public funders of science in South Africa, is to step into the world of actionable and integrated science. The science is exciting and innovative, and more likely to make a difference in a world urgently requiring scientific intervention and advice for our marine environments.

References

1. Cochrane KL, Sauer WHH, Aswani S. Science in the service of society: Is marine and coastal science addressing South Africa's needs? S Afr J Sci. 2019; 115(1/2), Art. #4418, 7 pages. https://doi.org/10.17159/sajs.2019/4418
2. Glassom D, Scharler UM, Macdonald AHH. Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019). S Afr J Sci. 2019;115(7/8), Art. #6294, 3 pages. http://doi.org/10.17159/sajs.2019/6294

3. Moore JW, Nowlan L, Olszynski M, Jacob AL, Favaro B, Collins L, et al. Towards linking environmental law and science. FACETS. 2018;3:375–391. https://doi.org/10.1139/facets-2017-0106

4. Palmer MA. Socioenvironmental sustainability and actionable science. Bioscience. 2012;62:5–6.

5. Press WH. What's so special about science (and how much should we spend on it?). Science. 2013;342:817–822. https://doi.org/10.1126/science.342.6160.817

6. Salter AJ, Martin BR. The economic benefits of publicly funded basic research: A critical review. Res Policy. 2001;30:509–532. https://doi.org/10.1016/s0048-7333(00)00091-3

AUTHORS:
Donrich Thaldar[1,2]
Julian Kinderlerer[1,2,3]
Sheetal Soni[1,2]

AFFILIATIONS:
[1]School of Law, University of KwaZulu-Natal, Durban, South Africa
[2]African Health Research Flagship, University of KwaZulu-Natal, Durban, South Africa
[3]Department of Commercial Law, Faculty of Law, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Donrich Thaldar

EMAIL:
thaldard@ukzn.ac.za

HOW TO CITE:
Thaldar D, Kinderlerer J, Soni S. An optimistic vision for biosciences in South Africa: A response to the ASSAf report on human genetics and genomics. S Afr J Sci. 2019;115(7/8), Art. #6146, 1 page. https://doi.org/10.17159/sajs.2019/6146

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
Constitution; regulatory environment; health care; ubuntu

PUBLISHED:
30 July 2019

An optimistic vision for biosciences in South Africa: A response to the ASSAf report on human genetics and genomics

The Fourth Industrial Revolution is upon us. One of the pillars of the Fourth Industrial Revolution is the biosciences. What will South Africa's role be in the new global bio-economy?

Our vision for South Africa is to have a vibrant bioscience research community that competes with the best in the world; a bioscience research community that is inspired to develop cures for diseases and improve people's lives; a bioscience research community that is attuned and responsive to local healthcare needs.

How can this vision be brought about? The answer is multifaceted, but includes a *regulatory environment* that is conducive to realising this vision. Such a regulatory environment must first and foremost be legally and ethically aligned with the Constitution. This means that the bioscience regulatory environment must give proper weight to, inter alia, the rights of research participants, the rights of researchers, and everyone's right of access to health care – and establish a reasonable balance between relevant rights.

Recently, the Academy of Science of South Africa (ASSAf) published a report[1] entitled *Human Genetics and Genomics in South Africa: Ethical, Legal and Social Implications*. The objective of this report was to inform the genetics and genomics regulatory environment in South Africa. But, is the ASSAf report itself legally and ethically aligned with the Constitution? We must express our reservations.

Although we commend the ASSAf report's engagement with the value of ubuntu, the lack of specificity in terms of which the ASSAf report interprets ubuntu is problematic. There are a variety of interpretations of ubuntu, with some being vague or otherwise questionable guides for public policy. For example, the ASSAf report mentions that, by some understandings of ubuntu, 'the task of the individual is to maintain a good relationship with the visible and the invisible worlds', the latter including the 'living-dead'. Such interpretations of the nature of reality and of how to live one's life are highly contested grounds for public policy in a pluralist, multicultural society such as South Africa. Repeatedly describing the ASSAf report as a 'consensus study' and 'consensus report' threatens to mask the real disagreements that may legitimately exist in our society. By positing ubuntu as a central value for informing the genetics and genomics regulatory environment in South Africa, but failing to propose a clear and specific interpretation of ubuntu, the ASSAf report offers a vague and confused vision for bioscience in South Africa.

Moreover, from a constitutional perspective, ubuntu can assist as a lens through which rights are interpreted, but cannot be a substitute for proper legal analysis of relevant constitutional rights. Although the ASSAf report makes several references to the Constitution and to rights, its legal analysis is thin. This is reflected in the fact that only four legal cases are cited in the entire 125-page report. It is especially worrying that the ASSAf report did not even mention the *constitutional right to freedom of scientific research*. How can ASSAf explain this cavernous omission?

The flourishing of our bioscience researchers is an essential part of our vision for a vibrant bioscience research community in South Africa. Moreover, the flourishing of our bioscience researchers is a human rights issue: If we take our Constitution seriously, the freedom of scientific research of bioscience researchers must be taken seriously, and considered *together* with other relevant rights and values.

The ASSAf report draws an analogy between people's genetic information and natural resources like water and minerals. The ASSAf report even refers to people's genetic information as 'genomic resources'. In what way is an individual's genetic information (something *personal*) the same as water or minerals (something *impersonal*)? This analogy is not only flawed, but dangerous. The ASSAf report proceeds to recommend that the *state* should manage the 'exploitation, protection, sustainability, and fair access to' these 'genomic resources'. Why should the state control the use, in research, of an individual's genetic information? It is hard to see how this proposed state control of individuals' genetic information can ever be squared with the individual's constitutional rights to human dignity and privacy. This natural-resource view of people's genetic information proposed by the ASSAf report reduces the individual to a mere carrier or container of a state-controlled resource. This dystopian vision offered by the ASSAf report undermines its ethical and legal credibility.

The state control of individuals' genetic information proposed in the ASSAf report appears to be based, at least in part, on the simplistic and incorrect characterisation of collectivism as being more authentically 'African' than individualism. Contemporary African value systems are diverse and not monolithic, and are dynamically evolving. The ASSAf report appears to conflate humaneness with collectivism. These are two completely different concepts. A collectivist state may strive to be humane, but also may not. History abounds with examples of inhumane collectivist states. Conversely, states that uphold individualism – the moral worth of the individual – can simultaneously strive to promote the value of humaneness amongst its people and in its law. Is this not the Constitution's aspiration for South Africa?

Will South Africa ride the wave of the Fourth Industrial Revolution? Will our regulatory environment be an effective launchpad for responsible, world-class bioscience research in South Africa? There are many factors that impact on this question, but here we make a simple, perhaps obvious, point: the development of South Africa's bioscience regulatory environment needs to be informed by thorough analysis of legal authority, and a balanced consideration of relevant constitutional rights and values. Sadly, the ASSAf report fails, in a fundamental way, to provide either of these. In contrast with the bleak vision offered by the ASSAf report, we offer an *optimistic* vision – a vision that is aligned with the individual freedoms and rights protected in our Constitution.

Reference

1. Academy of Science of South Africa (ASSAf). Human genetics and genomics in South Africa: Ethical, legal and social implications. Pretoria: ASSAf; 2018. http://dx.doi.org/10.17159/assaf.2018/0033

AUTHORS:
Michael S. Pepper[1,2]
Collet Dandara[3]
Jantina de Vries[4]
Amaboo Dhai[5]
Melodie Labuschaigne[6]
Freddy Mnyongani[7]
Keymanthri Moodley[8]
Antonel Olckers[9]
Anne Pope[10]
Raj Ramesar[11]
Michèle Ramsay[12]
Wayne Towers[13]

AFFILIATIONS:
[1]Institute for Cellular and Molecular Medicine, Department of Immunology, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa
[2]South African Medical Research Council Extramural Unit for Stem Cell Research and Therapy, University of Pretoria, Pretoria, South Africa
[3]Division of Human Genetics, Department of Pathology and Institute of Infectious Disease and Molecular Medicine, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa
[4]Department of Medicine, University of Cape Town, Cape Town, South Africa
[5]Steve Biko Centre for Bioethics, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[6]Department of Jurisprudence, School of Law, University of South Africa, Pretoria, South Africa
[7]School of Law, University of KwaZulu-Natal, Durban, South Africa
[8]Centre for Medical Ethics and Law, Department of Medicine, Faculty of Health Sciences, Stellenbosch University, Stellenbosch, South Africa
[9]DNAbiotec (Pty) Ltd, Pretoria, South Africa
[10]Emeritus Associate Professor, Department of Private Law, Faculty of Law, University of Cape Town, Cape Town, South Africa
[11]MRC/UCT Research Unit for Genomic and Precision Medicine, Division of Human Genetics, Institute of Infectious Diseases and Molecular Medicine, University of Cape Town, Cape Town, South Africa
[12]Sydney Brenner Institute for Molecular Bioscience, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[13]Africa Unit for Transdisciplinary Health Research (AUTHeR), North-West University, Potchefstroom, South Africa

CORRESPONDENCE TO:
Michael Pepper

EMAIL:
michael.pepper@up.ac.za

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

An optimistic vision for biosciences in South Africa: Reply to Thaldar et al. (2019)

Our reply to Thaldar et al.'s[1] response to the ASSAf report[2] on human genetics and genomics focuses on two elements of the Report which they highlight, namely ubuntu and sovereignty. The lack of engagement with other issues raised by Thaldar et al. does not acknowledge agreement with those views.

Ubuntu

Thaldar et al. state that there is no role for the value of ubuntu in the era of the Fourth Industrial Revolution; that the concept, insofar as it reflects African values, as presented in the ASSAf report, is either vague or provides questionable guidance for public policy. The undertone to this assertion appears to be that African values have no relevance in the Fourth Industrial Revolution era, particularly for competing against the best in the world.

We hold a different view as was expressed in the Introduction to Respect for Persons (p.42) where we note that 'respect for persons requires that the interests and rights of both the individual and the collective, specifically those relating to autonomy, privacy, confidentiality and access to the benefits arising from research results, are recognised and protected in a balanced, reasonable and justifiable manner'. Further, the notion of 'relative solidarity' appears to have been misconstrued by Thaldar et al. The recent article by Ogunrin et al.[3] was referred to in the Report to emphasise that generalisations, including those about ubuntu (p.41), are undesirable. Ogunrin et al. describe empirical research conducted in Nigeria which found that younger people and urban populations may value self-interest and individual rights more than the common good approach, espoused in the traditional concept of ubuntu. We acknowledge that neither South Africa nor the African continent is culturally homogeneous.

Sovereignty

A consensus study will provide a consensus if one can be reached and, where this is not the case, differing views are presented. The sovereignty issue illustrates a topic that did not lead to consensus. Thaldar et al. have, however, limited their comments to only one section of the discussion on this topic i.e. that presented on p.85 and p.86.

On p.85, we suggest that the State might take responsibility for 'providing the infrastructure to govern and manage access to and (re)use of samples and data', and we draw an analogy with 'the notion of State custodianship (similar meaning to stewardship) of natural resources'. We then point out that 'Infrastructure and governance systems are designed to manage exploitation, protection, sustainability and fair access to those resources and a form of redistribution or benefit sharing'. We conclude by noting that: 'There is no obvious reason, thus, why stewardship of genomic resources should not successfully recognize sovereignty over genomic resources in light of stewardship principles'. A number of other views are presented in the paragraphs that follow. The 12th recommendation at the end of the section (p.91–92) provides a balanced consensus view on this complex topic in which we recommend the following:

> *Debate, explore and adapt the 'sociologically informed model' for the principles of (a) custodianship/ownership of samples and (b) benefit sharing in South Africa. Include relevant stakeholders like the National Intellectual Property Management Office (NIPMO) and the South African Law Reform Commission, since the topics affect a cascade of implications: ethical values of equity and distributive justice; good governance principles of benefit sharing; whether intellectual property can exist if genomic resources are to be regarded as a 'common good'.*

We welcome critical engagement by others with the contents of the ASSAf report. Readers are encouraged to read and assess the Report in its entirety.

References

1. Thaldar D, Kinderlerer J, Soni S. An optimistic vision for biosciences in South Africa: A response to the ASSAf report on human genetics and genomics. S Afr J Sci. 2019;115(7/8), Art. #6146, 1 page. https://doi.org/10.17159/sajs.2019/6146
2. Academy of Science of South Africa (ASSAf). Human genetics and genomics in South Africa: Ethical, legal and social implications. Pretoria: ASSAf; 2018. http://dx.doi.org/10.17159/assaf.2018/0033
3. Ogunrin O, Woolfall K, Gabbay M, Frith L. Relative solidarity: Conceptualising communal participation in genomic research among potential research participants in a developing sub-Saharan African setting. PLoS ONE. 2018;13(4), e0195171, 18 pages. https://doi.org/10.1371/journal.pone.0195171

HOW TO CITE:
Pepper MS, Dandara C, De Vries J, Dhai A, Labuschaigne M, Mnyongani F, et al. An optimistic vision for biosciences in South Africa: Reply to Thaldar et al. (2019). S Afr J Sci. 2019;115(7/8), Art. #a0312, 1 page. https://doi.org/10.17159/sajs.2019/a0312

KEYWORDS:
ubuntu; sovereignty; human genomics

PUBLISHED:
30 July 2019

AUTHORS:
Clarisa Sutherland[1]
Ericka N. L'Abbé[1]

AFFILIATION:
[1]Physical Anthropology Section, Department of Anatomy, University of Pretoria, Pretoria, South Africa

CORRESPONDENCE TO:
Clarisa Sutherland

EMAIL:
clarisa.sutherland@up.ac.za

DATES:
Received: 13 Oct. 2018
Revised: 18 Mar. 2019
Accepted: 19 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Sutherland C, L'Abbé EN. Human evolution in the South African school curriculum. S Afr J Sci. 2019;115(7/8), Art. #5672, 7 pages. https://doi.org/10.17159/sajs.2019/5672

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☒ Not applicable

EDITORS:
John Butler-Adam
Maitumeleng Nthontho

KEYWORDS:
Life Sciences literacy; science education; Social Darwinism; evolution education; Life Sciences curriculum

FUNDING:
National Research Foundation (South Africa)

Human evolution in the South African school curriculum

A decade after the introduction of the topic into the South African public school curriculum, the theory of evolution by natural selection is poorly understood among those who teach it, and that flawed understanding is transferred to those attempting to learn it. The curricula, support material and textbooks designed to underpin teaching and learning of evolution are often inaccurate. Deeply held religious views in the country, especially Christianity, remain a stumbling block towards understanding and accepting evolution. The lack of scientific literacy allows for the continuation of Social Darwinism and racial stereotypes and deprives the victims of those ills of the knowledge and mechanisms of thought to counter these ideas. This review explores the relatively sparse but nevertheless well-conducted research into evolution education in South Africa. We conclude that an understanding of human evolution is essential to the country's growing democracy because it provides a framework within which South Africans can understand and appreciate the diversity and heterogeneous nature of our society.

Significance:

- Various obstacles in the teaching and learning of evolution are identified, and generalisable recommendations are provided to improve evolution education on a practical level.
- Evolution education is important for the South African public: to take pride in our rich fossil resources; to understand and appreciate human diversity; to dispel the racist myths of Social Darwinism; and to ensure the success of our education system by teaching the consilience of induction and logical reasoning.
- This synthesis of the research provides a starting point for anyone wanting to conduct evolution education research in South Africa in the future, specifically those in the fields of curriculum reform, life sciences or biological anthropology.

Introduction

The ability to discuss and debate controversial topics fairly, logically and democratically, is necessary for democracy to work.[1] One such topic is human evolution. Any accurate account of human evolution must be Africa-centred, and a thorough understanding of the concept will allow South Africans to appreciate the vast human diversity, socially and biologically, of our heterogeneous population. Research has shown that even small educational programmes can change students' attitudes towards human variation.[2] To escape the vestiges of Social Darwinism still prevalent in South African society, we need to cultivate a society that is scientifically literate, that understands human variation through the framework of human evolution and that can discuss and debate these issues effectively.

The aim of this review was to summarise and synthesise the research that has been undertaken on evolution education in South Africa. We highlight the interventions, observations and suggestions for education discussed in each study and interpret them within the larger contexts of South African history and evolutionary theory.

During apartheid, South Africa's school system was segregated into the National Education System (based on Christian National Education (1967–1994)) and the Bantu (sic) Education System (initiated in 1952). Science education was discouraged in the Bantu (sic) Education programme, and when taught, was done so in a hyper-factualised manner, one non-conducive to learning.[3,4] While science education was allowed under Christian National Education, the science of evolution specifically was ignored. The 'hidden' curriculum during this time made creationism, patriotism, race relations and religion part of the everyday school experience of white learners.[3]

Until 1994, evolution was seldom mentioned in South African government schools, because the laws of the country, and thus the state education system, were founded on strict Calvinism, which dictated the absolute sovereignty of the Christian god.[5] Evolution was mentioned in the state school curriculum only once in 1947, as part of an overview of historical figures. Despite the fossil evidence of early humans reported by South African universities at the time, even this one mention of evolution was removed in the 1950s in favour of a creationist approach.[3]

In 1925, when Raymond Dart introduced to the world what was dubbed the 'Taung child' – the fossilised skull and endocranium of an *Australopithecus africanus* – Jan Smuts, then President of the South African Association for the Advancement of Science, noted that the discovery vindicated Darwin's insights, and observed that it was likely that modern humans arose as a species in Africa, and not Asia or Europe as was previously believed.[6] Although neglected in schools, palaeoanthropology in South Africa has generally taken for granted the significance of evolutionary theory, and in some South African universities, notably the University of the Witwatersrand, the study of hominin fossils has flourished. This acceptance allowed the country to exploit our rich fossil resources as well as to produce appropriate scientists to study them. These well-trained palaeoanthropologists provided a stabilising influence to the otherwise vociferous advocates of eugenics and biological determinism in South Africa. However, while intellectuals at South African universities studied these remarkable finds, the South African school system, and the public emerging therefrom, grew ever more distrusting of the science. Consequently, the gap between scientists and the public widened.[4]

One of the first tasks of the democratically elected government in 1994 was to reform education, with the goal of producing internationally competitive, literate, creative and critical citizens.[5,7] Curriculum reform took place in

three stages[8]: (1) racist and sexist language, as well as outdated and controversial subjects, were removed from syllabi; (2) curricula design was according to an outcomes-based education model called Curriculum 2005, which was intended to change the education system in such a way that learners not only gained knowledge, but also acquired the skills to use the knowledge to reach certain outcomes; and (3) Curriculum 2005 was reviewed before implementation, resulting in the Revised National Curriculum Statement: Natural Sciences for Grades R–9[9] and the National Curriculum Statement for Grades 10–12[10]. These curricula were implemented gradually: Grades 1–3 in 2004, Grade 6 in 2005, Grades 7 and 10 in 2006, Grades 8 and 11 in 2007, and Grades 9 and 12 in 2008.[8]

In the National Curriculum Statement, the word 'evolution' was carefully avoided until Grade 12, where about 40 hours of teaching time (25% of the Grade-12 Life Sciences curriculum) was dedicated to concepts relevant to evolution.[11] Since 2008, the Life Sciences curriculum for Grade 12 has included all the basic aspects of evolutionary theory, including: an overview of the history of evolutionary thought including Darwin's and related theories of scientists other than Darwin, biological evidence for evolution by natural selection, the mechanisms of micro- and macro-evolution, mass extinctions and hominin evolution.[8,11]

Despite the progress made in South Africa in including evolution in the curriculum, understanding and acceptance of the topic is still low in the country. Research has shown that many people nowadays react to the theory of evolution much as they did during Darwin's time – they are distrustful and disbelieving and greatly resistant to change.[12] As a result, many teachers, schools and school systems in South Africa either avoid teaching evolution (even though it is included in the set curriculum), or do not teach it appropriately.[11] This problem is compounded by the fact that evolution is an inherently difficult concept to teach and to learn.[8] The lack of education, along with sometimes deliberate misdirection, has, regrettably, fuelled the growth of misconceptions and distrust in evolutionary theory.[11]

Problems with the teaching and learning of evolution have been well documented in other countries, especially in the United States of America, and review articles provide much valuable information about how we might improve evolution education.[13] A major difficulty in the science education system in South Africa is one of justice. If learners are denied access to higher-order thinking skills such as the consilience of inductions (combining multiple disparate avenues of evidence into a coherent theory[5]), and a correct understanding of subjects like evolution, the social justice imperative that frames the national Curriculum Statement is undermined[1,4,5]. Moreover, misconceptions around evolution often result in further learning problems when scientifically incorrect prior knowledge is committed to long-term memory and functions as the basis for further learning.[14]

Methodology

The following is a critical review of the evolution education research done in South Africa thus far as published in peer-reviewed journals. Additional criteria for inclusion in this review were:

- studies on evolution as the subject of instruction in formal institutions of learning;
- observational or intervention studies done on a South African sample; and
- studies with samples or subjects being South African curriculum documents and/or textbooks, or South African school learners or teachers, and/or South African university students and/or lecturers, respectively.

Google Scholar was used to conduct a preliminary literature search with the following search terms: "Evolution Education in South Africa", "Teaching Evolution in South Africa", "Learning Evolution in South Africa" and "South African Evolution Curriculum". Each search was extended up until the 10th page of search results. The results generally referred to the word 'evolution' as it relates to change (notably referring to the political environment in the country and South African curriculum reform), the evolution of South African animals, the geological changes related to South African environments or one of the fossil finds credited to South African sites.

All relevant and accessible articles were downloaded.[3-5,15,16] Those relevant articles that were not accessible were retrieved through a library request or via the specified journal platform. The literature referenced by the preliminary articles was then used to find further relevant research.

Review

The search resulted in a total of 14 publications dating from 1994 to 2016. It should be noted that there may have been more than these publications that were not found through our methodology. One of the publications is a compilation of 13 chapters on work of the Human Sciences Research Council.[6] While this publication was valuable for contextualising the other research, it did not comply with the inclusion criteria and was thus excluded. The remaining 13 publications are journal articles. Of these, three studies analysed the influence of textbooks and the curriculum statement on learning evolution[5,14,17]; four focused on teacher reactions to and acceptance of teaching evolution[1,3,4,11]; and six studies reported on student reactions to, and acceptance of learning about, evolution[8,15,16,18-20].

Research based on text analyses

In analyses of textbooks and curriculum statements[5,14,17], it has been found that the evolution curriculum and the evolution content in textbooks often achieve the opposite of what is desired: that is, they perpetuate misconceptions and unscientific ideas about evolution by using improper and misleading terminology and by reporting inaccurate information.

Teachers rely on the set curriculum and other educational resources for guidance on how to facilitate learning, especially during periods of curriculum reform.[17] In the case of evolution, many teachers lack the content knowledge and training to teach the topic and, therefore, rely heavily on the prescribed texts for the content, learning activities and assessments needed to facilitate learning.[3,11,14,17]

A *misconception* is a false or mistaken view or opinion and can be formed in two major ways: *acquired errors* or *true misconceptions.*[14] An acquired error is when incorrect ideas are taken up from an external source through rote learning – the idea is acquired verbatim from a parent, teacher or textbook and integrated into an individual's existing cognitive structure. True misconceptions are formed when individuals attempt to meaningfully incorporate an idea into their cognitive structure to form a mental model or schema, but the idea is misinterpreted, and becomes scientifically incorrect.[14]

Teachers who hold misconceptions about evolution are unable to identify and filter out these misconceptions from inaccurate textbooks.[14] In fact, these personally held biases might be reinforced by seeing the same misconceptions and scientific inaccuracies reproduced in print. In many cases, unscientific ideas are not the result of mistaken interpretation by students (*true misconceptions*), but the misdirection perpetuated by inaccurate textbooks, support material, curricula and teachers (*acquired errors*).[14]

Many of the misconceptions and unscientific ideas in evolution education emerge when curriculum slippages occur.[17] Curriculum slippages are small distortions between the initial ideal (and often idealised) curriculum and the curriculum as it is experienced by the learner. The *ideal curriculum* is the initial curriculum as it was envisioned during the planning phase. Planners attempt to capture this ideal in paper form, and this written version becomes the *formal curriculum* in all policy documents. The *perceived curriculum* is created from the *formal curriculum* when textbook authors and publishers interpret the policy documents in their own way. The textbooks and lesson plans from publishers are used in the classroom and the *enacted curriculum* becomes the *experienced curriculum* as learners participate in the learning environment.[17]

Scientifically incorrect statements (or *manifest errors* – errors that are obvious and easily identified) were found in every document analysed

in all three text-analysis studies. These studies included the formal curricula – Natural Sciences Learning Statement (Grades R–9, with Grades 7–9 analysed by two different authors)[9] and the Life Sciences Subject Statement (Grades 10–12)[10] – as well as perceived curricula – eight recommended Life Sciences textbooks in total[5,14,17].

Manifest (or actual) errors in curricula or support material were commonly characteristic of one of two alternative frameworks: 'evolution on demand' and 'survival of the fittest'. An alternative framework is an unscientific way of thinking that can generate many different individual misconceptions.[14,17]

'Evolution on demand' is characterised by teleological (explaining phenomena by the purpose they serve rather than their actual causes) and anthropomorphic (attributing human characteristics and behaviour to objects or animals) thinking. Five common unscientific ideas about adaptation fall into this framework[14]: (1) changing food types or environments cause evolution to occur; (2) individuals evolve (3) within their lifetime and (4) they decide to undergo these changes because they know the changes will be favourable; and 5) this evolution occurs in order to prevent extinction.

The alternative framework 'survival of the fittest' implies that[14]: (1) only the fittest, or those with favourable adaptations, survive; (2) less favourably adapted organisms will die or become extinct; (3) only the fittest will reproduce, while those not considered fit cannot reproduce; (4) all the offspring of those with favourable traits will inherit the favourable traits; and (5) the whole population will eventually be made up of only individuals with favourable traits. In addition to these manifest errors, in very few of the texts, was identification of common misconceptions attempted, despite having multiple opportunities to do so.[14]

More dangerous than the obvious and easily identifiable manifest errors, are *latent errors*. Latent errors are not errors per se, but rather seemingly harmless statements that might be misinterpreted by readers and thus contribute to the development of true misconceptions. Latent errors can result from the way the text is structured, as is the case with fragmentation and sequencing issues, or they can emanate from misleading and improper use of language.[17]

Text analyses have shown that the curricula and supporting material that underpin learning of evolution are fragmented into different phases and strands, which inhibits learners from understanding evolution holistically.[5,14,17] Evolution topics are also unequally distributed in difficulty, especially across Grades 10–12.[8] In addition to curriculum fragmentation, is the problem of inappropriate sequencing, where the concepts required to understand evolution are not addressed in a logical order, in addition to being fragmented.[14,17]

The concept of evolution by natural selection was originally formulated by using the consilience of inductions.[5] The consilience of inductions is an important skill for learners to master, not only in order to understand the theory of evolution, but also in order to guide their own logic of thought. Learners who are subjected to a fragmented curriculum and are not equipped with the skills necessary to perform the consilience of inductions will inevitably fail to create holistic mental models (schema) in order to correctly incorporate evolution into their knowledge base.[5] Language-related latent errors include poor to incomplete explanations and misleading wording, especially the use of paradoxical jargon (or risk terms), metaphors and euphemisms.

Misleading wording conveys inaccurate ideas which can lead to the formation of true misconceptions. This scenario occurs when a word has two meanings: one everyday and one specific to the science of evolution – these are called *risk terms*. Two examples of these risk terms are 'organism' and 'adapt'. Individual organisms do not adapt to their environment.[14] Rather, individual organisms can *acclimatise* or *adjust* to their environment within a single lifetime, while populations *adapt*, over many generations. Textbooks and learning material often imply that individual animals can choose to change to fit into their environment in an attempt to survive (as is seen in the 'evolution on demand' alternative framework). This implies that individual organisms have internal agency and believing this can lead to teleological misconceptions.[16] Use of these risk terms are often latent errors, but when used consistently without explanation, can contribute to manifest errors in the text.

Metaphors are commonly used to draw parallels between situations and euphemisms are used to avoid terms that might seem blunt or offensive. In their analyses, Dempster and Hugo[5] found that the word 'evolution' is specifically avoided in favour of terms like 'change' and 'development' until Grade 12, when considerable time is allocated to the topic (25% of the Life Sciences curriculum). They note that learners are taught the principles of evolution early on, without appreciating that they are learning about evolution.[5] Up until their last year of school, Life Sciences learners are therefore unaware that they have learnt about evolution at all. By denying learners meaningful access to higher-order thinking skills, the social justice imperative stated in the National Curriculum Statement is undermined.[5]

Perspectives from teaching and learning

Life Sciences teachers in South Africa are averse to teaching evolution mainly because they lack the content knowledge to do so and they are concerned about the controversial nature of the topic, specifically as it relates to religion.[11] Some teachers experience a conflict between their own religious beliefs and the requirement to teach evolution and some are worried about parents' and students' attitudes towards evolution.[3,4,11] Teachers in religious schools especially are faced with anti-evolution policies.[11,20] As a result of poor evolution education in schools (and before 2008, no evolution education in state schools), students arrive at university without adequate prior content knowledge or scaffolding on which to build learning of evolution, further complicating higher instruction.[4] Without proper teacher education, the legacies of Social Darwinism and a general mistrust in science will prevail in South African society.[4,5]

Teachers are unequipped to teach evolution

The Department of Basic Education has established various teacher training programmes since evolution entered the Life Sciences curriculum. One such programme was conducted by Sanders and Ngxola[11], who used a convenience sample of 125 secondary school Life Sciences teachers from a series of workshops designed to prepare them to teach evolution for the first time. They found that many teachers, schools and entire school districts simply omitted subject areas with which they felt uncomfortable. From one of these workshops emerged the disturbing admission that almost half of the 70 Grade-11 teachers in attendance omitted genetics from their teaching. Genetics is a topic that is poorly understood by many South African teachers and is not externally examined.[11] Teachers attending these workshops – actively practising teachers – knew that they were unequipped to teach evolution.

In a survey of student teachers who were not yet practising educators, 70% of respondents considered themselves prepared to teach evolution, even though the data show that they did not understand evolution or even the nature of the science well enough to teach it.[3] Many respondents held common misconceptions about evolution, such as: evolution is the purposeful development of higher forms; or humans developed from other primates like chimpanzees and gorillas.[3]

Teachers are afraid of controversial subjects

Not only do teachers themselves not have the subject knowledge to teach evolution (whether they realise it or not), but they also face the ever-present concern that evolution is a controversial topic.[1,11] Controversy is generally seen in a negative light because of the conflict it might cause. However, the ability to discuss controversial topics in a logical, respectful and insightful manner forms a cornerstone of democracy. South Africa's democracy is relatively young, and in many aspects still incomplete. True democracy requires an informed citizenry, in which individuals are capable of making wise and informed choices and behaving in a democratic manner in their daily lives.[1]

As with the lack in content knowledge, South African teachers are not trained to facilitate the discussion of controversial topics in the classroom. Indeed the complete avoidance of the topic of evolution, along with other

controversial topics such as race, sexuality, sex education, corporal punishment and xenophobia reflects this inability.[1,14,17]

Two major obstacles identified by teachers in regard to facilitating discussions about controversial topics are (1) the limited time allocated to teach and (2) the methods of assessment used to gauge learning.[1,11] Very little time is afforded to educators to ensure that all the curriculum content is covered – content which is later assessed through high-stakes assessments. In interviews with teachers and students at schools in South Africa and those in England, Chikoko and colleagues[1] found that schools and universities are likened to factories in which time constraints and standardised assessments produce graduates like products on a factory line. Both students and teachers are afraid to broach controversial issues in the classroom for fear of persecution. From the students' perspective, they might lose marks they need to achieve a pass in a subject. Teachers, on the other hand, want to maintain a closed and safe environment for fear of legal action from students, the school or parents.[1] Such an environment is non-conducive to open discussion and sets a bad example of democratic behaviour.

Contention with religion

A worldview is the lens through which we see the world and the filter through which we process information. A person's worldview predisposes them to a specific way of thinking that is constructed through life experiences.[13,19,20] Worldviews are generally subconscious, culturally dependent and non-rational.[13] They form the fundamental organisation of a person's mind and create the assumptions that predispose a person to think, feel and act in a predictable manner.[13] A person's worldview determines how they will gauge the plausibility of an assertion, thus providing a *plausibility structure* of ideas, activities and values.[21] *Confirmation bias* is when a person values evidence that reinforces beliefs already held and ascribes more legitimacy to experts who agree with them and share their beliefs. People are predisposed to reinforce their connection with those with whom they share important commitments and to reject claims that might separate them from their peers.[13]

Science and religion influence the way in which people view the world. A theistic worldview is often built on a framework of faith-based, absolute and unchanging knowledge from a higher power or creator. In contrast, the worldview that underpins science is generally inherently materialistic and requires observation and iterative empirical testing to produce knowledge that is, in turn, constantly subjected to doubt. It is, however, possible to accept two opposing worldviews at the same time. Conversely, someone might reject an idea as untrue simply because it opposes their worldview.[19]

Sanders and Kagan[20] use the framework of border crossing to explore the understanding and acceptance of evolution among Grade-12 students in a Jewish school. Border crossing is an apt framework to use when one considers science and religion as two different worldviews: these religious students entering a science classroom have to transition from their personal and familiar worldview to that prescribed by science, analogous to crossing the border from one's country to another. The greater the divide between the student's own personal worldview and the scientific worldview, the more challenging the border crossing becomes. Sanders and Kagan[20] use a framework with four types of border crossing, depending on the level of difficulty students face during the transition from one worldview to the other: (1) a *smooth transition* is characterised by a student who can cross the border between worldviews with ease; (2) a *managed transition* is when a student requires some adjustment to their worldview as they move into the world of science but still copes with the transition; (3) a *hazardous crossing* is when a student finds the transition extremely difficult, but still manages to cross; and (4) an *insurmountable* crossing is when a student finds the transition impossible because the value systems between the worldviews are too different.

People are generally able to distinguish between scientific and religious worldviews and a person does not need to abandon a personal worldview in order to function within a scientific worldview.[16,18,20] Although religious people might find the border crossing into a scientific worldview hazardous or insurmountable, they might still be able to maintain their own worldview outside of the science classroom. Research has consistently shown that it is possible to believe in different, contradicting, ideas at one time.[13,18] Even though an acceptance of evolution is positively correlated with understanding evolution, it is not necessary. A person can understand evolutionary theory without accepting it as true. Conversely, a person can accept evolution but not understand it.[13]

Anderson[18] examined the effect that evolutionary teachings had on students' views of god as creator and found that the teaching of evolution increased students' knowledge of evolution over a 3-year period and that it decreased students' susceptibility to logical fallacies. They also found that a belief in 6-day creationism dropped significantly in their student sample, although a belief in god as creator remained stable. Although they do not provide recommendations for teaching evolution, they do recommend that religious leaders 'do not attack evolution'[18], citing that this may heighten the perception that simultaneous beliefs in god and in evolution are incompatible. They also recommend that the Bible's version of the origin of earth should not be taught literally and that fundamentalist Christians might be at risk of losing their faith, because a literal belief in the Bible is inconsistent with the facts of evolution.[18] Anderson's[18] final recommendation advocates for an integration of evolutionary theory and faith, called theistic evolution.

Three major categories of misconceptions are formed when the theory of evolution is integrated within a faith-based religious system: essentialism, teleology and intentionality.[13] Essentialism is the belief in immutable categories or kinds – the idea that every individual belongs to a discrete and rigidly defined category based on observable properties that stem from unobservable causes; the properties are fixed, unchangeable and transmitted from parent to offspring.[13] Teleology is the idea that the form of a thing is needs based; that it was designed with a purpose in mind. Teleology explains phenomena by the purpose they serve rather than their actual causes.[13,14] And finally, intentionality is the assumption that events are purposeful and goal directed and that they are caused by intentional agency.[13]

Moore et al.[16] studied the language used when learning about evolution, employing a phenomenology-based probe to investigate the conceptions of a group of first-year university students who had not yet received any instruction in evolution. Moore and colleagues recognised that students tended to ascribe agency to the random processes of evolution – a common misconception in learning evolution. Two types of agency exist: internal agency describes when an organism drives its own change in a chosen direction, while an outside force, usually an omnipotent deity, dictates external agency.[16] In contrast to other studies, Moore et al.[16] found that students often ascribed internal agency to individuals in the language they used to describe evolution. These results are similar to those found by Sanders and Makotsa[17], who noted that this type of latent error and paradoxical jargon can lead to the development of true misconceptions about evolution.

Figurative language is potent because it may convey meaning over different contexts. This plasticity, however, carries the capacity to distort meaning.[16] Students are often unable to distinguish between the subject-specific shorthand or paradoxical jargon of a scientific field and the everyday use of figurative language.[17] Moore et al.[16] recognise the need to tailor and regulate the language and vocabulary used to teach evolution, especially when scaffolding upon terms and concepts that students already know. Employing anthropomorphised or teleological language, even figuratively, results in misunderstandings in learning.

Abrie[3] studied student teachers' attitudes toward, and willingness to teach, evolution in a changing South African environment. The sample included student teachers with no prior exposure to evolution (those graduating from National Curriculum Statement schools before 2008) who learnt about and had to teach evolution after they graduated. These student teachers were largely religious and rejected the theory of evolution. Despite their low acceptance of evolution, most (76%) agreed that it was important for Life Sciences teachers to understand the subject. Survey respondents felt that they should have the choice to not teach evolution (63%) and that learners should also be able to choose to learn evolution (44%). Only 42% of student teachers in Abrie's[3]

study thought that evolution should be a compulsory part of the Life Sciences curriculum. In contrast, 63% of student teachers supported the compulsory teaching of religion and 50% of respondents felt that evolution should be taught alongside creationism and intelligent design.

Abrie[3] also noted that deeply held religious beliefs are likely retained after instruction, even at the level of higher education, and will influence the way in which student teachers teach evolution to schoolchildren. There is no guarantee that National Curriculum Statement guidelines will be followed, and as has already been evidenced, some teachers choose to ignore the topic entirely.[3,11] This neglect has severe repercussions on student learning and achievement, especially considering that, since 2008, the higher grades are externally examined and that half of the second Life Sciences examination (25% of the Life Sciences syllabus in Grade 12) consists of content relating to evolution.[5]

In South Africa, many bridging programmes exist to remedy the lack of entry-level knowledge that students attending university are required to have. Waetjen and Parle[4] provide some reflexive insights into the practicalities of teaching evolution as part of such a bridging course called 'Africa in the World', presented in the Humanities Faculty at the University of KwaZulu-Natal. The reflective nature of Waetjen and Parle's[4] article allows them to disclose rich data about their experiences in teaching evolution. They note that African students are especially averse to learning about evolution because the topic is seen as 'Westernised science' that goes against their belief system. The irony, pointed out by the researchers, is that, beyond ancestral beliefs, the belief system in question (Christianity) is a consequence of colonisation.

The legacy of Social Darwinism

Among the difficulties of teaching evolution is the legacy of Social Darwinism, which is particularly difficult to overcome in South Africa where racialised politics have tainted the reputation of evolutionary science. Social Darwinism is the application of the concepts of natural selection to human societies. This application increases the problem of teaching evolution correctly in order to dispel harmful myths, misconceptions, prejudice and stereotypes. If discussed in class (or any environment for that matter), the topic of human origins, combined with racialised politics and an overwhelmingly fundamentalist Christian belief system, often creates heated debate.[4]

Even when using endemic examples of human fossils and highlighting the evolutionary importance of the African continent, negative portrayals of Africa and its people have left a legacy that is a significant barrier to understanding human evolution. South Africa has claim to the Cradle of Humankind, but researchers report that students see this type of publicity as an attempt to assert the 'primitiveness' of African people – a difficulty that might be overlooked when teaching evolution.[4] Some students felt that the facts of evolutionary theory portrayed African people as 'closer' to earlier species of *Homo* and instructors were accused of saying that 'Africans were closer to ape ancestors because they were still in Africa'[4]. Paradoxically, some students of the 'Africa in the World' course interpreted the adaptations of humans and their origins in Africa to mean that '…the "out of Africa" thesis was an indication that the only "pure race" was the "black man" and that "all other races" were derivatives'[4].

In order for South African democracy to function effectively, our citizenry needs to be able to celebrate social, political and biological diversity, with mutual respect and the understanding that all people, as human beings, have equal social and political rights.[1] In addition, South Africans should be able to analyse information critically, respect the evidence when forming their opinions and be willing to change their minds when presented with new and valid information.[1]

Accepting evolution

Research has shown that the views, opinions and attitudes that teachers have about a subject affect their curricular and instructional decisions. On the one hand, teachers might spend less time on a subject they do not care about, or go as far as to ignore it entirely if they feel strongly.[11] Students, on the other hand, might avoid learning about subjects they disagree with or find uninteresting.[8]

The Measure of Acceptance of the Theory of Evolution Instrument (MATE) is a well-known and often-used validated Likert-scale survey that assesses the acceptance of evolutionary theory, originally among teachers and later among students.[22] The MATE has since been updated by Cavallo and McCall[23], who added items to evaluate learner perceptions of the theory.

Mpeta and colleagues[19] used the updated MATE to assess the acceptance of evolution among Grade-12 Life Sciences students in the Vhembe District of the Limpopo Province. They found that, although most of the respondents in their sample subscribed to some form of religious worldview, almost half of the students accepted the theory of evolution as scientifically valid.[19] However, some students experienced a hazardous or even insurmountable border crossing; so opposed were they to evolution that they had no interest in learning about it. Other learners stated that their faith had weakened since learning about evolution. These results are similar to those of Anderson[18] who found that fundamentalist Christians might have trouble learning about evolution because the facts of evolution contradict their doctrine.

Chinsamy and Plaganyi[15] investigated the success of a first-year course in evolution (16 lectures, 94 students) at the University of Cape Town using a before-and-after questionnaire. Many students in their study found the evolution content interesting but were concerned with how the theory would challenge their religious views. Although an overall increase in student understanding of evolution was noted, the researchers found no statistically significant change in the acceptance of evolution.

Recommendations

In terms of recommendations for improving texts associated with teaching and learning evolution, the categorisation used by Tshuma and Sanders[14] is useful. The following list synthesises the problems identified and recommendations given in order to amend inaccurate and misleading texts in evolution education.[5,14,17]

Manifest errors:

- **Inaccuracies:** Scientific facts and terminology need to be accurate and up to date and should not include *manifest errors* (obvious and easily detectable inaccuracies).[5,14,17]
- **Not pointing out common misconceptions:** Textbooks should include a section about the misconceptions commonly associated with the mechanics of evolution and about evolution as it is seen by society.[14]

Latent errors:

- **Language errors:** Facts and processes need to be explained in scientific language, with few or no latent errors. The text should make accommodations where such errors might occur, by explaining the meaning of the terms in the correct context. Focus should be given to language differences when translating explanations into a different language might lead to latent errors.[17] Teachers should:
  - Be aware of **paradoxical jargon or risk terms** (words with more than one meaning – one everyday and one scientific, such as adapt, theory, fitness), where the scientific meaning is meant, but the everyday meaning might be used for interpretation, leading to latent errors.[14,17]
  - Avoid **metaphors** (figures of speech that use non-literal terms to represent comparable concepts), because they are open to multiple interpretations.[14]
  - Avoid **euphemisms** (milder alternatives to words that might be considered offensive), because learners might not realise that the euphemism is being used instead of another term. The word evolution is often avoided altogether, in favour of terms like 'change' and 'develop'. Learners do not realise they are learning about evolution at all, which contributes to concept fragmentation.[14,17]

- **Inadequate and poorly worded explanations:** Inadequate explanations occur when a key text lacks the information necessary for full understanding of a concept.[14,17]
- **Fragmentation:** Curriculum fragmentation should be kept to a minimum and the concepts needed to understand evolution need to be covered holistically. Evolution by natural selection should be taught as a single concept and not obscured by fragmentation in order to cultivate acceptance and foster political correctness.[5,14,17] Fragmentation includes:
  - **Not facilitating the consilience of inductions:** Learners should be taught how to form logical links between seemingly disparate topics such as geology and embryology, in order to prevent the creation of true errors (where learners integrate scientific facts into their own schema incorrectly, thereby forming misconceptions that are difficult to overcome).[5]
- **Inadequate sequencing:** The facts and concepts involved in evolution by natural selection should be covered in a logical format in such a way that learners can form meaningful links between concepts.[5,14,17]

Teacher content knowledge:

- Specific courses in evolution and the nature of science should be a requirement with supplementary training for teachers not previously exposed to the theory.
- Detailed instructional material should be made available to all teachers. This material should be prepared by professionals with knowledge about evolution and its misconceptions and good instructional practices for its teaching.
- Teachers should be knowledgeable about common misconceptions and logical fallacies, in order to filter learning material and diagnose misconceptions held by students.

Discussion of controversial issues:

- Teachers should be trained in how to facilitate discussion around controversial issues, particularly with the values of democracy in mind.
- Discussion has been proposed as an effective way of teaching the skills necessary to conduct a fair and informed debate and as a way to deal with issues of conflict.[1,11] A well-facilitated discussion is also beneficial to encourage students to engage with the content and to create an exciting, interactive and supportive learning environment.[15]
- Students are more accepting of facts than of processes, and improving the reasoning ability of students might improve their ability to grasp the processes involved in evolution.[15]

Conclusions

Evolution is a vital component of scientific literacy. It provides an explanatory framework in which to understand the complexity and diversity of life on earth and the relationships between organisms, populations and species. The theory is a powerful unifying theme that links concepts from different fields of science from biology to geology. There are various practical applications of evolutionary theory to human life, notably advancements in medicine to combat constantly evolving pathogens and understanding human diversity.[5,20]

Understanding evolution, especially human evolution, is essential to South Africa's growing democracy.[1] Controversial subjects, if taught correctly, instil upon learners the knowledge and skills they need to conduct fair, logical and democratically sound arguments. Understanding human variation is also the first step to respecting the heterogeneous nature of South African society, and can be achieved by designing and implementing proper educational strategies.[2]

A lack of scientific literacy – through choice or chance – allows for the continuation of racial stereotypes and deprives everyone of the knowledge and mechanisms of thought to counter these misperceptions.[4]

Acknowledgements

This review forms part of the larger PhD project of C.S., supervised by E.N.L. and funded by the National Research Foundation of South Africa. The PhD project has been granted ethical approval from both the PhD Committee and Research Ethics Committee of the Faculty of Health Sciences at the University of Pretoria (ethics code 390/2017). We appreciate valuable advice from Dr Werner Cordier.

Authors' contributions

C.S.: Conceptualisation; methodology; writing – initial draft; writing – revisions. E.N.L.: Student supervision; writing – revisions.

References

1. Chikoko V, Gilmour JD, Harber C, Serf J. Teaching controversial issues and teacher education in England and South Africa. J Educ Teach. 2011;31:5–19. https://doi.org/10.1080/02607476.2011.538268
2. Wilkonson TA, Štrkalj G, Gibbon VE. Teaching human variation: Can education change students' attitudes towards 'Race'? Glas Etnografskog Inst SANU T САНУ. 2007;55:253–257. https://doi.org/10.2298/gei0701253s
3. Abrie AL. Student teachers' attitudes toward and willingness to teach evolution in a changing South African environment. J Biol Educ. 2010;44:102–107. https://doi.org/10.1080/00219266.2010.9656205
4. Waetjen T, Parle J. Teaching African history in South Africa: Postcolonial realities between evolution and religion. Afr Spectr. 2005;40:521–534.
5. Dempster ER, Hugo W. Introducing the concept of evolution into South African schools. S Afr J Sci. 2006;102:106–112.
6. Lever J. The architect and the scaffold: Evolution and education in South Africa. Cape Town: Human Sciences Research Council; 2002.
7. Chisholm L. The making of South Africa's National Curriculum Statement. J Curric Stud. 2005;37:193–208.
8. De Villiers R. Student teachers' views: What is an interesting Life Sciences curriculum? S Afr J Educ. 2011;31:535–548. https://doi.org/10.15700/saje.v31n4a403
9. South African Department of Education. National policy regarding general education and training programmes: Approval of the revised National Curriculum Statement Grades R–9 (schools). Pretoria: Department of Education; 2002. Available from: https://www.education.gov.za/Portals/0/CD/GET/doc/overview.pdf?ver=2006-11-21-100143-000 (2002)
10. South African Department of Education. National Curriculum Statement Grades 10–12 (general) learning programme guidelines Life Sciences [document on the Internet]. c2003 [cited 2018 Aug 03]. Available from: http://www.eccurriculum.co.za/LifeSciences/34.01%20NCS%20LifeScience.pdf
11. Sanders M, Ngxola N. Addressing teachers' concerns about teaching evolution. J Biol Educ. 2009;43:121–128. https://doi.org/10.1080/00219266.2009.9656166
12. Rudolph JL, Stewart J. Evolution and the nature of science: On the historical discord and its implications for education. J Res Sci Teach. 1997;35:1069–1089. https://doi.org/10.1002/(sici)1098-2736(199812)35:10%3C1069::aid-tea2%3E3.3.co;2-1
13. Probiner B. Accepting, understanding, teaching, and learning (human) evolution: Obstacles and opportunities. Yearb Phys Anthropol. 2016;159:S232–S274. https://doi.org/10.1002/ajpa.22910
14. Tshuma T, Sanders M. Textbooks as a possible influence on unscientific ideas about evolution. J Biol Educ. 2015;49:354–369. https://doi.org/10.1080/00219266.2014.967274
15. Chinsamy A, Plaganyi E. Accepting evolution. Evolution. 2007;62:248–254. https://doi.org/10.1111/j.1558-5646.2007.00276.x
16. Moore R, Mitchell G, Bally R, Inglis M, Day J, Jacobs D. Undergraduates' understanding of evolution: Ascriptions of agency as a problem for student learning. J Biol Educ. 2002;36:65–71.
17. Sanders M, Makotsa D. The possible influence of curriculum statements and textbooks on misconceptions: The case of evolution. Educ Change. 2016;20:216–238. https://doi.org/10.17159/1947-9417/2015/555

18. Anderson ML. The effect of evolutionary teaching on students' views of God as creator. J Theol South Afr. 1994;87:69–73.

19. Mpeta M, De Villiers JJR, Fraser WJ. Secondary school learners' response to the teaching of evolution in Limpopo Province, South Africa. J Biol Educ. 2014;49:150–164. https://doi.org/10.1080/00219266.2014.914555

20. Sanders M, Kagan T. Use of confidence scales in analysing unscientific ideas about evolution among religious Jewish students. Afr J Res Math Sci Technol Educ. 2013;17(1–2):38–49. https://doi.org/10.1080/10288457.2013.826969

21. Aikenhead GS. Science education: Border crossing into the subculture of science. Stud Sci Educ. 1996;27:1–52.

22. Rutledge ML, Warden MA. The development and validation of the Measure of Acceptance of the Theory of Evolution Instrument. Soc Sci Math; 1999;99:13–18.

23. Cavallo AM, McCall D. Seeing may not mean believing: Examining students' understandings & beliefs in evolution. Am Biol Teach. 2008;70:522–527. https://doi.org/10.2307/27669336

AUTHOR:
Gerald J. Maarman[1]

AFFILIATION:
[1]Cardiovascular Research Group, Division of Medical Physiology, Department of Biomedical Sciences, Stellenbosch University, Stellenbosch, South Africa

CORRESPONDENCE TO:
Gerald Maarman

EMAIL:
gmaarman@sun.ac.za

DATES:
Received: 08 Mar. 2018
Revised: 10 Apr. 2019
Accepted: 12 Apr. 2019
Published: 30 July 2019

HOW TO CITE:
Maarman GJ. Cardioprotection conferred by rooibos (*Aspalathus linearis*): A mini review to highlight a potential mechanism of action. S Afr J Sci. 2019;115(7/8), Art. #4653, 4 pages. https://doi.org/10.17159/sajs.2019/4653

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☒ Not applicable

EDITOR:
John Butler-Adam

KEYWORDS:
South Africa; medicinal plants; novel heart drugs; heart research

FUNDING:
South African Rooibos Council; South African Medical Research Council; Stellenbosch University

Cardioprotection conferred by rooibos (*Aspalathus linearis*): A mini review to highlight a potential mechanism of action

A number of cardioprotective interventions have been identified throughout the years, and these include the use of natural antioxidants in sources like rooibos (*Aspalathus linearis*) tea. Recent studies have demonstrated that rooibos (either its isolated components or the crude rooibos extract/tea) confers cardioprotection in diabetic cardiomyopathy and myocardial ischaemic injury. In addition, a clinical study has shown that regular rooibos consumption reduces the risk for cardiovascular disease in adults. However, rooibos is currently not considered an official treatment against cardiac disease, mainly because the underlying mechanisms for rooibos-induced cardioprotection are not fully elucidated. Physiological actions of rooibos must be well investigated before rooibos can be used in a clinical setting as adjunct treatment for patients with heart disease. Thus, research to delineate the underlying mechanisms of rooibos-induced cardioprotection is key. In the light of the aforementioned, the available literature on rooibos-induced cardioprotection is reviewed here, highlighting the fact that rooibos preserves and maintains cardiac energy homeostasis. It is postulated that rooibos activates an AMPK-GLUT-4 glucose oxidation (cardiac energy-shortage sensing) pathway to shift cardiac energy usage, thereby conferring cardioprotection.

Significance:

- It is hypothesised that rooibos may alter the way in which the human heart uses energy and oxygen, in order to protect the heart against disease. The heart's mitochondria are responsible for the heart's energy processes, and therefore are most likely involved in rooibos-induced cardioprotection.
- Cardioprotection conferred by rooibos is likely via an AMPK-GLUT-4 glucose oxidation pathway.
- The mechanism of cardioprotection is important for future studies investigating how rooibos alters cardiac mitochondria.
- The more information gathered about the underlying mechanisms of rooibos, the easier it will be to recommend rooibos as an official cardioprotective intervention in patients with heart disease.

Introduction

Cardioprotection is the manipulation of cellular processes with various therapeutic interventions to protect the heart before, during or after disease.[1-3] These interventions include pre- and post-conditioning[4-6], remote ischaemic conditioning[4-6], and intake of antioxidants like melatonin[7,8] and rooibos (*Aspalathus linearis*)[9,10]. Rooibos is an endemic South African fynbos plant species that grows exclusively in the Cederberg mountain region.[11,12] Research investigating rooibos mainly describes the multiple biological effects of the two forms of rooibos leaf extracts: unfermented green and fermented rooibos.[13] Bioactive components within rooibos extracts/tea are categorised as polyphenols and flavonoids[14,15] and are responsible for the anti-inflammatory, anti-cancer[16,17] and antioxidant properties[13,18], of rooibos. Considering that polyphenols and flavonoids have a well-documented role in cardioprotection[19,20], rooibos extract is a possible candidate for cardioprotection[21,22].

Cumulative evidence suggests that either the individual rooibos components[9,23,24] or the crude rooibos extract/tea confers cardioprotection against heart disease in diabetes[10] and heart attacks[25]. In one recent study, rooibos conferred cardioprotection in rats that were on antiretroviral therapy and displayed myocardial ischaemic damage.[26] However, in all these aforementioned studies, the mechanisms underpinning the rooibos-induced cardioprotection were not fully understood. Considering that rooibos is reported as a cardioprotective strategy for patients with heart disease[21,22], the underlying mechanisms of rooibos-induced cardioprotection should be better understood. Without this understanding, in addition to a lack of evidence on the active ingredient(s) and safety/toxicity for patients taking heart disease medication[27], rooibos may not pass clinical standards as a cardioprotective intervention for heart disease patients. If more information were gathered about the physiological mechanisms of rooibos, there would be a solid scientific foundation for the recommendation of rooibos as an effective cardioprotective intervention in patients with heart disease.

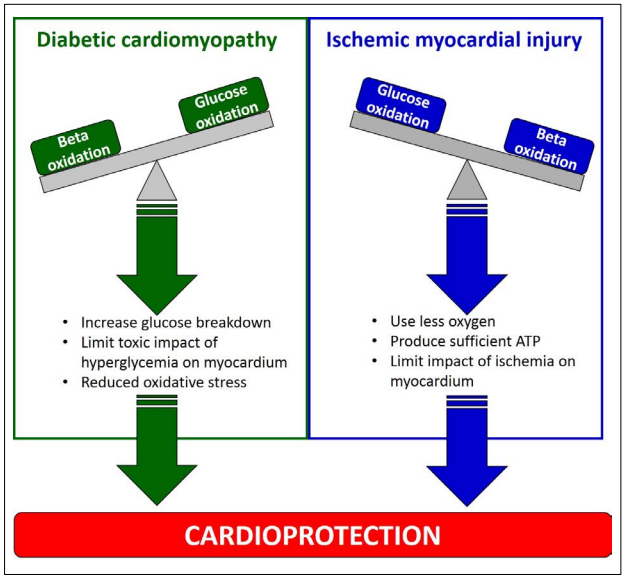
Considering the variety of bioactive components present in rooibos tea, it is likely that more than one component of rooibos contributes to cardioprotection. Additionally, these different components may activate different, yet synergistic, molecular pathways to bring about cardioprotection. This likelihood complicates the understanding of the underlying mechanisms of rooibos-induced cardioprotection. However, over the years, multiple studies have highlighted isolated mechanistic aspects related to rooibos-induced cardioprotection. To this end, a review paper is necessary to provide a novel perspective on current evidence, and to highlight a possible underlying mechanism for rooibos-induced cardioprotection. This elucidation of possible mechanisms might be useful for the design of future studies.

Overview of cardiac energy substrate utilisation in cardioprotection

Cardiac energy substrate utilisation plays a key role in cardiomyopathies[28,29] and cardioprotection[30,31]. In diabetes[32,33], high blood glucose (hyperglycaemia) as well as high glucose uptake without simultaneous glucose utilisation/oxidation,

induces toxic effects on the heart[34,35]. It induces this toxicity by activating programmed cell death (apoptosis of cardiomyocytes)[36] and thereby contributes to diabetic cardiomyopathy[37]. In this case, a sensible approach is to increase glucose oxidation, a pathway that can reduce the amount of glucose entering cardiomyocytes.[38] This approach limits cardiomyocyte apoptosis and confers cardioprotection.[39,40] Against this background, several therapeutic interventions modulate cardiac energy substrate utilisation in favour of glucose oxidation[39,40], in order to confer cardioprotection.

Another dimension to the negative impact of hyperglycaemia on the heart, is that it increases the production of toxic molecules called reactive oxygen species[41] that contribute to oxidative damage in the heart during hyperglycaemia. Therefore, in theory, a therapeutic intervention that can (1) increase myocardial glucose oxidation and (2) reduce reactive oxygen species, would accelerate glucose breakdown and thus limit the toxic effects of hyperglycaemia on the heart (Figure 1, green side).



ATP, adenosine triphosphate

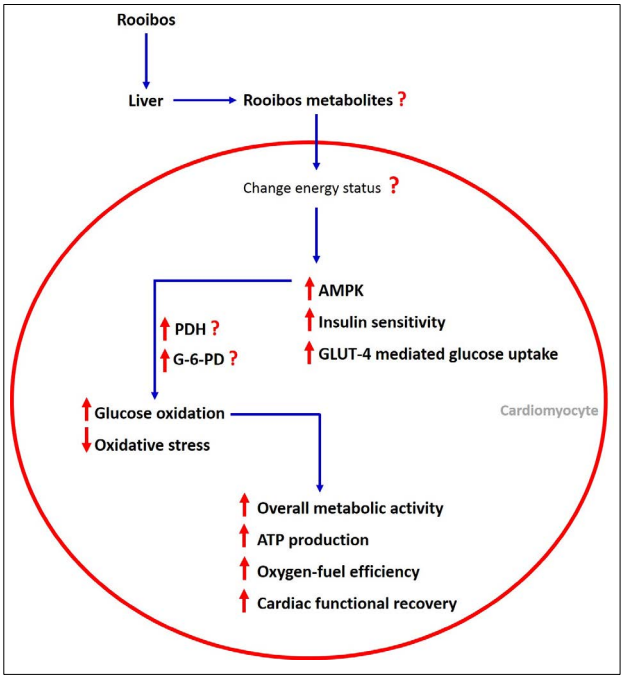
Figure 1: This figure demonstrates the role of glucose- and beta-oxidation in mitigating diabetic cardiomyopathy and myocardial ischaemic injury. In diabetic cardiomyopathy, hyperglycaemia induces toxic effects on the myocardium (heart muscle) and, therefore, increased uptake and breakdown of glucose alleviates the impact of hyperglycaemia. During myocardial ischaemia, increased myocardial glucose oxidation is a better fuel option, as it produces sufficient ATP with an oxygen sparing effect. Shifting of myocardial energy metabolism toward glucose oxidation, irrespective of whether diabetic cardiomyopathy or ischaemia-reperfusion is present, promotes cardioprotection.

In the case of a heart attack (myocardial ischaemia), oxygen availability to the myocardium is markedly reduced.[2] The heart normally generates energy through both glucose oxidation and fatty acid oxidation, while the latter uses less oxygen for the production of a similar amount of energy (adenosine triphosphate, ATP).[42] Thus, if fatty acid (beta) oxidation is elevated during a heart attack and not altered, the already limited oxygen will be used to produce ATP, which will produce more severe ischaemic effects on the heart.[29,43] Therefore, increased glucose oxidation during myocardial ischaemia is considered a better pathway as it produces sufficient ATP with an oxygen sparing effect.[29,43] In keeping with this logic, previous reports have demonstrated that in myocardial ischaemia, pharmacological modulation of cardiac energy metabolism (how the heart uses glucose or fatty acids as energy) confers cardioprotection mainly because it increases glucose oxidation.[31,44,45] Furthermore, other reports have demonstrated that a shift in cardiac energy substrate utilisation toward glucose oxidation (irrespective of whether cardiomyopathy is from hyperglycaemia or ischaemia) contributes to cardioprotection[43,46] (Figure 1, blue side).

Evidence that rooibos shifts cardiac energy substrate utilisation

A number of studies have demonstrated a link between rooibos and changes in energy substrate utilisation in the liver[47] and skeletal muscle[48]. A recent study showed that rooibos reduced hepatic insulin resistance by modulating adenosine 5′ monophosphate activated protein kinase (AMPK) pathways.[49] One research group was able to demonstrate that rooibos increases liver activity of adenosine AMPK.[48] Similarly, rooibos is able to increase AMPK activity, glucose oxidation[48], mitochondrial activity and ATP production in muscle[50]. AMPK is also the main sensor for cardiac energy status[51], and thus this effect of rooibos on AMPK was also recently demonstrated in the heart[9,10,52]. Taken together, these findings demonstrate the ability of rooibos to modulate cardiac energy substrate utilisation.

Rooibos also preserves and maintains cardiomyocyte ATP production[9] and improves cardiac functional recovery[25] by enhancing glucose oxidation[9]. From these data, it can be inferred that rooibos alters AMPK activity to enhance myocardial glucose uptake via glucose transport-4 (GLUT-4)[48] in order to promote myocardial glucose oxidation (Figure 2).



AMPK, 5′ AMP-activated protein kinase; GLUT-4, glucose transporter-4; RB, rooibos; ATP, adenosine triphosphate; PDH, pyruvate dehydrogenase complex; G-6-PD, glucose six phosphate dehydrogenase

Figure 2: This figure demonstrates that, after oral consumption, rooibos is metabolised in the liver, and after metabolism, metabolites are circulated to the heart. Upon entering cardiomyocytes, rooibos metabolites may change cardiomyocyte energy status and increase AMPK activity and GLUT-4 mediated glucose uptake. Subsequently, glucose oxidation is increased and beta-oxidation reduced (Randle Cycle), and, because of the antioxidant properties of rooibos, oxidative stress is mitigated. In concert, these changes increase metabolic activity (through increased ATP production, less oxygen used, increased functional recovery) and ultimately contribute to rooibos-induced cardioprotection. Therefore, this figure depicts the postulated hypothesis that rooibos confers cardioprotection via an AMPK-GLUT4 glucose oxidation pathway.

As a consequence of the feedback inhibition of increased glucose oxidation on beta-oxidation (also referred to as the Randle relationship)[37], rooibos may reduce fatty acid uptake/oxidation[9]. In concert, these processes allow the myocardium to have a reasonably high cardiac mitochondrial activity, and consume less oxygen in order to produce sufficient ATP production (Figure 2). Although not tested, this hypothesis could explain the enhanced

myocardial functional recovery after ischaemia-reperfusion[25], and the preserved cardiomyocyte ATP production[9] as previously reported. Therefore, in Figure 2, a hypothesis is depicted contending that rooibos may alter the overall cardiomyocyte energy status, and act via an AMPK-GLUT-4 glucose oxidation pathway to confer cardioprotection. Future studies could investigate this hypothesis, and test whether rooibos extracts are able to activate this pathway to execute its favourable impact on cardiac energy substrate utilisation, and confer cardioprotection.

Furthermore, considering that pyruvate dehydrogenase[53,54] and glucose-6-phosphate dehydrogenase[55] are regulators of glucose oxidation, it should also be investigated whether rooibos modulates these enzymes in order to activate this AMPK-GLUT-4 glucose oxidation pathway. Merely enhancing myocardial glucose oxidation may not solely account for rooibos-induced cardioprotection – other factors, such as reduced apoptosis signalling[9,10,23,25] mitochondrial connexin-43[56] and cardiolipin[57], G-protein-coupled receptor kinase-2[58] and the reduction of reactive oxygen species[21,59] may also contribute. There is a need for therapeutic interventions that confer cardioprotection, particularly those that can be consumed through dietary intake of rooibos. However, the cardioprotective properties of rooibos are not well described and the exact underlying mechanisms remain to be delineated.[60] Therefore, ongoing research is necessary to aid in the understanding of how rooibos confers cardioprotection and studies investigating the underlying mechanisms should be a priority. The identification of these underlying mechanisms would contribute to the body of knowledge on rooibos-induced cardioprotection, and possibly facilitate the use of rooibos as an accepted cardioprotective intervention in the clinical setting.

Conclusions

Studies on rooibos-induced cardioprotection, particularly those studies using models of diabetic cardiomyopathy and myocardial ischaemic injury, were reviewed. Based on the evidence presented and discussed in this review, it is hypothesised that rooibos may alter myocardial energy status, acting via an AMPK-GLUT-4 glucose oxidation pathway to confer cardioprotection. Future studies could further investigate this hypothesis and the activation of the proposed pathway in a suitable experimental model of cardiomyopathy.

Acknowledgement

I thank the South African Rooibos Council (SARC), South African Medical Research Council (SA-MRC), and the Faculty of Medicine and Health Sciences, Stellenbosch University, for financial support.

Disclosure statement

G.J.M. discloses that he was awarded a research grant from the South African Rooibos Council.

References

1. Gerczuk PZ, Kloner RA. An update on cardioprotection: A review of the latest adjunctive therapies to limit myocardial infarction size in clinical trials. J Am Coll Cardiol. 2012;59(11):969–978.
2. Habertheuer A, Kocher A, Laufer G, Andreas M, Szeto WY, Petzelbauer P, et al. Cardioprotection: A review of current practice in global ischemia and future translational perspective. Biomed Res Int. 2014;2014, Art. #325725, 11 pages. https://doi.org/10.1155/2014/325725
3. Shaikh F, Dupuis LL, Alexander S, Gupta A, Mertens L, Nathan PC. Cardioprotection and second malignant neoplasms associated with dexrazoxane in children receiving anthracycline chemotherapy: A systematic review and meta-analysis. J Natl Cancer Inst. 2016;108(4), djv357, 11 pages. https://doi.org/10.1093/jnci/djv357
4. Spath NB, Mills NL, Cruden NL. Novel cardioprotective and regenerative therapies in acute myocardial infarction: A review of recent and ongoing clinical trials. Future Cardiol. 2016;12(6):655–672. https://doi.org/10.2217/fca-2016-0044
5. Hausenloy DJ, Barrabes JA, Botker HE, Davidson SM, Di Lisa F, Downey J, et al. Ischaemic conditioning and targeting reperfusion injury: A 30 year voyage of discovery. Basic Res Cardiol. 2016;111(6), Art. #70, 24 pages. https://doi.org/10.1007/s00395-016-0588-8
6. Hausenloy DJ, Yellon DM. Ischaemic conditioning and reperfusion injury. Nat Rev Cardiol. 2016;13(4):193–209. https://doi.org/10.1038/nrcardio.2016.5
7. Nduhirabandi F, Lamont K, Albertyn Z, Opie LH, Lecour S. Role of toll-like receptor 4 in melatonin-induced cardioprotection. J Pineal Res. 2016;60(1):39–47. https://doi.org/10.1111/jpi.12286
8. Maarman G, Blackhurst D, Thienemann F, Blauwet L, Butrous G, Davies N, et al. Melatonin as a preventive and curative therapy against pulmonary hypertension. J Pineal Res. 2015;59(3):343–353. https://doi.org/10.1111/jpi.12263
9. Johnson R, Dludla P, Joubert E, February F, Mazibuko S, Ghoor S, et al. Aspalathin, a dihydrochalcone C-glucoside, protects H9c2 cardiomyocytes against high glucose induced shifts in substrate preference and apoptosis. Mol Nutr Food Res. 2016;60(4):922–934. https://doi.org/10.1002/mnfr.201500656
10. Dludla PV, Muller CJ, Louw J, Joubert E, Salie R, Opoku AR, et al. The cardioprotective effect of an aqueous extract of fermented rooibos (*Aspalathus linearis*) on cultured cardiomyocytes derived from diabetic rats. Phytomedicine. 2014;21(5):595–601. https://doi.org/10.1016/j.phymed.2013.10.029
11. Joubert E, De Beer D. Rooibos (*Aspalathus linearis*) beyond the farm gate: From herbal tea to potential phytopharmaceutical. S Afr J Bot. 2011;77(4):869–886. https://doi.org/10.1016/j.sajb.2011.07.004
12. Joubert E, Schulz H. Production and quality aspects of rooibos tea and related products. A review. J Appl Bot Food Qual. 2006;80(2):138–144.
13. Joubert E, Winterton P, Britz TJ, Gelderblom WC. Antioxidant and pro-oxidant activities of aqueous extracts and crude polyphenolic fractions of rooibos (*Aspalathus linearis*). J Agric Food Chem. 2005;53(26):10260–10267. https://doi.org/10.1021/jf051355a
14. Smith C, Swart AC. Rooibos (Aspalathus linearis) facilitates an anti-inflammatory state, modulating IL-6 and IL-10 while not inhibiting the acute glucocorticoid response to a mild novel stressor in vivo. J Funct Foods. 2016;27:42–54. https://doi.org/10.1016/j.jff.2016.08.055
15. McKay DL, Blumberg JB. A review of the bioactivity of South African herbal teas: Rooibos (*Aspalathus linearis*) and honeybush (*Cyclopia intermedia*). Phytother Res. 2007;21(1):1–16. https://doi.org/10.1002/ptr.1992
16. Marnewick JL, Van der Westhuizen FH, Joubert E, Swanevelder S, Swart P, Gelderblom WCA. Chemoprotective properties of rooibos (*Aspalathus linearis*), honeybush (*Cyclopia intermedia*) herbal and green and black (*Camellia sinensis*) teas against cancer promotion induced by fumonisin B-1 in rat liver. Food Chem Toxicol. 2009;47(1):220–229. https://doi.org/10.1016/j.fct.2008.11.004
17. Marnewick J, Joubert E, Joseph S, Swanevelder S, Swart P, Gelderblom W. Inhibition of tumour promotion in mouse skin by extracts of rooibos (*Aspalathus linearis*) and honeybush (*Cyclopia intermedia*), unique South African herbal teas. Cancer Lett. 2005;224(2):193–202. https://doi.org/10.1016/j.canlet.2004.11.014
18. Snijman PW, Joubert E, Ferreira D, Li XC, Ding YQ, Green IR, et al. Antioxidant activity of the dihydrochalcones aspalathin and nothofagin and their corresponding flavones in relation to other rooibos (*Aspalathus linearis*) flavonoids, epigallocatechin gallate, and trolox. J Agric Food Chem. 2009;57(15):6678–6684. https://doi.org/10.1021/jf901417k
19. Tangney CC, Rasmussen HE. Polyphenols, inflammation, and cardiovascular disease. Curr Atheroscler Rep. 2013;15(5):324. https://doi.org/10.1007/s11883-013-0324-x
20. Geleijnse JM, Hollman PCH. Flavonoids and cardiovascular health: Which compounds, what mechanisms? Am J Clin Nutr. 2008;88(1):12–13. https://doi.org/10.1093/ajcn/88.1.12
21. Marnewick JL, Rautenbach F, Venter I, Neethling H, Blackhurst DM, Wolmarans P, et al. Effects of rooibos (*Aspalathus linearis*) on oxidative stress and biochemical parameters in adults at risk for cardiovascular disease. J Ethnopharmacol. 2011;133(1):46–52. https://doi.org/10.1016/j.jep.2010.08.061
22. Persson IAL, Persson K, Hagg S, Andersson RGG. Effects of green tea, black tea and rooibos tea on angiotensin-converting enzyme and nitric oxide in healthy volunteers. Public Health Nutr. 2010;13(5):730–737. https://doi.org/10.1016/j.jep.2010.08.061
23. Dludla PV, Muller CJ, Joubert E, Louw J, Gabuza KB, Huisamen B, et al. Phenylpyruvic acid-2-O-beta-D-glucoside attenuates high glucose-induced apoptosis in h9c2 cardiomyocytes. Planta Med. 2016;82(17):1468–1474. https://doi.org/10.1055/s-0042-110856

24. Krishna KM, Annapurna A, Gopal GS, Chalam CRV, Madan K, Kumar VK, et al. Partial reversal by rutin and quercetin of impaired cardiac function in streptozotocin-induced diabetic rats. Can J Physiol Pharmacol. 2005;83(4):343–355. https://doi.org/10.1139/y05-009

25. Pantsi WG, Marnewick JL, Esterhuyse AJ, Rautenbach F, Van Rooyen J. Rooibos (*Aspalathus linearis*) offers cardiac protection against ischaemia/reperfusion in the isolated perfused rat heart. Phytomedicine. 2011;18(14):1220–1228. https://doi.org/10.1016/j.phymed.2011.09.069

26. Webster I, Imperial EG, Westcott C, Strijdom H. The cardiovascular effects of *Aspalathus linearis* supplementation in male Wistar rats receiving fixed-dose combination first-line antiretroviral therapy. Cardiovasc J Afr. 2019;30:1–8. https://doi.org/10.5830/cvja-2018-075

27. Liperoti R, Vetrano DL, Bernabei R, Onder G. Herbal medications in cardiovascular medicine. J Am Coll Cardiol. 2017;69(9):1188–1199. https://doi.org/10.1016/j.jacc.2016.11.078

28. Harvey PA, Leinwand LA. The cell biology of disease: Cellular mechanisms of cardiomyopathy. J Cell Biol. 2011;194(3):355–365. https://doi.org/10.1083/jcb.201101100

29. Boudina S, Abel ED. Diabetic cardiomyopathy, causes and effects. Rev Endocr Metab Disord. 2010;11(1):31–39. https://doi.org/10.1007/s11154-010-9131-7

30. Aravindhan K, Bao WK, Harpel MR, Willette RN, Lepore JJ, Jucker BM. Cardioprotection resulting from glucagon-like peptide-1 administration involves shifting metabolic substrate utilization to increase energy efficiency in the rat heart. PLoS ONE. 2015;10(6), e0130894, 18 pages. https://doi.org/10.1371/journal.pone.0130894

31. Jaswal JS, Keung W, Wang W, Ussher JR, Lopaschuk GD. Targeting fatty acid and carbohydrate oxidation – A novel therapeutic intervention in the ischemic and failing heart. Biochim Biophys Acta Mol Cell Res. 2011;1813(7):1333–1350. https://doi.org/10.1016/j.bbamcr.2011.01.015

32. Gray S, Kim JK. New insights into insulin resistance in the diabetic heart. Trends Endocr Metab. 2011;22(10):394–403. https://doi.org/10.1016/j.tem.2011.05.001

33. Abel ED. Myocardial insulin resistance and cardiac complications of diabetes. Curr Drug Targets Immune Endocr Metabol Disord. 2005;5(2):219–226. https://doi.org/10.2174/1568008054064869

34. Liang JL, Xiao DZ, Liu XY, Lin QX, Shan ZX, Zhu JN, et al. High glucose induces apoptosis in AC16 human cardiomyocytes via macrophage migration inhibitory factor and c-Jun N-terminal kinase. Clin Exp Pharmacol Physiol. 2010;37(10):969–973. https://doi.org/10.1111/j.1440-1681.2010.05420.x

35. Kawahito S, Kitahata H, Oshita S. Problems associated with glucose toxicity: Role of hyperglycemia-induced oxidative stress. World J Gastroenterol. 2009;15(33):4137–4142. https://doi.org/10.3748/wjg.15.4137

36. Singh AB, Guleria RS, Nizamutdinova IT, Baker KM, Pan J. High glucose-induced repression of RAR/RXR in cardiomyocytes is mediated through oxidative stress/JNK signaling. J Cell Physiol. 2012;227(6):2632–2644. https://doi.org/10.1002/jcp.23005

37. Hue L, Taegtmeyer H. The Randle Cycle revisited: A new head for an old hat. Am J Physiol Endocr Metab. 2009;297(3):E578–E591. https://doi.org/10.1152/ajpendo.00093.2009

38. Ceriello A, Esposito K, Giugliano D. Glucose metabolism and hyperglycemia. Am J Clin Nutr. 2008;87(1):217S–222S. https://doi.org/10.1093/ajcn/87.1.217s

39. Lloyd S, Brocks C, Chatham JC. Differential modulation of glucose, lactate, and pyruvate oxidation by insulin and dichloroacetate in the rat heart. Am J Physiol Heart Circ Physiol. 2003;285(1):H163–H172. https://doi.org/10.1152/ajpheart.01117.2002

40. Bhashyam S, Fields AV, Patterson B, Testani JM, Chen L, Shen YT, et al. Glucagon-like peptide-1 increases myocardial glucose uptake via p38alpha MAP kinase-mediated, nitric oxide-dependent mechanisms in conscious dogs with dilated cardiomyopathy. Circ Heart Fail. 2010;3(4):512–521. https://doi.org/10.1161/circheartfailure.109.900282

41. Ansley DM, Wang BH. Oxidative stress and myocardial injury in the diabetic heart. J Pathol. 2013;229(2):232–241.

42. Wolff AA, Rotmensch HH, Stanley WC, Ferrari R. Metabolic approaches to the treatment of ischemic heart disease: The clinicians' perspective. Heart Fail Rev. 2002;7(2):187–203. https://doi.org/10.1023/a:1015384710373

43. Fillmore N, Mori J, Lopaschuk GD. Mitochondrial fatty acid oxidation alterations in heart failure, ischaemic heart disease and diabetic cardiomyopathy. Br J Pharmacol. 2014;171(8):2080–2090. https://doi.org/10.1111/bph.12475

44. Maarman G, Marais E, Lochner A, Du Toit EF. Effect of chronic CPT-1 inhibition on myocardial ischemia-reperfusion injury (I/R) in a model of diet-induced obesity. Cardiovasc Drugs Ther. 2012;26(3):205–216. https://doi.org/10.1007/s10557-012-6377-1

45. Bhandari B, Subramanian L. Ranolazine, a partial fatty acid oxidation inhibitor, its potential benefit in angina and other cardiovascular disorders. Recent Pat Cardiovasc Drug Discov. 2007;2(1):35–39. https://doi.org/10.2174/157489007779606095

46. Lopaschuk GD. AMP-activated protein kinase control of energy metabolism in the ischemic heart. Int J Obes. 2008;32:S29–S35. https://doi.org/10.1038/ijo.2008.120

47. Beltran-Debon R, Rull A, Rodriguez-Sanabria F, Iswaldi I, Herranz-Lopez M, Aragones G, et al. Continuous administration of polyphenols from aqueous rooibos (*Aspalathus linearis*) extract ameliorates dietary-induced metabolic disturbances in hyperlipidemic mice. Phytomedicine. 2011;18(5):414–424. https://doi.org/10.1016/j.phymed.2010.11.008

48. Mazibuko SE, Muller CJ, Joubert E, De Beer D, Johnson R, Opoku AR, et al. Amelioration of palmitate-induced insulin resistance in C(2)C(1)(2) muscle cells by rooibos (*Aspalathus linearis*). Phytomedicine. 2013;20(10):813–819. https://doi.org/10.1016/j.phymed.2013.03.018

49. Mazibuko-Mbeje SE, Dludla PV, Roux C, Johnson R, Ghoor S, Joubert E, et al. Aspalathin-enriched green rooibos extract reduces hepatic insulin resistance by modulating PI3K/AKT and AMPK pathways. Int J Mol Sci. 2019;20(3), Art. #633, 16 pages. https://doi.org/10.3390/ijms20030633

50. Ulicna O, Vancova O, Kucharska J, Janega P, Waczulikova I. Rooibos tea (*Aspalathus linearis*) ameliorates the CCl4-induced injury to mitochondrial respiratory function and energy production in rat liver. Gen Physiol Biophys. 2019;38(1):15–25. https://doi.org/10.4149/gpb_2018037

51. Qi D, Young LH. AMPK: Energy sensor and survival mechanism in the ischemic heart. Trends Endocr Metab TEM. 2015;26(8):422–429. https://doi.org/10.1016/j.tem.2015.05.010

52. Kawano A, Nakamura H, Hata SI, Minakawa M, Miura Y, Yagasaki K. Hypoglycemic effect of aspalathin, a rooibos tea component from *Aspalathus linearis*, in type 2 diabetic model db/db mice. Phytomedicine. 2009;16(5):437–443. https://doi.org/10.1016/j.phymed.2008.11.009

53. Lydell CP, Chan A, Wambolt RB, Sambandam N, Parsons H, Bondy GP, et al. Pyruvate dehydrogenase and the regulation of glucose oxidation in hypertrophied rat hearts. Cardiovasc Res. 2002;53(4):841–851. https://doi.org/10.1016/s0008-6363(01)00560-0

54. Zhang S, Hulver MW, McMillan RP, Cline MA, Gilbert ER. The pivotal role of pyruvate dehydrogenase kinases in metabolic flexibility. Nutr Metab (Lond). 2014;11(1), Art. #10, 9 pages. https://doi.org/10.1186/1743-7075-11-10

55. Van de Werve G, Lange A, Newgard C, Mechin MC, Li Y, Berteloot A. New lessons in the regulation of glucose metabolism taught by the glucose 6-phosphatase system. Eur J Biochem. 2000;267(6):1533–1549. https://doi.org/10.1046/j.1432-1327.2000.01160.x

56. Rodriguez-Sinovas A, Ruiz-Meana M, Denuc A, Garcia-Dorado D. Mitochondrial Cx43, an important component of cardiac preconditioning. Biochim Biophys Acta Biomembr. 2018;1860(1):174–181. https://doi.org/10.1016/j.bbamem.2017.06.011

57. Paradies G, Paradies V, Ruggiero FM, Petrosillo G. Mitochondrial bioenergetics and cardiolipin alterations in myocardial ischemia-reperfusion injury: Implications for pharmacological cardioprotection. Am J Physiol Heart Circ Physiol. 2018;315(5):H1341–H1352. https://doi.org/10.1152/ajpheart.00028.2018

58. Sato PY, Chuprun JK, Grisanti LA, Woodall MC, Brown BR, Roy R, et al. Restricting mitochondrial GRK2 post-ischemia confers cardioprotection by reducing myocyte death and maintaining glucose oxidation. Sci Signal. 2018;11(560), eaau0144. https://doi.org/10.1126/scisignal.aau0144

59. Villano D, Pecorari M, Testa MF, Raguzzini A, Stalmach A, Crozier A, et al. Unfermented and fermented rooibos teas (*Aspalathus linearis*) increase plasma total antioxidant capacity in healthy humans. Food Chem. 2010;123(3):679–683. https://doi.org/10.1016/j.foodchem.2010.05.032

60. Smith C, Swart A. *Aspalathus linearis* (rooibos) – a functional food targeting cardiovascular disease. Food Funct. 2018;9(10):5041–5058. https://doi.org/10.1039/c8fo01010b

AUTHORS:
Gillian Kerchhoff[1]
Michelle Kahn[2]
Mary Nassimbeni[2]

AFFILIATIONS:
[1]Institute for Poverty, Land and Agrarian Studies, University of the Western Cape, Cape Town, South Africa
[2]Department of Knowledge and Information Stewardship, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Gillian Kerchhoff

EMAIL:
gillker@iafrica.com

DATES:
Received: 08 Oct. 2018
Revised: 13 Feb. 2019
Accepted: 05 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Kerchhoff G, Kahn M, Nassimbeni M. A 20-year evaluation of PLAAS research outputs: Impact on the scholarly domain and in social media. S Afr J Sci. 2019;115(7/8), Art. #5655, 8 pages. https://doi.org/10.17159/sajs.2019/5655

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☒ Not applicable

EDITORS:
John Butler-Adam
Maitumeleng Nthontho

KEYWORDS:
bibliometrics; altmetrics; research outputs; scholarly communication; grey literature

FUNDING:
National Research Foundation (South Africa)

A 20-year evaluation of PLAAS research outputs: Impact on the scholarly domain and in social media

Patterns and methods of scholarly communication have changed with the growth in information technology, particularly the Internet and the social web. The changes have necessitated a broader definition of scholarly communication and the role of social media in the research process. We sought to record the body of work that the Institute for Poverty, Land and Agrarian Studies (PLAAS), a research institute at the University of the Western Cape, produced over a 20-year period (1995–2015) – the first two decades of its existence – and to measure its visibility and impact using bibliometrics and altmetrics. A survey was also carried out to investigate to what extent PLAAS researchers knew and used social media in their research practice. Scopus and Google Scholar were used as citation indices and Altmetric.com provided Altmetric scores – a measure of impact through social and mainstream media. The full list of PLAAS outputs showed a composition of 54% grey literature and 46% journal articles and monographs. Given that over half of PLAAS research outputs were in the form of grey literature, and therefore not indexed in traditional bibliometric databases, we suggest that alternative metrics be used in conjunction with bibliometrics, to measure the impact of a body of work on the scholarly domain. Although the bibliometrics in this study were a useful quantitative indicator of the impact of PLAAS research, this study was inconclusive with regard to determining the impact of the research output via altmetrics, partly because not any of the grey literature, nor any author from PLAAS, had a unique identifier, thus making it difficult to track and find quantitative indicators. Nonetheless, the potential benefit for PLAAS of using altmetrics was demonstrated in selected case studies of the output of three PLAAS researchers active on social media platforms.

Significance:

- This study demonstrates that the use of bibliometric and altmetric analyses can yield a rich picture of research output and significance, providing insight into the patterns of scholarly communication of research and policy institutions.
- The application of the research design in other research units and departments could generate results that are useful to research management within those institutions.

Introduction

Research evaluation is an established practice in scholarly communication, and is important in the allocation of scarce funding to priority areas, as well as in decision-making around tenure and promotions.[1,2] There is growing interest in the metrics used to evaluate research and the people who produce it, particularly as individual peer review becomes more difficult with the growing volume of research produced.[2,3] Peer review is expensive, subjective and suited to small groups or individuals. However, metrics should be used with caution, and are preferable for assessing large research organisations or mapping trends rather than for evaluating individual researchers.[4,5]

Groos and Pritchard[6] defined bibliometric analysis as 'the application of statistical and mathematical methods to books and other media of communication'.[6] Bibliometrics is a quantitative method of evaluation and it is emphasised throughout the literature that qualitative peer review should be part of an overall evaluation, and that citation analysis, even using a number of different metrics, should not be used as the only basis on which to base decisions regarding promotion and tenure. Gorraiz et al.[7] state that 'it cannot be stressed often enough that citations are only used as a proxy for the impact (and not for the quality)' of the publications in scholarly communication.

Scholarly communication is defined by Borgman[8] as 'the study of how scholars in any field (e.g. physical, biological, social and behavioural sciences, humanities, technology) use and disseminate information through formal and informal channels'. The Association of College and Research Libraries defines it as 'the system through which research and other scholarly writings are created, evaluated for quality, disseminated to the scholarly community, and preserved for future use'[9].

There is agreement in the literature that scholarly communication has changed as a result of evolving information and communications technologies.[10-17] Since the introduction of the Internet, and particularly the rise of the social web (also called Web 2.0), publication and dissemination of research outputs have shifted from being the exclusive domain of formal publishers to being available to researchers themselves.[10,18] Knowing which social media and networks are effective for disseminating research assists researchers in reaching and influencing as wide an audience as possible.[5]

Another significant change to scholarly communication noted in the literature is that a networked and digital environment allows a variety of output types to be produced, in addition to the traditional journal article and monograph. Van de Sompel et al.[16] argue for a wider view of these currently privileged 'units' of scholarly communication as technology allows for greater variety, flexibility and speed in publication.

Altmetrics, or alternative metrics, is a form of measurement of scholarly communication at an article level and is a result largely of developments in technology that have presented new opportunities through the social web. There is still some debate around a definition of altmetrics[13,19] but it is clear that these metrics complement traditional metrics[20] and provide a broader picture of social impact and visibility of research[21]. Altmetrics are not yet standardised[13,22,23],

which means there is some difficulty in establishing categories and definitions in order to generate consistent and comparable indicators. While more research and refinement is needed in terms of the use and role of these metrics in measuring research impact, it is evident in the literature that the 'growing importance of this emergent application area of social media for research evaluation'[23] cannot be ignored. The impact of research on society, and not just within academia, is increasingly viewed as an important aspect of the practice of research and altmetrics is a means of measuring visibility and impact through social media activity.[20,23]

Using these tools, we evaluated the impact of the scholarly outputs of the Institute for Poverty, Land and Agrarian Studies (PLAAS) at the University of the Western Cape (UWC) from 1995 to 2015 using bibliometric and altmetric analyses. A survey was employed as a research instrument to discover the PLAAS researchers' extent of knowledge and use of social media (including Facebook, Twitter, Cite-U-Like, ResearchGate.net and others) in an academic environment. The specific objectives were:

1. To record the body of research outputs, both externally and internally published, for the period 1995 to 2015.
2. To use bibliometric and altmetric analyses to measure activity and visibility of the researchers at PLAAS and to investigate the impact of their scholarly outputs.
3. To gain an understanding of the awareness and use of social media by PLAAS researchers.

PLAAS, originally called the Programme for Land and Agrarian Studies, celebrated 20 years of existence in 2015. PLAAS's 20th anniversary provided an opportune time to document and evaluate PLAAS research against the background of increased pressure on academics to demonstrate impact in a rapidly changing research landscape in which the practice of scholarship is being significantly affected by new information and communication technologies. The Programme was established at UWC with the aim of conducting high-quality 'critical research' to enable the new government in South Africa to develop policy and practice around issues of land and its redistribution, as well as poverty and agrarian reform.[24] These subject areas are of topical significance in post-apartheid South Africa policy and research and attract interest not only from scholars and government but also from the general public.

PLAAS researchers produce scholarly outputs in peer-reviewed journals and elsewhere, and they collaborate with local, regional and international authors. However, at the time of undertaking this study, PLAAS had no empirical report of research outputs nor of the valuable bibliometric indicators derived from the outputs. The lack of such a record limited the ability of the Institute to measure the impact and visibility of its scholarly communication. In addition to scholarly publications, the Institute engages with policymakers and the public, through the publication of grey literature intended for that audience. This grey material is not indexed in citation databases and is therefore not usually included in a bibliometric analysis. Altmetrics could assist in measuring attention that is paid to all PLAAS outputs, thereby providing insight into whether more could be done to promote the research on social media.

This investigation was the first of its kind at UWC and it provides insight into the scholarly communication of research and policy institutions such as PLAAS, offering a methodology useful for research and evaluation management both at the institute and for the university.

Methodology

In order for the bibliometric and altmetric analyses to be conducted, it was first necessary to compile a master list of the total number of PLAAS outputs using records that are kept at PLAAS in the Zotero reference management system. Included in these records are publications such as journal articles, monographs, book chapters and conference papers, as well as documents such as parliamentary submissions or hearings, research reports, policy briefs and occasional papers. All conference papers were categorised as 'grey literature' and not 'scholarly outputs' as few of them appeared in formal conference proceedings. Zotero records are also kept for television and radio appearances, news media items which refer to PLAAS, policy engagement presentations, seminars and blogs, but these were not included in this study. The master list was corrected and updated to cover the period 1995–2015, and crosschecked against the PLAAS website on which new publications were routinely featured.

The final master list (Table 1) consisted of 33 PLAAS authors and 743 publications, including 100 publications authored by external researchers (that is, researchers working with staff members but not employed at PLAAS). It must be noted that in the case of a paper being co-authored by more than one PLAAS author, each author was assigned a record for that paper. This policy is the same as that followed by Scopus and Google Scholar when recording number of outputs and number of citations.

Although there are other databases Scopus was selected because it was readily available at PLAAS and Google Scholar was selected because its coverage includes the World Wide Web, which is therefore greater than that of Scopus and the Web of Science which rely on the journal titles in their databases only. Google Scholar also includes document types excluded by Scopus, such as patents, research reports, policy briefs, hardware or software artefacts and all self-archived and open access material. Furthermore, Google Scholar indexes publications in a greater range of languages and from a wider coverage of regions of the world, unlike Scopus and Web of Science which focus primarily on publications in English, and tend to favour the Global North in terms of coverage, while countries and languages from the Global South are less well covered.[2,25]

The number of publications between 1995 and 2015 indexed in Scopus, and their citation counts, were retrieved for each PLAAS-affiliated author through the author search function using their last name and first initial. Lists were checked for accuracy against the master list. It was noted that not all PLAAS authors were indexed by Scopus: of 33 in the master list, only 20 were found in Scopus. The total number of publications found in Scopus by these 20 authors for the period 1995–2015 was 134. This figure was further broken down into number of publications per year, author, and document type. Lastly, the *h*-indices of the authors, as presented in Scopus, were recorded.

All PLAAS author outputs in Google Scholar were found by performing an author search using the full name, and excluding patents and citing publications. The results for each author for the specified time period were then saved. There were, however, quite a few errors such as missing information, duplicates and erroneous items and the records had to be verified against the master list and false hits eliminated. A total of 32 authors and their 535 publications were found in Google Scholar for the specified time period. The *h*-indices and number of citations were also recorded. Table 1 provides a summary of the results of the author and publication searches in the two citation indices as well as the master list.

Table 1: Total counts of authors, publications and citations

Source	Number of authors	Number of publications	Number of citations
Master list	33	743	n/a
Scopus	20	134	1906
Google Scholar	32	535	11 678

Altmetric indicators for PLAAS outputs were more difficult to source than bibliometric indicators. The three main tools available for altmetric analysis of scholarly outputs are PlumX, ImpactStory and Altmetric.com. These tools aggregate social media activity and other metrics (such as mainstream media mentions) and citations, producing their own particular indicator/s accordingly. Altmetric.com was selected for this component of the research because Altmetric Explorer fitted our needs, namely to find altmetric indicators for particular authors' publications. Secondly, at the time of the study, Altmetric.com was the dominant product in the market, and thirdly, the company gave permission to use Altmetric Explorer free of charge for research purposes.

The search in Altmetric Explorer was conducted in January 2017, using each author's full name, and specifying a date range of 01 January 1995 to 31 December 2015. Altmetric.com's aggregated score, called the

Altmetric Attention Score (AAS), is available for items for which there has been some activity to collect and aggregate.

In addition, altmetric data were collected for three specific PLAAS documents for closer inspection through Google Analytics, Facebook and Twitter application programming interfaces (APIs) in the PLAAS website. These outputs were selected based on their high number of views and downloads.

A short, self-administered questionnaire was sent to the researchers at PLAAS to understand how much they knew about and used the various online social media tools and platforms for sharing scholarly information. This survey was approved by the Ethics Committee of the Humanities Faculty at the University of Cape Town (reference number UCTLIS201609-06).

Data analysis and interpretation

The data collected were used to achieve the main objective of this study, which was to record in detail the corpus of PLAAS research outputs over the period 1995–2015 and to investigate their activity and impact in the scholarly and social contexts.

Outputs 1995–2015

Table 2 summarises the master list of publications with a total of 743 outputs listed by document type. Slightly fewer than half of the publications (n=344) fell into the broad category of scholarly publications: namely journal articles, books and book chapters. The second category (n=399) comprised other documents or outputs (referred to here as grey literature) including policy briefs, videos, research reports and conference papers.

Table 2: PLAAS outputs (the master list) according to document type (n=743)

Document type	Number	Percentage
Journal article	231	31
Conference paper	137	19
Book chapter	68	9
Policy brief	68	9
Occasional paper	65	9
Research report	65	9
Book	45	6
Working paper	39	5
Parliamentary submission	9	1
Video	9	1
Fact check	7	1

Authors

Although it was not the intention of the study to focus on individual staff members, because many metrics operate at author level, individuals' scores have been highlighted as these significantly raised the overall impact of the Institute's outputs.

A total of 33 PLAAS-affiliated scholars were responsible for authoring or co-authoring 643 outputs over the 20-year period. The external researchers who co-authored the remaining 100 outputs were excluded from the set of 33 authors as categorised for the study.

Emeritus Professor Cousins, a founding member of PLAAS in 1995, was the most prolific author with 142 outputs over that period. Associate Professors Hall and Hara were ranked next with 84 and 69 outputs, respectively. Table 3 presents the analysis of results by document type from these three most productive PLAAS authors: Cousins, Hall and Hara. It is apparent that all the authors produced almost the same proportion of each kind of output, scholarly and grey literature, the greatest difference being in Hall's outputs which were 44% grey and 56% scholarly literature.

Table 3: Number of outputs by the highest-producing PLAAS authors

Author	Scholarly outputs		Grey literature		Total
	Number	%	Number	%	
Cousins	76	54	66	46	**142**
Hall	47	56	37	44	**84**
Hara	35	51	34	49	**69**

Lotka's law of author productivity, which states that

> *for any body of literature, there will be a substantial number of authors who have each contributed only one publication, a small number of authors who have each contributed a small number of publications, and a very small group of authors who have each contributed a substantial number of publications*[26]

has been shown to apply in studies such as that of Rotich and Onyancha[27]. Similarly, in our study, there is evidence in the patterns of author productivity that Lotka's law applies. Thus, the largest group of 23 authors produced a total of 138 publications (25%), the next group of 7 authors (15 papers or more each) contributed 210 publications (39%) and the top 3 authors (Cousins, Hall and Hara) contributed the most publications at 295 (46%) in total.

Bibliometric analysis

In both Scopus and Google Scholar databases, most items by PLAAS authors were journal articles: 139 (60%) on Google Scholar and 119 (52%) on Scopus. High value is assigned to the journal article in scholarly communication compared to other units like books and book chapters[25,26], making journal articles a sought-after output. Both Scopus and Google Scholar produced very few results for PLAAS-authored books and book chapters. Scopus did not retrieve any of the PLAAS grey literature, while Google Scholar provided records for 74 (19%) of the 399 grey literature outputs.

Citation analysis is central to bibliometrics and is based on the premise that the number of times that an article is cited indicates a measure of use and impact of that article. Citation analysis 'involves the construction and application of a series of indicators of the "impact", "influence" or "quality" of scholarly work, derived from citation data'[28] and impact is even viewed as 'synonymous with citation-based metrics'[29]. Using 'volume of impact as a proxy for value (i.e. number of citations or more recently number of online mentions)'[30] is largely accepted.

The 134 publications found in Scopus, equating to 18% of the total number of PLAAS outputs (Table 4), were used to calculate a citation count. The data set presented in Figure 1 shows that Hall's 16 outputs had the most citations (601) in Scopus, Cousins' 28 outputs had the second highest number of citations (368), and Du Toit's 16 publications had 337 citations.

Table 4: Number of PLAAS outputs on Scopus, by document type

Document type	Master list	Scopus	% Master list
Article (including editorials, notes and reviews)	231	119	52
Book chapter	68	12	18
Book	45	1	2
Grey literature (including conference papers)	399	2	1
Total	**743**	**134**	**18**

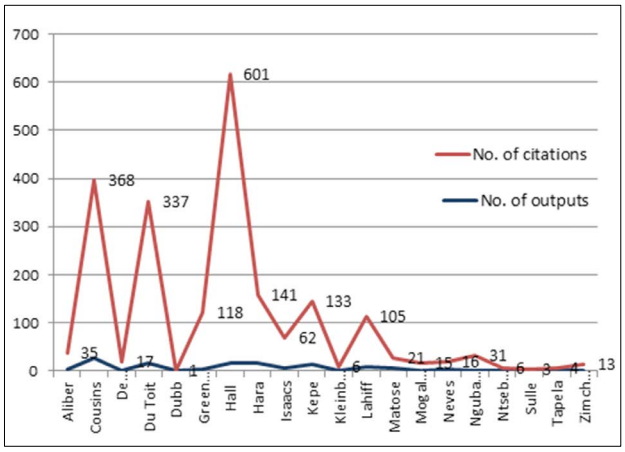


Figure 1: Publication and citation counts per author, according to Scopus.

Onyancha and Ocholla[31] found in their research that Google Scholar provided a more comprehensive set of publication results than either Scopus or Web of Science. This finding is similar to our results, as shown in Table 5: 535 records, or 72% of the total outputs, were retrieved from Google Scholar – 54% more than that from Scopus.

Table 5: Number of PLAAS outputs on Google Scholar, by document type

Document type	Master list	Google Scholar	% Master list
Article	231	139	60
Working paper	39	20	51
Research report	65	25	38
Policy brief	68	22	32
Book	45	14	31
Book chapter	68	10	15
Fact check	7	1	14
Video	9	1	11
Conference paper	137	14	10
Occasional paper	65	5	8
Parliamentary submission	9	n/a	n/a
Blank records	n/a	283	n/a
Total	**743**	**535**	**72**

Within these results, as depicted in Figure 2, Cousins, Hall and Du Toit were identified as the top researchers in terms of productivity and number of citations, reflecting the pattern found in Scopus (1831 citations to Cousins' 61 publications; 2344 to Hall's 66 publications; and 1896 to Du Toit's 67 publications). Their senior rankings (Professor and South African Research Chair, Associate Professor and Professor, respectively) in the university hierarchy and extensive periods of tenure at PLAAS (20, 13 and 20 years, respectively) are likely contributing factors to their high productivity and associated metrics. This finding is consistent with other studies in the literature[7,27] which have found that seniority is a reliable predictor of high metrics.

The average number of citations per author in Scopus was 62; 8 authors had 62 or more citations, while 12 authors had fewer than 62 citations. In Google Scholar, the average per author was 350 citations and, out of 32 authors in the Google Scholar results, 8 authors had more than 350 citations and 24 authors had fewer than 350 citations. Significantly, of the eight, five authors scored above the average in both citation databases: Cousins, Du Toit, Hall, Hara and Isaacs; three of these authors (Cousins, Hall, Hara) also had the highest number of publications, citations and *h*-indices (cf Figures 1 and 2).

The *h*-index is a useful author-level metric intended by Jorge Hirsch (who proposed the formula in 2005) to provide a better indicator for measuring research impact than a citation count on its own. Castillo[32] expressed confidence in the *h*-index, saying that 'the *h*-index, at least for now, provides a robust single metric that combines quality and quantity'. The calculation takes both the number of publications and the number of citations into account, is widely used in bibliometrics, and is commonly accepted in research evaluation exercises. It is noted that the *h*-index does not mean much in isolation and needs to be shown in comparison with those of others in a similar discipline and with a similar career age.[7,32,33] Castillo[32] compared *h*-indices from Google Scholar and Scopus and found a high correlation.

For the sake of comparison, the *h*-indices of three highly cited academics from a related social science discipline at UWC were explored (Figure 3). Professors A, B and C were considered the most suitable researchers, respectively, to provide a reasonable comparison to Cousins, Du Toit and Hall (the top PLAAS researchers in terms of productivity and number of citations), being of similar career age and status. Data on Professor A's, B's and C's outputs were collected from both Google Scholar and Scopus, using Harzing's Publish or Perish software to retrieve the Google Scholar *h*-index and using Scopus for its *h*-index. The 1995–2015 time period was specified in the search so only outputs in those years are included in the calculations of *h*-index. This was an attempt to limit the comparison of different authors' career ages, but some authors have obviously published for longer because of their greater chronological age.

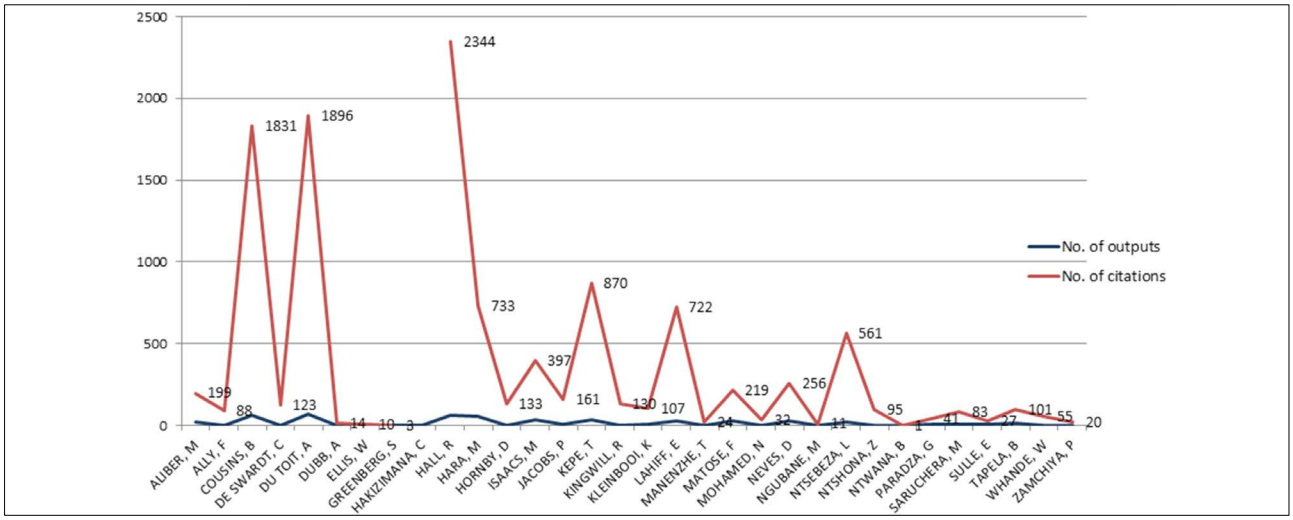


Figure 2: Publication and citation counts per author, according to Google Scholar.

The results (depicted in Figure 3) showed that, of the six researchers, Cousins had the highest *h*-index in both databases (32 in Google Scholar and 14 in Scopus), which is slightly more than Professor A, who had the highest score of the three academics from the comparative sample with an *h*-index of 28 in Google Scholar and 10 in Scopus. Du Toit and Hall both scored higher than Professors B and C, respectively. The total score of the three scholars from PLAAS was higher than the total score of the three top scholars in the related discipline in both Google Scholar and Scopus.

The *h*-index has shortcomings, as do many other bibliometric indicators. It can 'oversimplify a researcher's impact' as Haustein and Larivière[34] argue, and does not always give accurate comparisons between researchers' impacts. However, given the results from both Scopus and Google Scholar, the higher *h*-indices of PLAAS scholars compared with those of the top researchers in the comparative sample indicate that the productivity and impact of the research from PLAAS was greater.

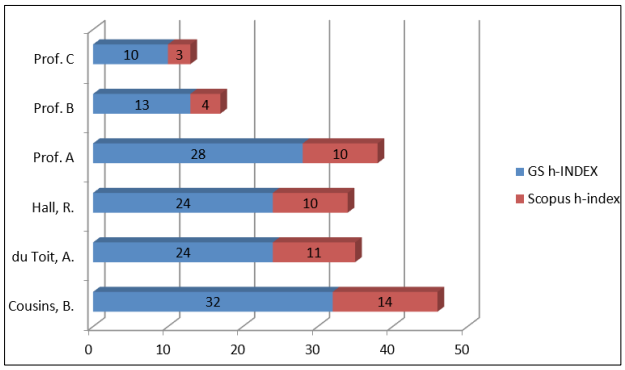


Figure 3: Comparative *h*-indices of researchers from Google Scholar (GS) and Scopus.

Altmetric analysis

An Altmetric.com search for PLAAS outputs returned a low number of results: 46 of the 743 records (6%). It was hoped that some of the grey literature would be available in Altmetric.com's database, but this was not the case. Of the 46 outputs found in Altmetric.com, 38 were journal articles, 5 were book chapters and 3 books. One of the reasons for this low coverage is most certainly the lack of a unique identifier for most PLAAS outputs. The use of identifiers such as digital object identifiers (DOIs), PubMed IDs, arXiv IDs or handles from repositories has been investigated by a number of authors. Peters et al.[35] 'suggest that the adoption of this permanent identifier increases the online visibility of research data and inclusion in altmetrics tools', while Araújo et al.[36] note that the absence of a DOI diminishes the likelihood of outputs 'obtaining altmetrics data in the current scenario'. Torres-Salinas et al.[37] also emphasise the need to have a DOI when searching for altmetrics on outputs. Some of the PLAAS outputs were in the UWC institutional repository and therefore had a handle which can be used as an identifier, but in this case none was found by Altmetric because there had been no activity, such as in social media, associated with the item at the time of the search.

Altmetric.com provides the AAS which is 'derived from an algorithm, and represents a weighted count of all the attention data picked up for that research output'[38]. Holmberg[30] and Mukherjee et al.[17] are cautious about the use of an aggregated score, as the advantage of altmetrics is its 'multidimensional nature'[17] and the diversity at article level, in contradistinction to an aggregated number. However, a single value is useful as a first step in evaluating outputs which should then be followed up by studying the details of a particular article.

Of the 46 PLAAS outputs from Altmetric.com, 38 had an AAS. The other eight records are nevertheless in Altmetric.com's Explorer database and any future activity related to an item (such as tweets, Facebook shares, Mendeley readers) will be reflected in Altmetric.com and its AAS.

Along with the total outputs picked up by Altmetric.com, Figure 4 displays the AASs for authors found in Altmetric Explorer, showing that the majority of authors had a total score of less than 10. Those that scored an AAS higher than 10 were Matose (11), Hara (27) and Hall (99). The notes given in Altmetric.com alongside the AAS (not shown here) are useful as they indicate ranking according to the score e.g. if it is in the top 25, 10 or 5 percentiles or whether it is 'average', 'above average' or 'good'. The highest scoring article by Hall, with an AAS of 59, was in the top 5% of all research outputs scored by Altmetric.com indicating an excellent result. However, not all the records had notes indicating the broader significance of the score.

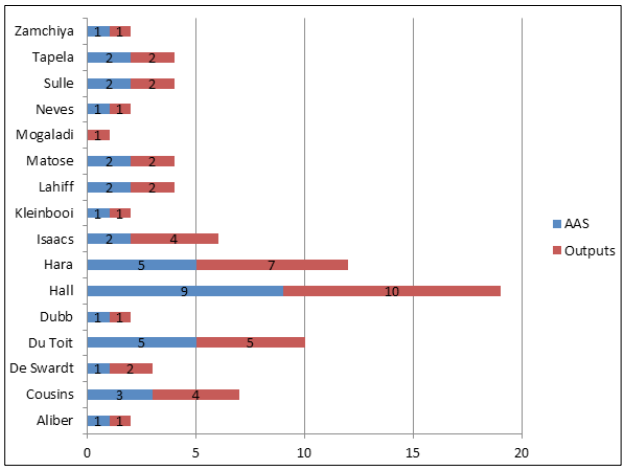


Figure 4: Authors' total outputs and those with an Altmetric Attention Score (AAS).

The Altmetric.com information for the articles that were found did nevertheless give a broader and richer understanding of the visibility and impact at article level. Twitter activity by far exceeded any other social media activity in this set of 38 records for which there were 120 tweets and only seven Facebook shares in total. It is possible that the Twitter counts were affected by the fact that PLAAS has a Twitter account and research outputs are tweeted about through this account. Altmetric information for these records included counts of news outlets (mainstream news), policy sources (such as the Food and Agriculture Organisation documents) and mentions in blogs, all of which are potentially useful information for a policy institute such as PLAAS.

As shown in Figure 4, of the 33 PLAAS authors investigated, 16 authors were included in the Altmetric Explorer database, only one of whom did not have an AAS. The highest number of outputs per author retrieved from Altmetric Explorer was 10; of these, 9 outputs had an AAS while the 10th was included in the database but had no score.

Table 6: Three PLAAS outputs with high altmetric scores

Author	Title	Year	Document type	Unique views	Downloads	Twitter	Facebook
Lahiff	Land reform in South Africa: Is it meeting the challenge?	2001	Policy brief	1252	262	0	0
Walker and Dubb	The distribution of land in South Africa: An overview	2013	Fact check	2711	494	63	6
Du Toit	Making sense of 'evidence': Notes on the discursive politics of research and pro-poor policy making	2012	Working paper	1282	595	102	51

The results from Altmetric Explorer covered a small percentage of the outputs from PLAAS and were limited to journal articles, books and book chapters only. We aimed to look at the impact and visibility of grey literature as well as traditional scholarly publications. The lack of anticipated altmetric results for grey literature (possibly because PLAAS grey literature did not have unique identifiers) necessitated a selection of three publications for analysis. These publications – a policy brief, a 'fact check' and a working paper – received the highest number of page views and downloads according to Google Analytics and therefore were considered noteworthy for further investigation. These publications and their usage metrics (page views and downloads) are shown in Table 6, along with social media metrics (Twitter and Facebook activity) associated with each. Because these three outputs were not in the Altmetric.com database, the counts of views and downloads were found by using Google Analytics, while the Facebook and Twitter APIs on the PLAAS publications website were used to count Twitter and Facebook shares.

These indicators were higher for these three outputs than for other PLAAS outputs, with downloads in the hundreds for all three. The highest number of page views (2711) was for Fact Check 1, followed by Working Paper 21 (1282 views) and Policy Brief 1 (1252 views). Working Paper 21 was downloaded the most (595 downloads) and Policy Brief 1 the least (262 downloads) of the three documents. These three publications were the only publications in the top 10 of page downloads for the PLAAS website as a whole.

Fact Check 1 had 6 Facebook shares and 63 tweets and Working Paper 1 had 52 Facebook shares and 102 tweets (Table 6). The Policy Brief was published in 2001, before Twitter was available, and so did not have any tweets recorded. The recorded counts did not include other tweets that referred to these publications but which did not provide a direct link to the URL (which often is shortened for Twitter, which can create difficulty for tracking) so the actual number of tweets relating to these publications could be considerably higher.

In order to find out more about the context in which these outputs were produced and shared, the authors were contacted via email and information was gathered from the Communications and Information Officer of PLAAS who was responsible for their online publication.

Policy Brief 1 entitled 'Land reform in South Africa: Is it meeting the challenge?' was published in 2001 and it was the first time that 'the key land reform issues were summarised and solutions offered, in a popular format' (Pointer R 2017, written communication, February 08). This first brief was originally sent out in printed form by post to a number of policymakers and others. It was uploaded onto the website in 2011 and was downloaded 262 times between then and the time of the study.

Working Paper 21 entitled 'Making sense of "evidence": Notes on the discursive politics of research and pro-poor policy making' was published in 2012 and was one of the first papers in which evidence-based policymaking practice was challenged. This approach was originally taken in the health sector in the United Kingdom and was adopted by countries in the Global South (including South Africa) that received research funding from the British Department for International Development and other donors. Shortly after the paper was released, PLAAS held a symposium which looked at evidence-based policymaking in the South African context and the paper was presented there by Du Toit, which gave it greater coverage. A final contributing factor to its online popularity was that 'a champion of the cause', Enrique Mendizabal, who was himself challenging evidence-based policymaking doctrine, actively spread word of this paper through Twitter and his blog (Du Toit A 2017, written communication, February 06). Mendizabal was an expert in the field, so when he championed the paper, many people in the field sought it out, which contributed to it being downloaded the most (595) of the three publications.

Fact Check 1 entitled 'The distribution of land in South Africa: An overview' was the first in a series of four concise papers that challenged the many land reform myths that had been widely circulating, particularly in the media. The series gave current and statistical evidence in the form of infographics regarding land ownership and land reform. At the time that the series was published, a major international conference was held that commemorated the South African 1913 Land Act and the fact checks reached a number of journalists and others at the conference. According to the PLAAS Communications and Information Officer, the series was also vigorously promoted in a social media campaign at the time of publication and the papers are still being used 4 years later, with 494 downloads for Fact Check 1 at the time of writing (Pointer R 2017, written communication, February 08). There is no updated replacement yet for these fact checks and 'in broad terms Fact Check 1 remains relevant and helps to complicate simplistic claims' (Walker C 2017, written communication, February 14).

In each of these cases, there were substantive reasons for the high altmetric counts. Either a new way of presenting information to a non-scholarly audience and wide dissemination was introduced (as in the case of the Policy Brief and Fact Check) or the publication was championed by a particularly powerful individual (as happened with the Working Paper) or was publicised at concurrent events and through the mainstream media or social media (as with the Working Paper and the Fact Check).

Survey

Of the 12 PLAAS researchers approached, 10 responded to the questionnaire about social media and online sharing tools. This survey was used to test the premise that if researchers used some of the many available social media platforms and networks that can benefit their research, then their online presence, and therefore attention paid to their work, would be high. Questions were phrased to discover how active researchers were in their academic capacity on social networking platforms; whether they had a personal website; what reference management and sharing software they used, if any; whether they had Wikipedia entries; what professional online profiles, if any, they maintained; whether they had an Open Researcher and Contributor ID (ORCID); and, what, if any, social media tools they used for research purposes.

Overall, the responses to the questionnaire illustrate that the majority of PLAAS researchers had little knowledge of the various social media platforms and tools which would give them an online research presence. Consequently, the use of many such platforms and tools was also low. The highest response rate was related to the academic networking sites Academia.edu and ResearchGate.net. In this instance, seven respondents said that they had a profile on Academia.edu and six had one on ResearchGate.net. There was a nil response to the use of ORCIDs, Wikipedia entries and to having personal websites. PLAAS researchers were shown to be active in blogging, with six saying that they write blogs (PLAAS's blog, *Another country*, is one avenue for researchers). Researchers were also relatively active on Twitter (four) and LinkedIn (five). The reference management system, Zotero, was used by seven of the respondents and one used Mendeley.

Conclusion

We have shown that in the period under review, PLAAS produced a high number of outputs of many different types, not only scholarly journal articles and books but also much grey literature. While Google Scholar and Scopus are valuable tools for measuring visibility and impact of research outputs, both have the limitation of not being able to provide a definitive list of outputs from an author or institution; for this study, a master list was compiled as the full record of the body of research published by PLAAS from 1995 to 2015.

The bibliometric and altmetric analyses were successfully carried out to measure the visibility and impact of PLAAS's body of research. The citations and the comparative *h*-indices from both Google Scholar and Scopus show that PLAAS researchers' visibility and impact in the scholarly domain, relative to others in the social science disciplines at UWC, was high. This indicates that the PLAAS research produced in the years 1995–2015 has had an impact in the scholarly context, at least for those outputs included in the citation indices.

The altmetric results were, however, disappointing overall. Only a few journal articles in the Scopus index were also included in the Altmetric.

com database. Thus, the visibility and impact of the PLAAS grey literature is largely unknown at this stage. There are data available from Google Analytics and the Twitter and Facebook APIs at article level, but these data are scattered and difficult to access. Moreover, other indicators that could contribute to measuring impact are not readily available, such as citations and use by policy documents.

The potential for altmetrics to be beneficial for PLAAS was demonstrated in the three case studies of PLAAS-published material. The high numbers of downloads and tweets, some citations and Facebook shares of the particular outputs show this potential. Much of the social media activity can be attributed to the campaigns or events that took place around these publications or by particular individuals using social media platforms such as Twitter extensively to discuss and disseminate the research.

The survey investigating the use of social media with respect to research outputs by PLAAS researchers showed that the majority of the researchers are unaware of the social media tools and platforms that could be used to increase the visibility of their research. They do not prioritise the use of social media in their research activities even if they see it as potentially beneficial. This finding is consistent with the low coverage of PLAAS outputs by altmetrics.

In terms of visibility and impact, we have demonstrated that the use of bibliometric and altmetric analyses which make use of a variety of sources can yield a rich picture of research output and significance, providing insight into scholarly communication at a research unit such as PLAAS. The application of this research design in other research units and departments at UWC can generate results that could be useful to research management at UWC.

PLAAS is a reputable institute which produces a high volume of research on important and contentious issues in South Africa. PLAAS researchers participate in high-level government forums, for instance Prof. Hall is on the advisory panel appointed in 2018 by President Ramaphosa working towards practical implementation of the redistribution of land. It would be worth investigating ways in which to increase the visibility and impact of this work, thus ensuring its application to serious policy debates around land reform in the country. Some practical recommendations for improving visibility include:

- using unique identifiers such as DOIs for all publications and ORCIDs for all authors;
- promoting open access publishing by contributing to relevant repositories, and by publishing in suitable open access journals;
- becoming familiar with social media tools and platforms and how their use can benefit research activity for the Institute and individual researchers; and
- improving and maintaining Google Scholar profiles in order to keep them current and accurate as a source of publication and citation counts.

Acknowledgements

This work is based on research funded by the National Research Foundation of South Africa. We thank the Institute for Poverty, Land and Agrarian Studies at the University of the Western Cape for the contribution of information provided for the development of this study.

Authors' contributions

G.K.: conceptualisation, methodology, data collection, data analysis, writing the initial draft and revisions. M.K.: conceptualisation, methodology, writing – revisions, student supervision. M.N.: conceptualisation, methodology, writing – revisions, student supervision, funding acquisition.

References

1. Pouris A. South Africa's research publication record: The last ten years. S Afr J Sci. 2003;99(9/10):425–428.
2. Van Leeuwen T. Measuring research: What everyone needs to know. J Informetr. 2018;12(4):1232–1234. http://dx.doi.org/10.1016/j.joi.2018.08.010
3. Gingras Y. Bibliometrics and research evaluation: An overview [document on the Internet]. c2011 [cited 2018 Feb 21]. Available from: https://issek.hse.ru/data/2011/05/30/1212612098/Bibliometrics-Evaluation.Intro.pdf
4. Lundberg J. Bibliometrics as a research assessment tool – impact beyond the impact factor [thesis]. Stockholm: Karolinska Institutet; 2006 [cited 2016 Apr 02]. Available from: https://openarchive.ki.se/xmlui/handle/10616/39489
5. Ebrahimy S, Setareh F. Direct and indirect influence of altmetrics on citation in social systems: Assessing a new conceptual model. Int J Inform Sci Manage. 2018;16(2):161–173. Available from: https://ijism.ricest.ac.ir/index.php/ijism/article/view/1277
6. Groos O, Pritchard A. Documentation notes. J Doc. 1969;25(4):344–349. https://doi.org/10.1108/eb026482
7. Gorraiz J, Wieland M, Gumpenberger C. Individual bibliometric assessment @ University of Vienna: From numbers to multidimensional profiles [article on the Internet]. c2016 [cited 2016 Jun 05]. Available from: https://arxiv.org/ftp/arxiv/papers/1601/1601.08049.pdf
8. Borgman CL. Digital libraries and the continuum of scholarly communication. J Doc. 2000;56(4):412–430. http://dx.doi.org/10.1108/EUM0000000007121
9. ACRL Scholarly Communications Committee. Principles and strategies for the reform of scholarly communication 1 [article on the Internet]. Chicago, IL: Association of College and Research Libraries (ACRL); c2003 [cited 2016 May 09]. Available from: http://www.ala.org/acrl/publications/whitepapers/principlesstrategies
10. Barjak F. The role of the Internet in informal scholarly communication. J Am Soc Inf Sci Technol. 2006;57(10):1350–1367. https://doi.org/10.1002/asi.20454
11. Borgman CL, Furner J. Scholarly communication and bibliometrics [article on the Internet]. Medford, NJ: ARIST. c2002 [cited 2016 Mar 28]. Available from: http://works.bepress.com/furner/1/
12. Czerniewicz L. Power and politics in a changing scholarly communication landscape. Paper 23. In: Proceedings of the International Association of Scientific and Technological University Libraries Conferences; 2013 April 14–18; Cape Town, South Africa. West Lafayette, IN: IATUL, Purdue University; 2013. Available from: http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1982&context=iatul
13. Haustein S, Sugimoto C, Larivière V. Guest editorial: Social media in scholarly communication. Aslib J Inform Manage. 2015;67(3). https://doi.org/10.1108/AJIM-03-2015-0047
14. Liu Z. Trends in transforming scholarly communication and their implications. Inf Process Manag. 2003;39(6):889–898. https://doi.org/10.1016/S0306-4573(02)00057-2
15. Maron NL, Smith, KK. Current models of digital scholarly communication results of an investigation conducted by Ithaka for the Association of Research Libraries [article on the Internet]. Washington DC: Association of Research Libraries; 2008 [cited 2016 Feb 21]. Available from: https://www.arl.org/resources/current-models-of-digital-scholarly-communication-results-of-an-investigation-conducted-by-ithaka-for-the-association-of-research-libraries/
16. Van de Sompel H, Payette S, Erickson J, Lagoze C, Warner S. Rethinking scholarly communication: Building the system that scholars deserve. D-Lib Magazine. 2004 September. Available from: http://www.dlib.org/dlib/september04/vandesompel/09vandesompel.html
17. Mukherjee B, Subotić S, Chaubey AK. And now for something completely different: The congruence of the Altmetric Attention Score's structure between different article groups. Scientometrics. 2018;114(1):253–275. https://doi.org/10.1007/s11192-017-2559-8
18. Czerniewicz L, Kell C, Willmers M, King T. Changing research communication practices and open scholarship: A framework for analysis [article on the Internet]. Cape Town: Scholarly Communication in Africa Programme; 2014 [cited 2017 Mar 10]. Available from: https://open.uct.ac.za/bitstream/item/9250/SCAP_Czerniewicz_ChangingResearchOpenScholarship_2014.pdf?sequence=1
19. Erdt M, Nagarajan A, Sin S-CJ, Theng Y-L. Altmetrics: An analysis of the state-of-the-art in measuring research impact on social media. Scientometrics. 2016;109(2):1117–1166. https://doi.org/10.1007/s11192-016-2077-0
20. Holmberg K, Vainio J. Why do some research articles receive more online attention and higher altmetrics? Reasons for online success according to the authors. Scientometrics. 2018;116(1):435–447. https://doi.org/10.1007/s11192-018-2710-1

21. Bornmann L, Haunschild R, Adams J. Convergent validity of altmetrics and case studies for assessing societal impact: An analysis based on UK Research Excellence Framework (REF) data [article on the Internet]. c2018 [cited 2018 Oct 21]. Available from: https://figshare.com/articles/Convergent_validity_of_altmetrics_and_case_studies_for_assessing_societal_impact_an_analysis_based_on_UK_Research_Excellence_Framework_REF_data/7165333

22. Roemer RC, Borchardt R. Meaningful metrics: A 21st-century librarian's guide to bibliometrics, altmetrics and research impact. Chicago, IL: Association of College and Research Libraries; 2015.

23. Sutton S. Altmetrics: What good are they to academic libraries? CULS Proceedings. 2014;4(2). https://doi.org/10.4148/2160-942X.1041

24. The Institute for Poverty, Land and Agrarian Studies (PLAAS). History [webpage on the Internet]. No date [cited 2016 Jun 06]. Available from: http://www.plaas.org.za/history

25. Tran C, Aytac S. Measuring scholarly productivity of Long Island educational institutions: Using Web of Science and Scopus as a tool. Evid Based Libr Inf Pract. 2016;11(3):16–33. https://doi.org/10.18438/B8JS8P

26. Kahn M. A bibliometric analysis of South Africa's scientific outputs – some trends and implications. S Afr J Sci. 2011;107(1/2), Art. #406, 6 pages. https://doi.org/10.4102/sajs.v107i1/2.406

27. Rotich DC, Onyancha OB. Trends and patterns of medical and health research at Moi University, Kenya, between 2002 and 2014: An informetrics study. S Afr J Libr Inf Sci. 2017;82(2):20–33. https://doi.org/10.7553/82-2-1626

28. Moed HF, Halevi G. Multidimensional assessment of scholarly research impact. J Assoc Inf Sci Technol. 2015;66(10):1988–2002. https://doi.org/10.1002/asi.23314

29. NISO Altmetrics Initiative Working Group A. Altmetrics definitions and use cases. Draft for public comment. Report no. NISO RP-25-201x-1 [document on the Internet]. Baltimore, MD: NISO; 2016 [cited 2016 Apr 17]. Available from: http://www.niso.org/apps/group_public/download.php/16268/NISO%20RP-25-201x-1%2C%20Altmetrics%20Definitions%20and%20Use%20Cases%20-%20draft%20for%20public%20comment.pdf

30. Holmberg K. Classifying altmetrics by level of impact. In: Salah AA, Tonta Y, Salah AAA, Sugimoto C, Al U, editors. Proceedings of the 15th International Society for Scientometrics and Informetrics Conference; 2015 July 03 – June 29; Istanbul, Turkey. Leuven: ISSI; 2015. p. 101–102. Available from: https://pdfs.semanticscholar.org/49df/91ccd2579b4b345c135a6ff751bf39f7ee86.pdf

31. Onyancha OB, Ocholla DN. Assessing researchers' performance in developing countries: Is Google Scholar an alternative? [article on the Internet]. Mousaion. 2009;27(1):43–64. [cited 2017 Feb 01]. Available from: https://www.researchgate.net/publication/228911588_Assessing_researchers'_performance_in_developing_countries_is_Google_Scholar_an_alternative

32. Castillo M. Measuring academic output: The h-index. AJNR Am J Neuroradiol. 2010;31(5):783–784. https://doi.org/10.3174/ajnr.A1888

33. Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci USA. 2005;102(46):16569–16572. https://doi.org/10.1073/pnas.0507655102

34. Haustein S, Larivière V. The use of bibliometrics for assessing research: Possibilities, limitations and adverse effects. In: Welpe IM, Wollersheim J, Ringelhan S, Osterloh M, editors. Incentives and performance: Governance of knowledge-intensive organizations. Cham: Springer International Publishing; 2015. p. 121–139.

35. Peters I, Kraker P, Lex E, Gumpenberger C. Research data explored: Citations versus altmetrics. In: Salah AA, Tonta Y, Salah AAA, Sugimoto C, Al U, editors. Proceedings of the 15th International Society for Scientometrics and Informetrics Conference; 2015 July 03 – June 29; Istanbul, Turkey. Leuven: ISSI; 2015 [cited 2016 Apr 17]. Available from: https://arxiv.org/abs/1501.03342

36. Araújo RF, Murakam TRM, De Lara JL, Fausto S. Does the Global South have altmetrics? Analyzing a Brazilian LIS journal. In: Salah AA, Tonta Y, Salah AAA, Sugimoto C, Al U, editors. Proceedings of the 15th International Society for Scientometrics and Informetrics Conference; 2015 July 03 – June 29; Istanbul, Turkey. Leuven: ISSI; 2015 [cited 2016 Apr 17]. Available from: https://pdfs.semanticscholar.org/5859/d62b55e76d906c84401254172ff96545fc49.pdf

37. Torres-Salinas D, Robinson-Garcia N, Jiménez-Contreras E. Can we use altmetrics at the institutional level? A case study analysing the coverage by research areas of four Spanish universities. In: Proceedings of the 21st International Conference on Science and Technology Indicators; 2016 September 14–16; Vienna, Austria [cited 2016 Jun 04]. Available from: https://arxiv.org/ftp/arxiv/papers/1606/1606.00232.pdf

38. An introduction to altmetric data – what can you see? [webpage on the Internet]. The Source. 2015 August 13 [cited 2017 Mar 05]. Available from: http://www.springersource.com/an-introduction-to-altmetric-data-what-can-you-see/

AUTHORS:
Jaya Raju[1]
Andiswa Mfengu[1]
Michelle Kahn[1]
Reggie Raju[2]

AFFILIATIONS:
[1]Department of Knowledge and Information Stewardship, University of Cape Town, Cape Town, South Africa
[2]UCT Libraries, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Jaya Raju

EMAIL:
Jaya.Raju@uct.ac.za

DATES:
Received: 11 Dec. 2018
Revised: 05 Mar. 2019
Accepted: 05 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Raju J, Mfengu A, Kahn M, Raju R. Transition to open: A metrics analysis of discoverability and accessibility of LIS scholarship. S Afr J Sci. 2019;115(7/8), Art. #5867, 8 pages. https://doi.org/10.17159/sajs.2019/5867

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☒ On request from author(s)
☐ Not available
☐ Not applicable

EDITORS:
John Butler-Adam
Maitumeleng Nthontho

KEYWORDS:
open access; journal metrics; scholarship discoverability; scholarship accessibility

FUNDING:
None

Transition to open: A metrics analysis of discoverability and accessibility of LIS scholarship

Metrics analysis of journal content has become an important point for debate and discussion in research and in higher education. The *South African Journal of Libraries and Information Science* (*SAJLIS*), a premier journal in the library and information science (LIS) field in South Africa, in its 85-year history, has had multiple editors and many contributing authors and has published over 80 volumes and 160 issues on a diversity of topics reflective of LIS theory, policy and practice. However, how discoverable and accessible has the LIS scholarship carried by the Journal been to its intended readership? *SAJLIS* transitioned to open access in 2012 and this new format in scholarly communication impacted the Journal significantly. The purpose of this paper is to report on a multiple metrics analysis of discoverability and accessibility of LIS scholarship via *SAJLIS* from 2012 to 2017. The inquiry takes a quantitative approach within a post-positivist paradigm involving computer-generated numerical data as well as manual data mining for extraction of qualitative elements. In using such a multiple metrics analysis to ascertain the discoverability and accessibility of LIS scholarship via *SAJLIS* in the period 2012 to 2017, the study employs performance metrics theory to guide the analysis. We highlight performance strengths of *SAJLIS* in terms of discoverability and accessibility of the scholarship it conveys; identify possible growth areas for strategic planning for the next 5 years; and make recommendations for further study for a more complete picture of performance strengths and areas for improvement.

Significance:

- The importance of discoverability and accessibility of scholarship carried by a scholarly journal is conveyed.
- The need to use multiple metrics for objective evaluation of the discoverability and accessibility of the scholarly content of a journal is emphasised.
- The impact of open access on the discoverability and accessibility of the content of a scholarly journal is assessed.

Introduction and background to the study

Evaluation of scientific and scholarly content is a critical element of the scholarly communication process. Harnad[1] differentiates between subjective evaluation of such content (for example peer review) and objective evaluation (for example metrics analysis such as bibliometrics, or more broadly scientometrics). Neither evaluation, Harnad[1] claims, has 'face-validity' (that is, a personal assessment that the evaluation instrument appears, on the face of it, to measure the construct it is intended to measure) and thus 'multiple tests rather than a single test [are required] for evaluation'. It is in this context that we report here on the use of multiple metrics as an objective means of determining the discoverability and accessibility of library and information science (LIS) scholarship via the *South African Journal of Libraries and Information Science* (*SAJLIS*) when it transitioned to an online open access platform; after all, the benefit of open access (that is, free online availability of scholarly content for all to access without cost or licensing barriers) cannot be realised if such content is not discoverable. For purposes of providing a research context, an account of the history of the Journal is necessary.

History of the Journal

The *South African Journal of Libraries and Information Science* 'has, since 2002, Vol. 68(1), been published as the official research journal of the Library and Information Association of South Africa (LIASA)'[2]. LIASA was established in 1997 as the result of a unification of the library and information services (LIS) associations SAILIS (South African Institute for Librarianship and Information Science) and ALASA (African Library Association of South Africa). The establishment of LIASA was part of a nationwide reconstruction and development effort in the aftermath of the establishment of a new democratic order in South Africa in 1994 following decades of apartheid governance.

The first issue of the Journal was published in July 1933 as *South African Libraries*, the quarterly journal of the South African Library Association (SALA), founded in 1930. The title of the Journal has 'changed slightly at various stages in its existence' but the Journal itself has run continuously since its first issue.[2] Volumes 1 to 48 of *South African Libraries* (1933–1980) were published by SALA and were edited by prominent South African academic and public librarians appointed by SALA.[2] In 1979, SALA reconstituted itself as a professional graduate association known as the South African Institute for Librarianship and Information Science (SAILIS). Following this reconstitution, from 1982 the title of *South African Libraries* changed to the *South African Journal for Librarianship and Information Science*.

Walker[2] explains that, in 1984, SAILIS transferred the management and publication of *SAJLIS* to the Bureau for Scientific Publications of the Foundation for Education, Science and Technology for financial and operational reasons. Within this structure, the Council for Scientific Publications managed the publication of a number of South African scientific journals. *SAJLIS* joined this stable of publications from 1984 and was then renamed the *South African Journal of Library and Information Science*. *SAJLIS* remained a quarterly publication but the Bureau for Scientific Publications imposed some design and content changes.[2] SAILIS appointed a Scientific Editor, a

Reviews Editor and an Editorial Secretary. The Journal's Editorial Committee was made up of senior South African LIS professionals. Instructions to Authors and an Editorial Policy focusing on contributions that reflect scientific investigation were published with each issue. *SAJLIS* remained with the Bureau for Scientific Publications from 1984 until the disestablishment of SAILIS in 1998 when it was transferred to the SALI (South African Library and Information) Trust, which was formed to manage the assets of SAILIS until their transfer to LIASA. During this transitional period spanning 1998–2001, Walker[2] records 'a hiatus in the frequency of publication' of *SAJLIS*. Responsibility for the Journal was transferred by the SALI Trust to LIASA in 2002 and, once again, continuity in publication of issues was re-instated but with a slight change in title and a new ISSN. The *South African Journal of Libraries and Information Science* became the official journal of LIASA, with two issues published per year.

Since 2002, *SAJLIS* has had three Editors-in-Chief – all senior LIS academics – an Editorial with each issue and a globally representative Editorial Advisory Board of eminent library and information scholars and professionals. The Editor-in-Chief serves for fixed maximum terms of office as per LIASA's election of office bearers' policy. In 2011, LIASA signed the *Berlin Declaration on Open Access to Knowledge in the Sciences and the Humanities* and, as a demonstration of its commitment to the open access movement, took the decision to publish *SAJLIS* as an online-only open access publication from 2012 onwards using OJS (Open Journal Systems) as an online publishing platform. All back issues of *SAJLIS* from 1997 to 2011 have been digitised, thus making all issues of *SAJLIS* in the LIASA era openly available for all to access freely at http://sajlis.journals.ac.za/pub.

The online era of the Journal also saw the establishment of a journal management team comprising the Editor-in-Chief, a Journal Manager to look after the OJS management of the Journal, a Language and Layout Editor, and Communication and Advocacy Support. The Journal has an online ISSN, digital object identifiers (DOIs) are assigned via Crossref to each article published, and the content is licensed under a Creative Commons Attribution-Share-Alike 4.0 International Licence. The Journal continued with its practice of charging page fees to authors for manuscripts accepted for publication, in the form of article processing charges (APCs) to cover basic online publication costs. Author guidelines were updated for an online format and online submission guidance is provided on the Journal site. This phase in the development of *SAJLIS* saw the inclusion of ORCIDs for each author to promote the unique identification of authors and their contribution to scholarly literature; and emerging scholars began to be included on the Editorial Advisory Board. In 2015–2017, *SAJLIS* underwent the Academy of Science of South Africa (ASSAf)'s rigorous peer-review evaluation. The outcome, announced in 2018, included continued listing of *SAJLIS* on the Department of Higher Education and Training (DHET) list of accredited journals and an invitation for *SAJLIS* to join the SciELO South Africa platform – South Africa's premier open access full-text journal database which includes a selected collection of peer-reviewed South African scholarly journals.

Since its inception to the present, *South African Libraries* and then *SAJLIS* have been indexed by a range of local and international bibliographical and indexing services. These include Library Literature, Library Science Abstracts (later called Library and Information Science Abstracts), Index to South African Periodicals (ISAP), INSPEC (later INSPEC-Computer and Control Abstracts), Academic Abstracts, Academic Search, Current Awareness Bulletin IBZ+IBR, Internet Access BUBL, Masterfile, South African Studies, Information Science and Technical Abstracts (ISTA).[2] Currently, *SAJLIS* is indexed by, inter alia, EBSCOhost, Proquest and Online Computer Library Center.[3] The inclusion of a journal in indexes allows its content to be discoverable and, importantly, the selection of a journal for inclusion in indexing services is also a reflection of its quality. *SAJLIS* is yet to access Web of Science and Scopus index listings.

Research problem

In its 85-year-old history, *SAJLIS* has seen over 80 volumes, more than 160 issues, multiple editors, many authors and a diversity of topics within LIS theory, policy and practice reflective of the times through which the Journal has been published. The objective of the Journal is to 'serve and reflect the interests of the South Africa LIS community across the spectrum of its wide-ranging activities and research'[4]. In addition to formal scholarly articles, articles on issues of practice are solicited 'to actively encourage young writers, researchers and practitioners to share their experiences and findings so that all aspects of research, teaching, thinking and practice are brought together'[4]. The Journal's primary target audience is LIS and related research communities, including academics and scholars (nationally and internationally), practising information professionals as well as policymakers.

Despite this illustrious history of a premier journal in the LIS field in South Africa, the question is: how discoverable and accessible has the LIS scholarship carried by the Journal been to its intended readership? As mentioned earlier, motivated by the Open Movement and its promotion of discoverability and accessibility,[5,6] *SAJLIS* transitioned to open access in 2012, one of the first titles, both within South Africa and internationally, to do so. This new format in scholarly communication impacted the Journal significantly. The purpose of this paper is to report on a metrics analysis of discoverability and accessibility of LIS scholarship via *SAJLIS* from 2012 to 2017.

Theoretical framing

A metric 'is a verifiable measure, stated in either quantitative or qualitative terms and defined with respect to a reference point'[7]. Metrics exist as tools demonstrating performance and as such provide the following functions: *control* (metrics enable people to evaluate and control the performance of a resource for which they are responsible, in this case *SAJLIS*); *communication* (metrics communicate performance to stakeholders such as the discoverability and accessibility of LIS scholarship carried by *SAJLIS*); and *improvement* (metrics identify gaps 'between performance and expectation' that 'ideally point the way for intervention and improvement').[7] Using metrics analysis to ascertain discoverability and accessibility of LIS scholarship via *SAJLIS* in the period 2012 to 2017 addresses these three areas of *control, communication* and *improvement* for purposes of demonstrating strengths and gaps and to identify growth areas and future challenges.

Literature

We present a review of the literature related to discoverability and accessibility of open access journals, including metrics that may be used for evaluating journals, communicating performance and identifying gaps in performance (the three functions of metrics – *control, communication* and *improvement* – as identified by Melnyk et al.[7]). These metrics include bibliometrics, such as citation analysis; webometrics like downloads, views and reads, and altmetrics like social media links and mentions; and indications of journal rigour like the review process or editorial board composition.

Citations as indicators of discoverability and accessibility

Historically, citations have been viewed as a measure of use and 'the best available approximations of academic impact'[8], whether of the individual author, an institution or country, or a journal. Schimmer et al.[9] report that evidence of growth in open access publishing can be seen in the growth in the number of papers published in open access journals. Whether this growth is reflected in citation counts has been a subject of several studies.

Sotudeh and Horri[10] – examining a sample of gold open access journals – found that, although not all open access articles are cited, 'citations to [open access] articles increase at a faster rate relative to the increase in publication of [open access] articles'[10], thus indicating that citation counts can be affected by the number of articles published in a journal. Mukherjee[11] counted total articles published in a 4-year period (2000–2004) for 17 open access LIS journals but did not find an increase in citations for all journals in the sample, thus concluding that 'just being open access is not a guarantee of success'[11]. Mukherjee[11] counted only content considered 'citable' (that is, excluding editorials, book reviews, news items and such) and listed on Google Scholar, as not all journals – and particularly LIS

journals – are indexed in the large scientific databases of Web of Science and Scopus.

The ease with which open access journal articles can be discovered and accessed can create a 'citation advantage' for open access journals[12] in which the availability of these articles results in more reads and citations than those of articles from closed journals. While citation advantage is not a given, results from a study by Atchison and Bull[13] who looked at citations of self-archived (green) open access articles, were 'mixed' across disciplines, but there was shown to be citation advantage in the social sciences when it came to open access publishing.

Citation counts can likewise be affected by geography: Fukuzawa[14] found that papers published in open access journals were cited in a greater number of countries. The wide discoverability and free online accessibility of these journals also resulted in total citations for open access journals being higher than those for non-open access journals.[14] Tang et al.[12] tested whether geography had an effect on citations, hypothesising that open access articles, because free, would be more highly cited in developing countries. While they were not able to prove their assumption, they did find that open access articles in their sample 'showed significant citation advantages' overall over a 4-year period.[12]

Mukherjee[11] concluded that 'open access journals in LIS are rapidly establishing themselves as a viable medium for scholarly communication' because of the quantity of open access articles being published. LIS open access journals had a low journal self-citation rate (that is, contributors do not cite the journal to which they are contributing), which could mean 'higher visibility and a higher impact in the field' for these journals as citations are coming from outside the contributor community.[11]

Alternative measures of performance

While citations are one way of demonstrating the visibility and accessibility of a journal, alternative counts, such as downloads, views, reads and social media mentions can also be used as indicators, particularly in a non-traditional publishing context. Kurtz and Henneken[15] defined 'download' as 'any accessing of data on an article, whether full text, abstract, citations, references, associated data, or one of several other lesser-used options'. Downloads are 'a good surrogate for usage' with an added advantage of being a simple measure.[16] A download, even if it does not result in a citation, can indicate 'respect' for research[15], an interest in it and intention to read it. Altmetrics, which count social media activity at the article level (for example, recommendations and 'captures' such as bookmarks and saves of the online article)[17] can, along with views and downloads, be used to complement traditional metrics. Through tools such as Altmetric Explorer, ImpactStory and Plum Analytics, more immediate evidence of engagement with scholarly content can be collected than what traditional metrics can supply. Altmetrics can be used to study 'the attention received by journals through social media and other online access platforms'[18]. In an investigation of the activity of six PLoS journals, Huang et al.[17] compared traditional metrics (citations) and altmetrics to see whether there was a correlation between altmetrics, measured using the Altmetric Attention Score (AAS), and citations in Web of Science. They found that there was 'a possibility that AAS may be an indicator of citation numbers' if the nature of the journal is considered,[17] supporting the call for altmetrics to be used alongside traditional metrics.

With access to relevant software, views and downloads are easy to count and can thus be used to track the growth of a journal. Mintz and Mograbi[19] did so for the journal *Political Psychology* over a 6-year period (2009–2014) and discovered that the number of downloads grew by over 680% in the period under review. Views and downloads are also a more immediate measure of use than citations which require years to accumulate.[20] Moed and Halevi[20] also report that downloads do not necessarily result in citations.

Similarly, Bazrafan et al.[21] investigated submissions, downloads, readership and citation data for the *Journal of Medical Hypotheses and Ideas* for the year 2012 and found that, while all articles had been viewed and downloaded, the average citation per article of those published in 2012 was only 0.7.

Downloads can be affected by the interest and location of the reader. While download numbers were high overall for the *Journal of Medical Hypotheses and Ideas*, it was discovered that articles about innovative ideas or on topical research were downloaded more than others.[21] There were more downloads from America and Africa because of 'the role of these regions in the share of the world's medical knowledge'[21] but the journal was accessed from all over the world.

As with downloads, altmetrics such as tweets, likes and shares can easily be counted but do not necessarily result in citations. They are, however, awareness- and visibility-generating altmetrics.[22] Onyancha[18] found that the 273 DHET-accredited South African journals (not all open access) that he investigated had a social media presence, particularly on Twitter. Papers from these journals that received the most mentions on social media were multidisciplinary.[18]

Journal rigour and content

While studies focusing on objective (quantitative) measures to analyse discoverability and accessibility dominate the literature, Fischer[23] advocated for 'top-quality service to authors and other stakeholders', along with a rigorous review process and a highly reputable editorial board, to improve journal performance, particularly when it comes to attracting submissions. Open access journals have had to deal with the fallout from predatory journals which have 'tainted the reputation' of genuine open access publishing.[24] Thus, open access journals which retain the rigour and standards of traditionally published academic journals are bound to receive more submissions – and consequently more downloads and citations – than other open access journals. Te et al.[25] examined LIS journals that were indexed in the Directory of Open Access Journals (DOAJ) and the Open Access Journal Search Engine (OAJSE) and found that the 65 LIS journals in these lists were of a high standard and maintained levels of rigour of traditional journals.

Subjects covered in a journal also affect its use and therefore Te et al.[25] also examined the content matter of the LIS journals in their sample, finding that the most popular topics were research, information systems and technology, information science, information literacy, academic librarianship and libraries, and local librarianship.[25] Mukherjee[11] found that information technology articles predominated in the LIS journals sampled. Logically, articles related to on-trend topics would positively influence the attention a journal receives, both from contributors and readers. Despite increased submissions, academic rigour of a journal would preclude a high acceptance rate.[23]

Björk[24] claims that open access publishing also increases the societal impact of the research that is available open access – something that publishers and researchers should not overlook. South Africa is playing a role in the open access movement by being the biggest producer of open access journals on the continent after Egypt, as highlighted by Nwagwu and Makhubela[26] in a study assessing the progress of open access in Africa. However, with Egypt publishing 75.9% of the continent's open access journals, South Africa 11.1% and Nigeria 5.9%, the uptake of open access journals in the rest of Africa is low.[26] Nwagwu and Makhubela[26] report that, in a global context, the number of African open access journals is small (only 6.3% of journals listed in the DOAJ database are African). The small uptake means less competition and therefore an increased visibility for the open access journals already being published, particularly if they are addressing important research areas on the continent.

In summary, while it is still relevant to measure the performance of a journal using traditional means (for example, via peer review), as research is no longer disseminated and accessed only via traditional channels such as journal publication, measurement must take place via other channels too.[18] For a holistic picture, multiple indicators are necessary, as pointed out by Harnad[1]. Metrics can include objective evaluation involving bibliometrics and altmetrics as well as subjective evaluation of the quality of a journal (such as its peer review process and the content it publishes), all of which influence visibility and accessibility. The literature reviewed here shows that becoming open access does not automatically mean an improvement in journal performance but that better discoverability and accessibility, publishing articles on topical issues in the discipline, and a good reputation

(founded on journal rigour) will lead to more exposure for a journal, thus giving it the potential to improve its performance. In this inquiry, the focus is on objective indicators of *SAJLIS* performance.

Methodology

The inquiry takes a quantitative approach within a post-positivist paradigm, that is, objective or empirical science that allows for the consideration of the behaviour of humans. In the case of this research, this approach translates into the use of largely computer-generated numerical data but also some manual data mining for extraction of a few qualitative elements which are then reduced to quantitative measures.[27] We use performance metrics theory to guide the analysis, which covers three broad performance areas during the Journal's open era:

1. The extent of growth and rigour of the Journal covering areas such as number of submissions, acceptances and rejections; geographical distribution of authors; academic and practitioner input;
2. Discoverability and accessibility using Matomo (Piwik) to ascertain the geographical distribution of the views and downloads; and altmetrics tools such as Plum Analytics to determine usage, capture and social media mentions at article level; and,
3. Citation analysis of the Journal using Google Scholar. Google Scholar was used to count citations as *SAJLIS* is not currently indexed by the large indexing services, Scopus and Web of Science. For article-level analysis, purposive sampling was employed to select 25% of the journal articles published over the identified 6-year period based on topical issues in LIS as reflected in the Association of College and Research Libraries (ACRL)[28] top trends and in the International Federation of Library Associations and Institutions (IFLA)[29] trend report.

Such a metrics analysis using objective albeit multiple indicators of performance as advocated by Harnad[1] to achieve 'face-validity' in the evaluation of the Journal's performance would serve to highlight performance strengths of *SAJLIS* as well as identify growth areas for the next 5 years in terms of discoverability and accessibility of the scholarship it conveys.

For this multiple testing, data were retrieved from the journal hosting platform, OJS, and Matomo (previously known as Piwik), an open source web analytics application, to track the visits and downloads. As much as OJS and Matomo provide important data, there was a need for the researchers to do a combination of computer-generated data and manual data mining to extract such data as geographical distribution of authors, and practitioner and academic contribution. Article-level metrics (altmetrics) were accessed from PlumX metrics to provide insights into the ways people interact with individual pieces of research output in the online environment,[30] and citation data were retrieved from Google Scholar. These data extractions provided means for objective evaluation of the Journal using multiple metrics or indicators.

Each visit by an individual to the website, as long as subsequent visits are more than 30 minutes later, is counted by Matomo[31] as a new site visit. Actions refer to the number of actions performed by visitors to a site. Actions can be page views, internal site searches, downloads or outlinks (that is, external URLs that are clicked by visitors from *SAJLIS* website pages).[31] Unique visitors refer to the number of unduplicated visitors calling at the website, and every user is only counted once even if they visit the website multiple times a day.[31] *SAJLIS* published 62 articles between 2012 and 2017 (excluding editorials and book reviews), as shown in Table 1. The study sampled 25% (16) of the published articles in this period, and the sample was purposively selected according to the ACRL top trends[28] and IFLA trend report[29]. The ACRL reviews developments and issues affecting academic libraries and higher education while IFLA in its trend report reflects on the forces shaping library and information services broadly. These reports identified the following top trends, among others: research data management, open scholarship and open access, open education, e-books, information literacy, social media, patron-driven collection development, ICTs (infrastructure and connectivity).

Table 1: *South African Journal of Libraries and Information Science* submissions, acceptances, rejections and user numbers

Year	2012	2015	2016	2017	2018
Issues evaluated	2	2	2	2	1
Total submissions	32	41	40	62	35
Peer reviewed submissions	21	33	28	58	22
Submissions accepted and published [62]	16	14	13	13	6
Submissions declined	18	27	27	49	29
Days to review	53	51	55	56	69
Days to publication	81	90	74	122	102
Registered users	86	423 (80 new)	516 (93 new)	943 (427 new)	1135 (192 new)
Registered readers	85	393 (62 new)	471 (78 new)	875 (404 new)	1048 (173 new)

It should be noted that in the data presentation (see Table 1), the number of submitted, accepted for publication and rejected manuscripts for the years 2013 and 2014 were not included because the *SAJLIS* digitisation of back issues (referred to earlier) in 2013 and 2014 inadvertently distorted the OJS statistics for these years. Notwithstanding this exclusion, sufficient chronological data are available to reflect important trends. Similarly, PlumX metrics for *SAJLIS* articles published in 2012 were not available, for reasons beyond our control. PlumX metrics are divided into five categories: usage, capture, mentions, social media and citations. Usage is a way to signal if anyone is reading the articles or otherwise using the research; usage counts such things as clicks, downloads and views, and it is the most used metric after citations.[30] Captures indicate that someone wants to return to the work as it would be bookmarked, added to favourites, saved to readers, and so on; captures can be an indicator of future citations.[30] Mentions are a measure of activity in news articles or blog posts while social media measures track the attention around the research, and these collectively ascertain if people are truly engaging with the research and how well the research is being promoted.[30] Three of the PlumX metrics (that is, usage, captures and social media) were used for this inquiry; mentions were excluded (because there were limited mention metrics), as were citations (because Google Scholar was available for complete citation analysis).

Findings and discussion

Findings and related discussions are presented in terms of the core metric functions of *control, communication* and *improvement*.[7]

Control

Metrics may be used to monitor and evaluate (control) the performance of *SAJLIS.* The extent of growth and rigour of the Journal is reported using the number of submissions, acceptances and rejections, the geographic distribution of authors, and practitioner and academic contribution. Table 1 reflects the growth pattern of *SAJLIS* (despite the omission of years 2013 and 2014). Also note that, for 2018, statistics are presented for one issue only – the second issue for the year was yet to be published at the time of undertaking this research. Table 1 reflects a general trend of increase in the number of submissions. In 2012, 2016 and 2018, an average of over 30% of manuscripts was declined before the peer review process, perhaps because of non-compliance with submission requirements, demonstrating the rigour of the Journal in terms of acceptance of manuscripts for peer review. In 2017, 62 manuscripts were received and 58 were peer reviewed (the decrease in desk rejection possibly indicating that authors were more compliant). However, of the 58 papers that were peer reviewed, only 22.41% were published – demonstrating the rigour of the *SAJLIS* peer review process. The open access years have seen continuous growth in the number of users (authors and reviewers) and readers who have registered with the Journal. There has been a 166.7% increase in registered readers from 2015 to 2018 despite the fact that, at the time of data generation, 2018 still had 4 months to completion.

The growth pattern in Figure 1 shows that the discoverability of the Journal (its openness) promotes accessibility. This finding is in alignment with the assertion made by Gargouri[32] that there are many independent studies which show that discoverability improves accessibility. In the fledgling year of its openness mode, *SAJLIS* did not attract too many international authors. Hence it can be inferred that, as *SAJLIS* has become more discoverable and accessible, it has been able to attract authors from several countries besides South Africa. As pointed out by Czerniewicz and Goodier[33], genuine global scholarship should be 'shaped by academic rigour and quality' and not geographical borders, technical and other inequalities. The academic rigour of the Journal, as assessed by the number of submissions declined, has not been compromised with this trend of submissions from different regions of the world (see Table 1). A consistently high rejection rate is an indication of journal rigour[23], and in the case of *SAJLIS*, when viewed in the context of its use of APCs, supports the case for its academic rigour as manuscripts are not being accepted for the sake of making a profit through APCs. Manual data mining of OJS reveals that *SAJLIS* has published articles from India, Kenya, Lesotho, Malawi, New Zealand, Nigeria, Senegal, Swaziland, Tanzania, Zambia and Zimbabwe. In volume 80(1), there were more international authors (either as first or co-authors) than there were South African authors; in volume 83(2), there was a near 50-50 split between South African and non-South African authors, possibly indicating that the open access mode has made a contribution to the growth of *SAJLIS* in terms of expanding the geographical spread of contributing authors. This wider reach affords the Journal more from which to select (evident in the increasing submission figures in Table 1), thus allowing the Journal the opportunity to enhance quality promotion in the content that it publishes. *SAJLIS* has gained an increasing number of registered readers (see Table 1) during its open access years, because it is accessible to any reader in the world who has access to the Internet. Likewise, Figure 2 indicates that the number of LIS practitioners publishing in *SAJLIS* has grown by 55% in the period under review (when articles written among practitioners as well as in conjunction with academics/researchers are considered), which suggests the Journal is more accessible to practitioners. This finding speaks to the high views and downloads but low citations (see Figures 5 and 8), as the readership includes both scholars and practitioners. Views and downloads indicate an interest in the material[15] but would not necessarily result in formal citation, despite the content being regarded as valuable to the reader.

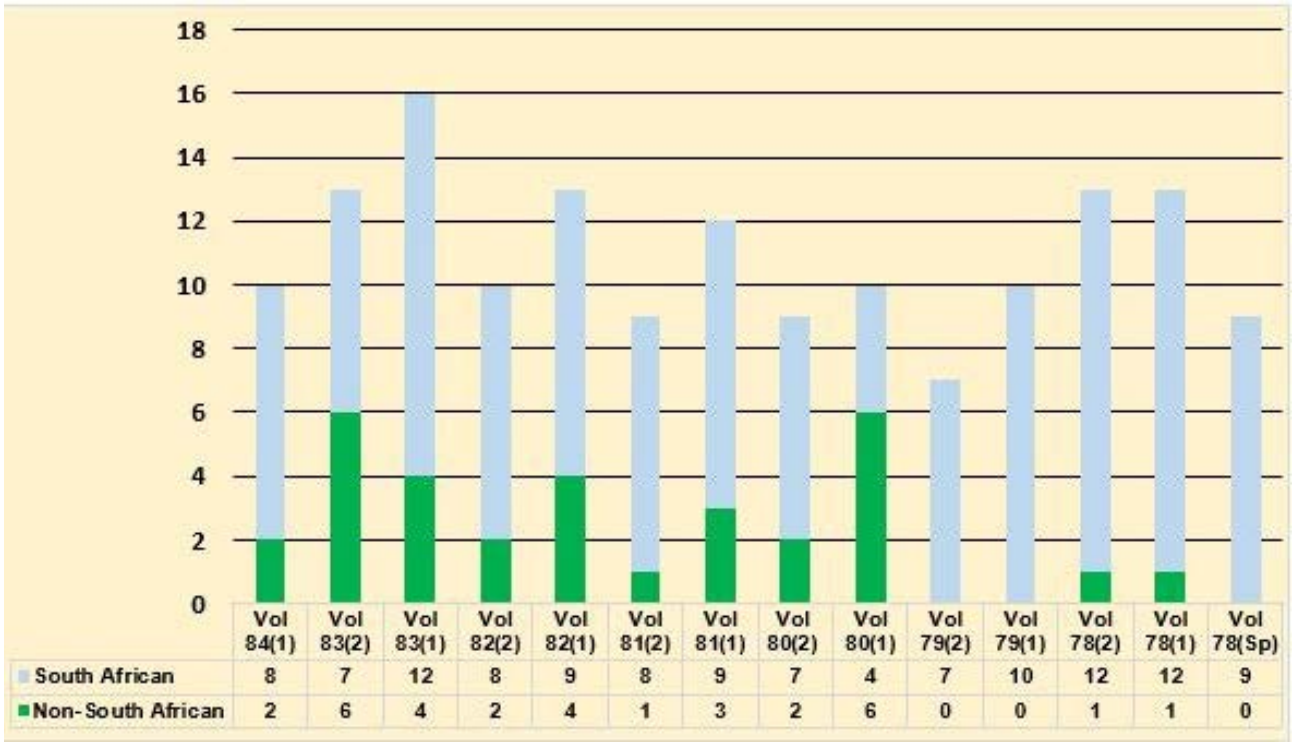


Figure 1: Number of published articles in *South African Journal of Libraries and Information Science* by South African affiliated and non-South African affiliated authors.

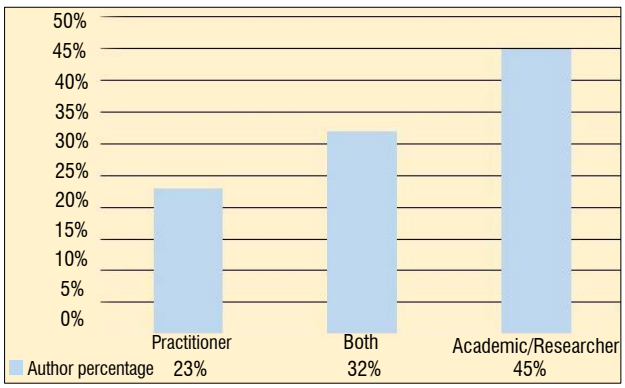


Figure 2: Practitioner and academic authors of *South African Journal of Libraries and Information Science*, 2012–2017.

Communication

Metrics communicate performance to stakeholders,[7] such as the discoverability and accessibility of LIS scholarship. Views and downloads for the journal and its articles may be used to ascertain the discoverability and accessibility of *SAJLIS* content. As *SAJLIS* is openly accessible, a subscription fee or pay-per-view charge, which some cannot afford, is not required for access. Figure 3 shows that the Journal had an aggregated 23 543 unique visitors over the review period. Figure 3 also indicates that *SAJLIS* is not only discoverable, but that users can access the research – in aggregate, *SAJLIS* articles were downloaded 75 461 times over the review period, worldwide. For the same period, there were 46 615 downloads from Africa (Figure 4), which represents 62% of the total downloads worldwide. The number of downloads, both worldwide and in Africa, is high, which suggests the Journal is more accessible to practitioners, as it is likely that practitioners rarely cite but make use of the research in their professional practice.

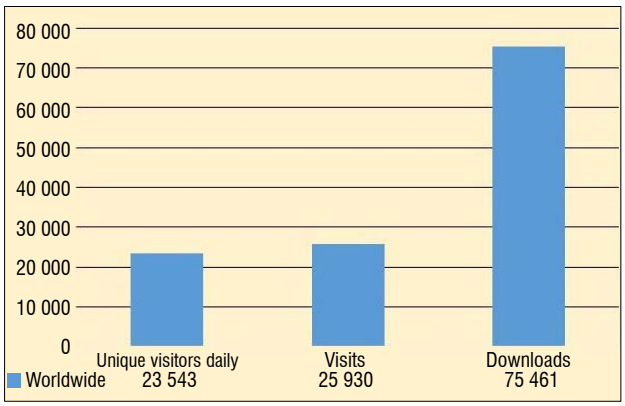


Figure 3: User visits and downloads worldwide for the *South African Journal of Libraries and Information Science*, 2012–2017.

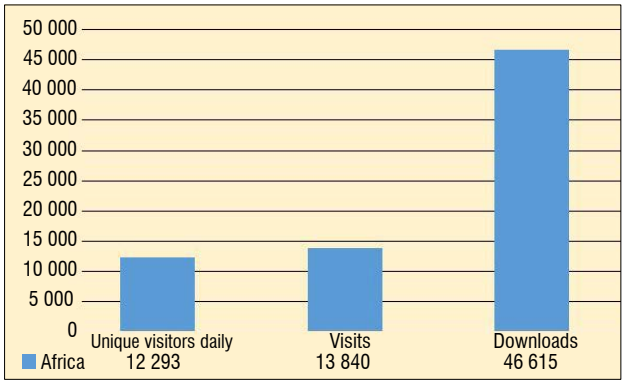


Figure 4: User visits and downloads from Africa for the *South African Journal of Libraries and Information Science*, 2012–2017.

Figures 5 and 6 show the usage of articles in the purposive sample between 2013 and 2016 (2012 and 2017 are not reflected because the selection of 25% of articles for article-level analysis, explained earlier, fell outside of these two years). Data show spikes for 2013 and 2015, years in which several significant articles – five and seven, respectively – were published on e-books, research data services and social media and seem to have attracted more usage and capture. The year 2014, while still showing respectably high usage and capture, only had two such significant articles, which resulted in the observed decline because fewer articles relating to the top LIS trends were published in that year. Even though there is a drop in usage and capture for 2014, one significant cross-disciplinary article was published which contributed to most of the observed usage and capture counts for 2014 while other articles, by comparison, underperformed. Globally, multidisciplinary research does tend to have higher views and downloads.[18]

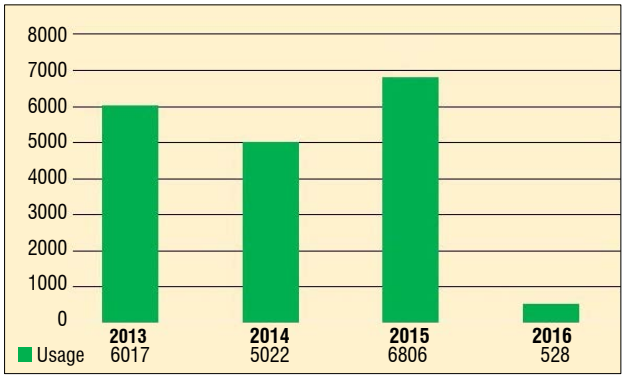


Figure 5: Usage of articles published in *South African Journal of Libraries and Information Science* between 2013 and 2016, expressed as a count of views, downloads, etc. from PlumX.

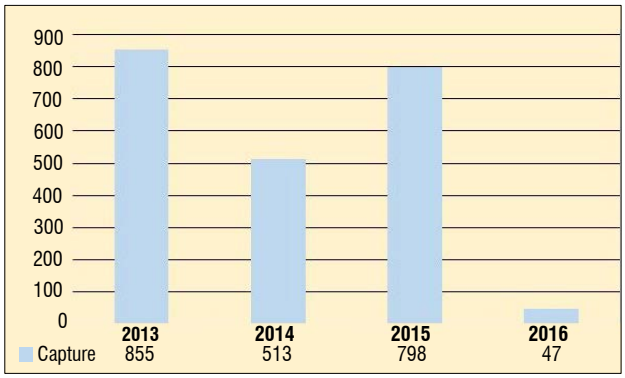


Figure 6: Capture of articles published in *South African Journal of Libraries and Information Science* between 2013 and 2016, expressed as a count of bookmarks, saves, etc.

The social media metrics demonstrate how research published in the Journal is promoted. Figure 7 reflects that most of the *SAJLIS* articles were promoted on Facebook (a total of 340 visits and actions) as compared to 189 visits and actions on Twitter. This suggests *SAJLIS* researchers/authors and users are more active on Facebook (as opposed to that reported in Onyancha's[18] study which found Twitter to be more popular among South African journals). While the current study used Plum Analytics to ascertain social media metrics, Onyancha[18] used Altmetric.com. We did not use Altmetric.com as it did not include complete data for all the sample articles. Notwithstanding that different altmetrics tools present different social media data depending on the harvesting coverage of the tool, the *SAJLIS* trend, established with the use of Plum Analytics, is commensurate with the universal inclination of Facebook being more popular amongst middle-aged adults (such as researchers, authors, scholarly journal users) than any other social network.[34]

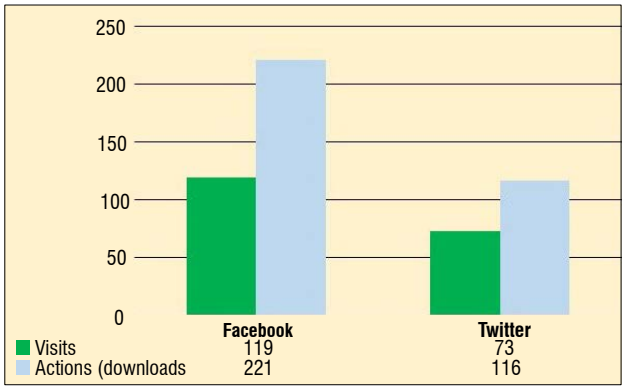


Figure 7: Visits to and actions on *South African Journal of Libraries and Information Science* social media, 2013–2016.

Even though altmetrics are open to 'gaming', they give a good overview of how accessible a journal's content is to the broader community. Citations, on the other hand, indicate how well used the research is and accumulate over time. Figure 8 shows a steady accumulation of citations for *SAJLIS* articles from 2012 to 2017. Logically, citations are the highest for 2012 and lowest for 2017 as there is a 2–3-year 'gestation period' for the generation of citations for published research.[20] Citations of *SAJLIS* articles follow a similar pattern to that of usage and capture counts (see Figures 5 and 6), namely with 2013 and 2015 showing spikes in usage relative to 2014 and 2016. This reflection supports views and downloads as an indicator of future citations.[30] Accordingly, Figure 8 shows that, in 2014, there was a small decline in citations due to fewer articles covering top trends compared to 2013 and 2015 (as pointed out earlier). Harnad and Brody[6] state that access is not a sufficient condition for citation, but it is a necessary one. Google Scholar analytics show that, within 3 months of publication, an article published in *SAJLIS* in the second half of 2017 had already generated citations, thus demonstrating that openness and online availability improve accessibility which increases the chances of

citation. It is understood that discoverability must precede accessibility; this suggests that openness improves discoverability. It is acknowledged that Google Scholar citations include both scholarly and grey literature; however, citation or use of articles would not be possible if the articles were not discoverable and accessible. Harnad and Brody[6], among others[12,13], demonstrate that open access articles can have an advantage compared to non-open access articles when it comes to citation counts.

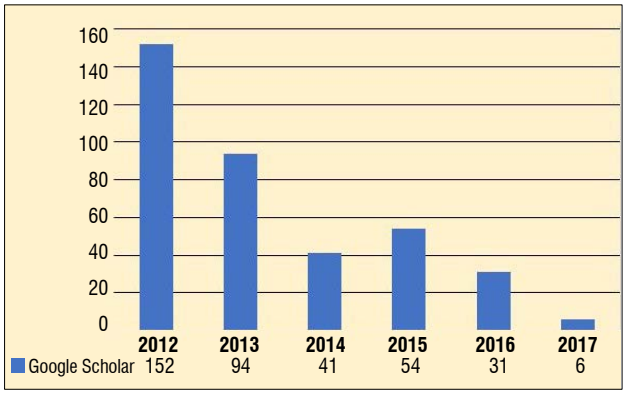


Figure 8: Number of citations to *South African Journal of Libraries and Information Science* according to Google Scholar.

The patterns from the views, downloads, PlumX metrics (article level usage, capture, social media measures) and article citations are indicative that *SAJLIS* content is discoverable and accessible globally, thus promoting its reach and impact.

Improvement

Notwithstanding these positives relating to discoverability and accessibility in *SAJLIS*'s 'open era', as pointed out by Melnyk et al.[7], metrics also serve to identify gaps and 'point the way for intervention and improvement'[7], and these are identified here for *SAJLIS* for the next 5 years. While findings indicate that open access and an online presence have extended the reach of *SAJLIS* (see Table 1 and Figure 1) beyond South Africa into the African continent and even to other parts of the world, this growth trajectory has potential for further global expansion. This potential applies both geographically and across the theory and practice divide for further reach and impact of LIS scholarly endeavours as well as LIS policy and professional practice. In pursuing this growth trajectory, *SAJLIS* would need to continue to give attention to the academic rigour of its peer review process and promote quality of scholarship published in order to further increase its registration of authors, reviewers, readers and other users (see Table 1).

While Figures 3 to 7 demonstrate healthy indicators of discoverability and accessibility (views, downloads, usage, capture and social media measures) of *SAJLIS* and Figure 8 reflects citation numbers that reflect use of the LIS scholarship published, there is room for improvement to increase publishing activity. Figures 5 and 6, as well as Figure 8, show that article usage (views and downloads), captures (bookmarking and saves) as well as article citations (use of research) are influenced by the topic of published research.[28,29] Bazrafshan et al.[21] too discovered in their study that articles on topical areas were downloaded more often than others. Based on this observation, a possible intervention for *SAJLIS* would be to increase its two issues per year by the publication of special issues targeting top LIS trends as themes of these special issues, for greater discoverability and accessibility through the open access format and online tools and environments discussed in this paper. Such expansion would lead to greater use of the scholarship *SAJLIS* carries through citations and subsequent impact on LIS and related research, policy and professional practice.

In this quest for further growth, *SAJLIS* also needs to explore advancing software delivery platforms that promote greater discoverability and accessibility through views, downloads, captures, social media measures, and other newer forms of user engagement, as the latter are often precursors to future citations[30] and research use.

As observed from the literature reviewed, open access alone does not lead to better journal performance. Hence, further promoting discoverability and accessibility of *SAJLIS* content through, for example, greater social media presence; expanding the reach of the Journal to further increase submissions and subsequent publishing of more articles, especially on topical issues in the LIS discipline; and, promoting the reputation of the Journal based on its academic rigour, are ways and means of affording *SAJLIS* opportunity to improve its performance further. Such improved performance in publishing activity (quantity) and quality will hold the Journal in good stead in possible applications in the future for Scopus and Web of Science index listings.

Conclusion and recommendation

We have reported on the use of multiple metrics (as advised by Harnad[1]) as an objective means of determining the discoverability and accessibility of LIS scholarship via the *South African Journal of Libraries and Information Science* (*SAJLIS*) in its open years (2012–2017). The inquiry was guided by the core metric functions of *control, communication* and *improvement* as identified by Melnyk et al.[7] in relation to performance metrics theory. The findings highlight performance strengths of *SAJLIS* in terms of discoverability and accessibility of the scholarship it conveys. Despite *SAJLIS* being a 'small' journal title communicating scholarship for a small discipline (LIS), its performance strengths highlighted in this study are commensurate with its 2018 ASSAf peer review evaluation resulting in its continued accreditation by the DHET for author subsidy earning purposes and its selection for inclusion in the SciELO South Africa list of accredited journals. This study also highlights growth areas for *SAJLIS* for its strategic planning for the next 5 years. This inquiry focused on objective evaluation of the discoverability and accessibility performance of *SAJLIS* using multiple metrics (data mining on OJS, webometrics, altmetrics and citation analysis). It is therefore recommended that, for a more complete picture of performance strengths and areas for improvement, future enquiries could also target subjective evaluation of, for example, the *SAJLIS* peer review process, quality and diversity of the editorial board, and editor profile. However, as cautioned by Harnad[1], this subjective evaluation too requires 'multiple tests' to achieve 'face-validity' necessary in research.

Authors' contributions

J.R.: Conceptualisation, formulation of overarching research aims, compiling the paper, theory integration and write-up, methodology write-up. A.M.: Data collection, data analysis and write up of analysis. M.K.: Crafting the literature review and formatting the paper for submission. R.R.: Data collection, data analysis and write up of analysis.

References

1. Harnad S. Validating research performance metrics against peer rankings. Ethics Sci Environ Polit. 2008;8:103–107. https://doi.org/10.3354/esep00088
2. Walker C. Brief history of the journal [homepage on the Internet]. c2014 [cited 2018 Sep 20]. Available from: http://sajlis.journals.ac.za/pub/about/editorialPolicies#custom-1
3. Ulrichsweb. Title details [homepage on the Internet]. c2018 [cited 2018 Oct 04]. Available from: http://ulrichsweb.serialssolutions.com/title/1538648430754/467586
4. South African Journal of Libraries and Information Science. Focus and scope [homepage on the Internet]. c2018 [cited 2018 Sep 20]. Available from: http://sajlis.journals.ac.za/pub/about/editorialPolicies#focusAndScope
5. Lynch CA. Institutional repositories: Essential infrastructure for scholarship in the digital age. Portal-Libr Acad. 2003;3(2):327–336. http://dx.doi.org/10.1353/pla.2003.0039
6. Harnad S, Brody T. Comparing the impact of open access (OA) vs. non-OA articles in the same journals. D-Lib. 2004;10(6). https://doi.org/10.1045/june2004-harnad
7. Melnyk SA, Stewart DM, Swink, M. Metrics and performance measurement in operations management: Dealing with the metrics maze. J Oper Manag. 2004;22:209–217. https://doi.org/10.1016/j.jom.2004.01.004

8. Roemer RC, Borchardt R. Meaningful metrics: A 21st century librarian's guide to bibliometrics, altmetrics, and research impact. Chicago, IL: Association of College and Research Libraries; 2015.

9. Schimmer R, Geschuhn KK, Vogler A. Disrupting the subscription journals' business model for the necessary large-scale transformation to open access. A Max Planck Digital Library Open Access Policy White Paper; 2015. https://doi.org/10.17617/1.3

10. Sotudeh H, Horri A. The citation performance of open access journals: A disciplinary investigation of citation distribution models. J Am Soc Inf Sci Technol. 2007;58(13):2145–2156. https://doi.org/10.1002/asi.20676

11. Mukherjee B. Do open-access journals in Library and Information Science have any scholarly impact? A bibliometric study of selected open-access journals using Google Scholar. J Am Soc Inf Sci Technol. 2009;60(3):581–594. https://doi.org/10.1002/asi.21003

12. Tang M, Bever JD, Yu F-H. Open access increases citations of papers in Ecology. Ecosphere. 2017;8(7), e01887, 9 pages. https://doi.org/10.1002/ecs2.1887

13. Atchison A, Bull J. Will open access get me cited? An analysis of the efficacy of open access publishing in Political Science. PS Polit Sci Polit. 2015;48(1):129–137. https://doi.org/10.1017/S1049096514001668

14. Fukuzawa N. Characteristics of papers published in journals: An analysis of open access journals, country of publication, and languages used. Scientometrics. 2017;112:1007–1023. https://doi.org/10.1007/s11192-017-2414-y

15. Kurtz MJ, Henneken EA. Measuring metrics: A 40-year longitudinal cross-validation of citations, downloads, and peer review in astrophysics. J Am Soc Inf Sci Technol. 2017;68(3):695–708. https://doi.org/10.1002/asi.23689

16. Coughlin DM, Jansen BJ. Modeling journal bibliometrics to predict downloads and inform purchase decisions at university research libraries. J Am Soc Inf Sci Technol. 2016;64(9):2263–2273. https://doi.org/10.1002/asi.23549

17. Huang W, Wang P, Wu Q. A correlation comparison between Altmetric Attention Scores and citations for six PLOS journals. PLoS ONE. 2018;13(4), e0194962, 15 pages. https://doi.org/10.1371/journal.pone.0194962

18. Onyancha OB. Altmetrics of South African journals: Implications for scholarly 0impact of South African research. Pub Res Q. 2017;33:71–91. https://doi.org/10.1007/s12109-016-9485-0

19. Mintz A, Mograbi E. *Political Psychology*: Submissions, acceptances, downloads, and citations. Polit Psychol. 2015;36(3):267–275. https://doi.org/10.1111/pops.12277

20. Moed HF, Halevi G. On full text download and citation distributions in scientific-scholarly journals. J Am Soc Inf Sci Technol. 2016;67(2):412–431. https://doi.org/10.1002/asi.23405

21. Bazrafshan A, Haghdoost AA, Zare M. A comparison of downloads, readership and citations data for the *Journal of Medical Hypotheses and Ideas*. J Med Hypotheses Ideas. 2015;9:1–4. https://doi.org/10.1016/j.jmhi.2014.06.001

22. Holmberg K. Classifying altmetrics by level of impact. In: Salah AA, Tonta Y, Salah AAA, Sugimoto CR, Al U, editors. Proceedings of ISSI 2015: 15th International Conference on Scientometrics & Informetrics; 2015 June 29 – July 03; Istanbul, Turkey. Istanbul: Bogaziçi University Printhouse; 2015.

23. Fischer CC. Editor as good steward of manuscript submissions: 'Culture,' tone, and procedures. J Scholarly Publ. 2004;36(1):34–42.

24. Björk B. Scholarly journal publishing in transition: From restricted to open access. Electron Markets. 2017;27:101–109. https://doi.org/10.1007/s12525-017-0249-2

25. Te EE, Owens F, Lohnash M, Christen-Whitney J, Radsliff Rebmann K. Charting the landscape of open access journals in Library and Information Science. Webology. 2017;14(1):8–20.

26. Nwagwu W, Makhubela S. Status and performance of open access journals in Africa. Mousaion. 2017;35(1):1–27. https://doi.org/10.25159/0027-2639/1262

27. Creswell JW. Research design: Qualitative, quantitative and mixed methods approaches. 4th ed. Los Angeles, CA: Sage; 2014.

28. Association of College and Research Libraries (ACRL) Research Planning and Review Committee. 2018 Top trends in academic libraries: A review of the trends and issues affecting academic libraries in higher education. C&RL News. 2018;79(6):286. https://doi.org/10.5860/crln.79.6.286

29. International Federation of Library Associations and Institutions (IFLA). IFLA trend report [homepage on the Internet]. c2018 [cited 2018 Sep 25]. Available from: https://trends.ifla.org/

30. Plum Analytics. PlumX metrics [homepage on the Internet]. c2018 [cited 2018 Sep 25]. Available from: https://plumanalytics.com/learn/about-metrics/

31. Matomo. Frequently asked questions [homepage on the Internet]. c2018 [cited 2018 Oct 01]. Available from: https://matomo.org/faq/

32. Gargouri Y, Hajjem C, Larivière V, Gingras Y, Carr L, Brody T, et al. Self-selected or mandated, open access increases citation impact for higher quality research. PLoS ONE. 2010;5(10), e13636, 12 pages. https://doi.org/10.1371/journal.pone.0013636

33. Czerniewicz L, Goodier S. Open access in South Africa: A case study and reflections. S Afr J Sci. 2014;110(9–10), Art. #20140111, 9 pages. https://doi.org/10.1590/sajs.2014/20140111

34. Walton J. Twitter vs. Facebook vs. Instagram: Who is the target audience? (TWTR, FB) [homepage on the Internet]. c2015 [cited 2018 Sep 25]. Available from: https://www.investopedia.com/articles/markets/100215/twitter-vs-facebook-vs-instagram-who-target-audience.asp

AUTHORS:
Darelle T. Janse van Rensburg[1,2]
Lesley A. Cornish[1]
Josias van der Merwe[1]

AFFILIATIONS:
[1]School of Chemical and Metallurgical Engineering and DST-NRF Centre of Excellence in Strong Materials, University of the Witwatersrand, Johannesburg, South Africa
[2]Orytech (Pty) Ltd, Roodepoort, South Africa

CORRESPONDENCE TO:
Darelle Janse van Rensburg

EMAIL:
darelle@orytech.co.za

DATES:
Received: 08 Apr. 2018
Revised: 25 Feb. 2019
Accepted: 11 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Janse van Rensburg DT, Cornish LA, Van der Merwe J. Corrosion map of South Africa's macro atmosphere. S Afr J Sci. 2019;115(7/8), Art. #4901, 8 pages. https://doi.org/10.17159/sajs.2019/4901

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☒ Not available
☐ Not applicable

EDITOR:
Tania Douglas

KEYWORDS:
atmospheric; inland; coastal; mild steel

FUNDING:
Orytech (Pty) Ltd; South African Department of Science and Technology; National Research Foundation (South Africa); University of the Witwatersrand; Hot Dip Galvanizers Association of Southern Africa

Corrosion map of South Africa's macro atmosphere

The first atmospheric corrosion map of South Africa, produced by Callaghan in 1991, has become outdated, because it primarily focuses on the corrosivity of coastal environments, with little differentiation given concerning South Africa's inland locations. To address this problem, a study was undertaken to develop a new corrosion map of the country, with the emphasis placed on providing greater detail concerning South Africa's inland regions. Here we present this new corrosion map of South Africa's macro atmosphere, based on 12-month corrosion rates of mild steel at more than 100 sites throughout the country. Assimilations and statistical analyses of the data (published, unpublished and new) show that the variability in the corrosion rate of mild steel decreases significantly moving inland. Accordingly, the average first-year corrosion rate of mild steel at the inland sites (at all corrosion monitoring spots located more than 30 km away from the ocean) measured 21 ± 12 μm/a [95% CI: 18–23 μm/a]. The minimum inland figure was about 1.3 μm/a (recorded at Droërivier in the Central Karoo) and the maxima were approximately 51 μm/a and 50 μm/a in the industrial hearts of Germiston (Gauteng) and Sasolburg (Free State), respectively. The variability in the corrosion rate of mild steel also decreased by as much as 80% between 150 m and 1000 m from the coastline. Moreover, the impact of changing altitude on the corrosivity of the environment was confirmed, particularly along the coastal regions.

Significance:

- A new corrosion map of South Africa's inland and coastal regions is presented.
- The map facilitates the identification of South Africa's least to most corrosive environments; enabling the selection of more appropriate corrosion protection solutions for general, business, mining and industrial installations.
- In identifying South Africa's least corrosive areas, the use of more environmentally friendly corrosion protection procedures is potentially encouraged.

Introduction

The first atmospheric corrosion map of South Africa was published 28 years ago.[1] This map (Figure 1), referred to as the Callaghan map, was developed based on the atmospheric corrosion monitoring results of studies conducted during the 1970s to 1990s, at 11 sites, of which 60% were situated along the South African and Namibian coastlines.

Since its publication in 1991, the Callaghan map has undergone only minor adaptations.[2-7] However, due to the lack of differentiation of inland locations, overstatement of the corrosivity of environments, changes in international standards regarding the measurement of corrosive atmospheres, increased industrialisation of South Africa's large metropolitan areas, global climate change effects, and improved mapping techniques,[8] this chart has become outdated.

Background

Corrosion maps are useful tools in many scientific and engineering fields, e.g. in research, design, construction, maintenance, and operations, as well as from a public perspective. Corrosion maps are also advantageous in the sense that they provide potential means to assess the effects of pollution[9] and climate change[10,11] on communities, materials and the environment.

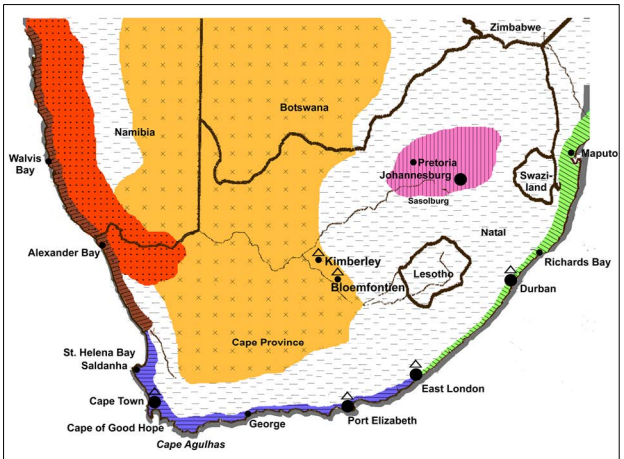
According to The Worldwide Corrosion Authority (NACE)[12], the cost of corrosion in 2016 was estimated to be USD2.5 trillion (about 3.4% of the global GDP). This average is based on the results of corrosion cost studies conducted by the USA, India, Japan, Kuwait and United Kingdom. It is reported that about 15–35% of this cost can be saved by using effective preventative measures. A similar study was also conducted in South Africa in 1986.[13] During the South African study – which covered the mining, power generation, shipping and transportation sectors – corrosion protection preventative measures, metal losses and replacement costs were estimated at ZAR1 250 million/annum or USD625 million/annum.[13] This number was based on an exchange rate of approximately USD1:ZAR2 at the time[14], which amounted to about 5% of South Africa's GDP.

In line with The World Bank's[15] 2017 numbers, South Africa's GDP was given as USD348.9 billion (approximately ZAR4 885 billion). By applying NACE's 2016 figure of 3.4% of the global GDP as the cost of corrosion per annum, this means that, currently, about ZAR166 billion is spent annually in South Africa in trying to combat or prevent corrosion problems. Of this amount, atmospheric corrosion of coated and uncoated metal surfaces is viewed as a significant contributor – more than 50% or ZAR83 billion.[11,16,17] Undoubtedly, the usefulness of corrosion maps to prevent or manage corrosion problems is immense.

Historical overview of South Africa's atmospheric corrosion data

Pre-1970, several small atmospheric corrosion monitoring studies were carried out in South Africa. The Council for Scientific and Industrial Research (CSIR)[18] and Callaghan[1] provided comprehensive overviews of these very early exposure programmes. Post-1970 to the early 1990s, the first national exposure programme was conducted.[1] The initial work involved two 4-year exposure programmes, of which one included the exposure of a range of metals and alloys[18], while the other involved metallic coatings on steel substrates at several sites throughout South Africa.[1] However, because of shortcomings identified with these very early exposure studies, a 20-year

exposure programme was initiated. This work was conducted at sites in Cape Town, Port Elizabeth, Strandfontein, Pretoria, Sasolburg, False Bay, Durban, Simonstown and East London in South Africa, and in Gobabeb and Walvis Bay in Namibia, which culminated in the publication of the first corrosion map of southern Africa (Figure 1).[1]



Key	Description	Type of corrosion	Mild steel corrosion rate µm/year	Galvanised steel sheet life in years
	Inland arid	Semi desert	5 – 10	> 30
	Inland	Rural	10 – 20	> 20
	Inland dry	Desert	< 5	> 30
	Inland urban	Inland industrial	15 – 40	5 – 15
	Inland	Industrial	10 – 30	5 – 15
	Sub-tropical marine	Medium to severe marine	50 – 80	3 – 5
	Desert marine (mists)	Severe marine corrosion	80 – 100	0.5 – 2
	Temperate marine	Marine	30 – 50	3 – 7
	Intertidal to 5 km inland	Severe marine corrosion	100 – 300	Up to 3

Figure 1: Atmospheric corrosion map of southern Africa – adapted from the Callaghan 1991 map[1] and taken from Janse van Rensburg (2010)[7].

From 1990 to 1993, Eskom Holdings SOC Limited, the leading electricity producer in South Africa, henceforth referred to as 'Eskom', conducted atmospheric corrosion research work along the eastern, southern and western Cape coastlines.[19] Their study involved exposure to the corrosive marine atmosphere of wire-on-bolt (CLIMAT) units, currently manufactured according to ASTM G116:1999[20] procedures.

Simultaneously, Eskom launched a 5-year corrosion study relating to the atmospheric corrosivity of sites in other areas along the South African coastline, as well as in the southern and eastern Highveld regions. This work, done by Nixon and Janse van Rensburg[21-23], Colloby[24] and Northcott[25], entailed the exposure of mild steel, copper, aluminium, zinc, galvanised mild steel, stainless steel and 3CR12 panels to different corrosive atmospheres. Changes in the electrical resistance of iron, zinc, copper and aluminium were also investigated.[24] The studies were performed at locations near Melkbosstrand, Klienzee, Richards Bay, Kriel, Sasolburg, Elandsfontein, Bethal (Palmer), Volksrust and Vanderbijlpark.

During 1991 to 1994, a 3-year project was launched by the CSIR in the Eastern parts of the Gauteng Highveld region. This study was performed in conjunction with Eskom at sites located at Pretoria, Grootpan (close to Ogies), Elandsfontein and Verkykkop (in Volksrust).[21-23,26] The purpose of the CSIR research work, done by Gnoinski and Ramothlola, was mainly to determine the effectiveness of a rapid method for the assessment of atmospheric corrosion.[26]

Numerous atmospheric corrosion tests were also carried out by John E. Leitch, over a period of more than 20 years.[4] His work was done mainly on behalf of Hulett Aluminium (Pty) Ltd, the CSIR, Eskom, and other interested parties. During earlier years, Leitch's studies primarily involved the exposure of wire-on-bolt units to different corrosive atmospheres – to classify the atmospheres of sites using the CLIMAT (CLassify Industrial and Marine ATmospheres) method.[27] However, with the inception of a new technique for the corrosion monitoring of atmospheric environments in 1992, for which the methodology is described in detail in ISO 9223:1992[28] and ISO 9226:1992[29], most of Leitch's work in his later years was effected in accordance with the open wire helix (zinc and aluminium) method[3,5]. Leitch's studies culminated in the publication of an updated corrosion map of South Africa in 1999[3], and again in 2003[4], with the latter chart subsequently incorporated into SANS 1796:2013[30].

The new maps were hailed in the sense that they represented the first attempts by a South African researcher to classify the corrosivity of atmospheric environments based on the ISO 9223 and ISO 9226 procedures.[27,28] Leitch employed the ISO 9226:1992 open zinc and aluminium wire helix technique at places such as Cape Town, Mossel Bay, Port Elizabeth, Durban, Umhlanga Rocks and Richards Bay.[4]

In 2005, the Hot Dip Galvanizers Association of Southern Africa (HDGASA)[6] also published an updated atmospheric corrosion map for zinc (after the Callaghan map) based on the ISO 9223:1992 classification system. Additional work worth mentioning is that of Vosloo of Eskom, in partnership with Pietersen and Holtzhausen of the Stellenbosch University.[31] Their studies involved the development of an insulator pollution severity application map for South Africa, which added to the knowledge base relating to atmospheric pollution in South Africa. Calitz and Potgieter[32] also conducted atmospheric corrosion studies of overhead power transmission conductors at a marine site near Koeberg Nuclear Power Station, situated along the Western Cape coastline.

The SAIAE (South African Institute of Agricultural Engineers) likewise launched an 11-year atmospheric exposure programme on five diverse agricultural wire types at seven sites in South Africa.[33] Findings of this work, dating back to December 1990, are currently still used to provide recommendations regarding suitable fencing materials for different corrosive environments. Materials tested included light galvanised, heavy galvanised, aluminium coated, Galfan and 3CR12 wires, which were exposed at Bathurst and Riviersonderend. Work in this field was also conducted by R.J. Bronkhorst and K.L. Rodseth.[33]

Between 2005 and 2010, Janse van Rensburg[34] initiated one of the most extensive atmospheric corrosion programmes in South Africa. This study, performed on behalf of Eskom, involved the atmospheric corrosion monitoring of 50 sites throughout South Africa – covering both inland and coastal regions. Janse van Rensburg also conducted smaller studies at other locations in the country. Moreover, during 2013 to 2017, a further study was undertaken that focused on the development of a new corrosion map for South Africa,[8] also providing greater detail concerning the atmospheric corrosivity of South Africa's inland industrial areas. This new South Africa atmospheric corrosion map, based on assimilations and statistical analyses of the historical published, unpublished and new 12-month corrosion rates of mild (carbon) steel, as measured at different sites throughout South Africa, is presented in this paper.

General methodology of historical and new corrosion monitoring studies

In general, corrosion monitoring sites were established throughout South Africa, covering industrial, marine, desert, urban and rural environments. The methodology followed mainly involved the exposure of mild steel (low carbon steel) coupons to the different environments over a period of 12 months, after which weight-loss measurements of the metal coupons were conducted. This was after chemical cleaning of the metallic test coupons by conventional procedures, like ISO 9226,[29,35] followed by drying and reweighing of the test specimens. Subsequently, the 12-month corrosion rate of each mild steel coupon was calculated as per Equation 1.[29,35]

$$\text{Corrosion rate of metal} = \frac{\Delta m}{At\rho} \qquad \text{Equation 1}$$

where: Δm is the mass loss in grams (g); A is the exposed surface area in m^2; t is the exposure time per annum; and ρ is the density of the metal

(g/cm^3). The corrosion rate (r_{corr}) is in μm/a, and the density of the steel was taken as 7.86 g/cm^3.[29,35]

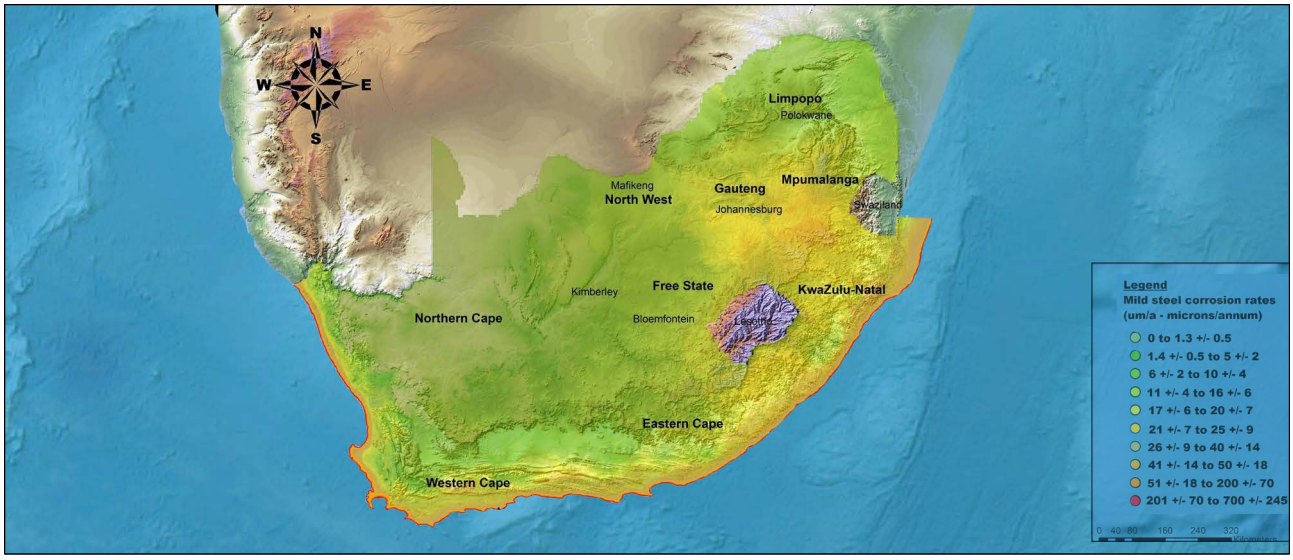
The corrosivity of the atmosphere was classified successively based on the 12-month corrosion rate of mild steel as per the ISO 9223:2012 rating scheme: C1 – *very low* (≤1.3 μm/a), C2 – *low* (≤25 μm/a), C3 – *moderate* (≤50 μm/a), C4 – *high* (≤80 μm/a), C5 – *very high* (≤200 μm/a) and CX – *extreme* (≤700 μm/a) corrosive.[36] The corrosion data were then processed into an atmospheric corrosion map of South Africa using Esri ArcGIS 10.2, which is a geographical information system (GIS) developing software programme. It is noteworthy that because of the sensitive nature of some of the sites, not all the site names or detailed corrosion data are given. Consequently, the results are presented as an interpolated corrosivity map, for which legends are provided.

Regarding the latest corrosivity map, the interpolated vector data are projected over physical and annual rainfall maps for South Africa, as supplied by Esri ArcGIS and the South African Weather Service. Furthermore, select conventional map symbols are included to facilitate ease of interpretation and widespread use of this map.

Results and discussion

The new atmospheric corrosion map for South Africa is presented in Figure 2,[8] while the linked meteorological and corrosion data for some of the sites are given in Table 1.

Assimilations, statistical analyses and interpolations of the 12-month corrosion rates of mild steel for South Africa and the Highveld region, based on the historical published, unpublished and new data, revealed that the average first-year corrosion rate of mild steel at the inland sites (at all corrosion monitoring spots located more than 30 km away from the ocean) was about 21±12 μm/a [95% CI: 18–23 μm/a]. The minimum inland measurement was about 1.3 μm/a and was recorded at Droërivier



Caveat: This map is issued for general information purposes only and does not consider any plant design, operational mode or site-specific pollution that can influence the corrosivity of local atmospheres. The authors accept no responsibility for the use of this map.

Figure 2: Atmospheric corrosion map of South Africa[8] (base maps provided by Esri – ArcGIS and the South African Weather Service).

Table 1: Meteorological data and first-year corrosion rates of mild steel for select historical and new corrosion monitoring sites

Site name	Approximate average rainfall per annum (mm/a)	Approximate average midday temperatures (°C)	Approximate average first-year corrosion rate of mild steel (μm/a)	References
Bedford	390	17.8–27.8	12	7,37
Belfast	674	14.7–22.5	18	22,37
Cape Town – Ysterplaat	788	15.5–25.9	28	1,37
De Aar	196	16.0–30.3	2	7,37
Dealesville	357	17.0–30.0	7	7,37
Droërivier	160	16.8–30.9	1.3	7,37
Durban – Bayhead	759	22.2–27.4	66	1,37
Durban – Congella	759	22.2–27.4	122	1,37
Durban – Salisbury Island	759	22.2–27.4	134	1,37
Empangeni	948	23.0–29.0	58	7,37
Gariep	273	15.8–31.3	4	7,37
Germiston	601	16.5-26.1	51	7,37
Grabouw	990	15.0–24.8	20	7,37
Melkbosstrand	318	16.0–27.0	460	7,37
Mossel Bay	333	18.4–26.0	57	7,37
Oyster Bay	591	18.2–24.2	40	37
Sasolburg	550	17.0–27.9	50	7,37
Secunda	560	16.4–25.8	38	7,37
Vredendal	105	19.2–31.5	16	7,37

in the Central Karoo, a hot semi-arid environment (Table 1 and Figure 3). The maxima, of approximately 51 μm/a and 50 μm/a were recorded in Germiston (Gauteng) and Sasolburg (Free State), respectively,[7] both located in South Africa's heavy industrialised Highveld and Vaal Triangle areas, with average rainfall of approximately 550–600 mm/a.[37] It is significant that these corrosion rates are outside the 5–40 μm/a range given in the Callaghan map for inland (arid, rural, urban and industrial combined) environments.[1]

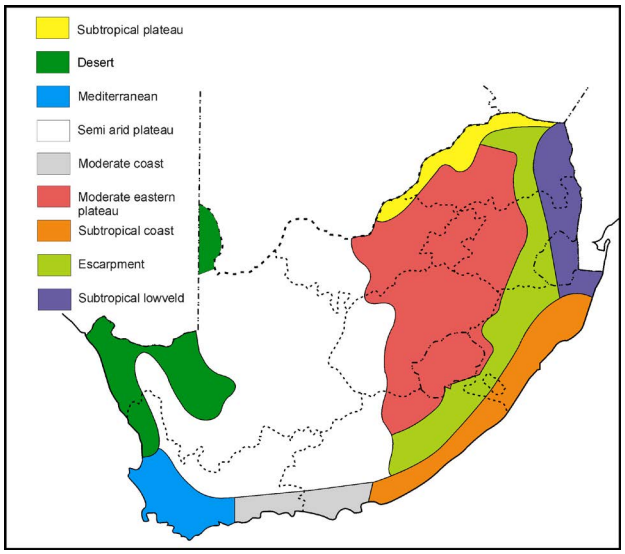


Figure 3: Climatic regions of South Africa[48]; note the climatic variations along the coastlines.

Based on the assimilated results, the inland sites vary from low to potentially highly corrosive, corresponding with the lowest limits given in the ISO 9223 standard for C2 and C4 corrosive environments, namely 1.3 μm/a and 50 μm/a, respectively.[36] This finding suggests that in the desert and semi-arid (non-industrial) inland areas, with average low rainfall (≤400 mm/a),[37] the corrosivity of the environment is better rated *very low* (C1) to *low* (C2) corrosive. Conversely, in inland areas with an average rainfall of more than 400 mm/a,[37] the atmosphere is best ranked *low* (C2) to *moderate* (C3) corrosive, with a potential for *high* (C4) corrosive 'hotspots', in and around heavy-industrial locations.

Concerning the coastal regions of South Africa, the average first-year corrosion rate of mild steel exposed within the first 150 m from the high-water mark, was 319 ± 112 μm/a [95% CI: 215–422 μm/a]. The minimum value was about 134 μm/a (recorded at Salisbury Island in Durban)[1] and the maximum near 460 μm/a (measured close to Melkbosstrand in the Western Cape)[7]. This finding was despite the fact that the former site exhibits higher rainfall than the latter locale (Table 1), and was attributed to the increased surf action near Melkbosstrand compared to the calmer sea and landscaped terrain of the Salisbury Island area.[7] These findings concur with ISO 9223:2012 relating to the factors affecting the deposition rate of chlorides along coastlines.[36] The data further suggest that the atmosphere within the first 150 m from the shoreline can be rated as *extremely* (CX) corrosive, as per ISO 9223.[36] However, as shown by the high standard deviation, the variation in the corrosivity of the atmosphere along the coastline is substantial and depends on the surf action of the ocean, the altitude, topography, temperature and onshore wind flow (i.e. speed and direction).[1,7]

Regarding those sites which are located within 150–1000 m from the shoreline, the average first-year (12-month) corrosion rate of mild steel was 60 ± 22 μm/a [95% CI: 45–75 μm/a]. The lowest value was about 40 μm/a (at Oyster Bay in the Eastern Cape) and the highest was approximately 122 μm/a (at Congella in Durban)[1], which is expected as Oyster Bay exhibits lower rainfall and midday temperatures than Durban (Table 1)[37]. The above range is significantly lower than the 100–300 μm/a span given in the Callaghan map for the intertidal to 5-km zone along South Africa's coastline. It is also far less than the C5 (200–300 μm/a) classification given in the HDGASA map.[6] Evidently, the 150–1000 m zone along South Africa's coastline is best classified mid-C4 (*high*) to mid-C5 (*very high*) corrosive.

Of note is the near 80% reduction in variability in the corrosion rate of mild steel for the 150–1000 m zone along the coastline, compared to that of the first 150 m from the ocean, with a change in the standard deviation from 112 μm/a to 22 μm/a (Figure 2). This decrease suggests that the effects of airborne salts, altitude, topography and onshore wind flow on the atmospheric corrosivity of the environment lessen when moving inland. Janse van Rensburg[8] made a comprehensive study in this regard. Doyle and Godard[18,27] also reported an 80–85% decrease in the corrosivity of the environment within the first 800 m from the ocean in Durban and Port Elizabeth. Similarly, O'Donnell et al.[33] found a 'rapid' change in the corrosivity of marine atmospheres, mainly from 1 km onwards.

The sharp decrease in the corrosivity of the environment within the 150–1000 m zone is likely attributable to the gravitational settling, turbulence diffusion and momentum-dominated impact of the airborne salts[38] within the first 150 m from the sea, causing lower levels of salts (chlorides) to be deposited onto surfaces in the following 150–1000 m span. Denser and more abundant vegetation next to the coast, as encountered along the eastern coastline[39], further encourages the deposition of aerosols within a shorter distance from the ocean[40]. This dramatic change in the deposition rate of salts in marine environments, particularly within 1 km from the ocean, has also been demonstrated during other corrosion studies.[41]

At 1–3 km from the ocean, the average first-year corrosion rate of mild steel decreases further to about 43 ± 14 μm/a [95% CI: 28–58 μm/a], suggesting significant stabilisation of the corrosivity of the environment with increasing distance from the ocean. The minimum recorded value was approximately 28 μm/a (at Ysterplaat in Cape Town)[1] and the maximum about 66 μm/a (at the Durban Bayhead)[1]. Of significance is that the former locale is situated to the west of Cape Town, and is separated from the ocean by numerous houses, industrial plants and office buildings. Conversely, the Durban Bayhead site is not only located in a high rainfall, sub-tropical region (Table 1 and Figure 3), but is also nearly encircled by the Durban Harbour, causing a further spike in the local relative humidity levels, while the open sea is positioned close by to the eastern side, resulting in an increase in airborne salt concentrations.

Regarding mild steel corrosion, the 1–3 km zone along the South African coastline is best classified as *moderate* (C3) corrosive, which is significantly overstated in the older maps. Concerning Callaghan's map[1] (Figure 1), the corrosion rate of mild steel in the 'Intertidal to 5 km inland mark', is given as 100–300 μm/a, whereas in the case of the HDGASA map[6], the 'Exterior: industrial with high humidity or high salinity coastal' region is given as varying between 80 μm/a and 200 μm/a.

The average first-year corrosion rate of mild steel at all sites located within 3–10 km from the coastline, measured 37 ± 13 μm/a [95% CI: 27–47 μm/a]. The lowest was about 20 μm/a at Grabouw in the Western Cape (above Sir Lowry's Pass near Gordons Bay)[7] and the highest was approximately 57 μm/a at Petro SA's Mossgas plant near Mossel Bay[7]. This finding is irrespective of the fact that Grabouw is located in a higher rainfall region than Mossel Bay (Table 1) – the lower corrosivity of the former site being attrbuted to its elevation of approximately 265 m above sea level,[42] whereas the latter exposure site is located at a much lower altitude, thus being more exposed to the salt-laden winds from the ocean. Hernandez et al.[43] and Del Angel et al.[44] similarly found that altitude plays a significant role in marine corrosion. The overall results also suggest a decrease in the average corrosivity of the atmosphere by approximately 6 μm/a (from about 43 μm/a to 37 μm/a), between the 3 km and 10 km marks, with an additional ~1% stabilisation of the corrosivity of the atmosphere. Typically, this zone may be classified as *moderate* (C3) corrosive.

Regarding the 10–30 km region, the average first-year corrosion rate of mild steel measured 35 ± 14 μm/a [95% CI: 22–48 μm/a], suggesting a further ~1% decrease in the average corrosivity of the atmosphere. Correspondingly, this zone along South Africa's coastline is best classified as *moderate* (C3) corrosive. The minimum recorded value

was approximately 16 μm/a at Vredendal in the Western Cape[7] and the highest was about 58 μm/a at a site in Empangeni (KwaZulu-Natal)[7]. Noteworthy is the significant difference in the corrosivity of these two sites, which can be ascribed to their unique meteorological conditions (Table 1 and Figure 3), with Vredendal in a hot semi-desert environment and Empangeni in a high-rainfall, sub-tropical region.

The apparent slowdown of further stabilisation of the corrosivity of the environment is of note, and implies that, from approximately 30 km onwards, windborne marine salts are no longer the dominant force driving the atmospheric corrosion process. This demarcation line was also identified by Callaghan in 1991.[1] However, the coefficient of variation of the average corrosion rate of mild steel remained high at nearly 40%. Congruently, studies in other countries showed that sea salts may still affect atmospheric corrosion more than 50 km[45] to 1400 km[46] from the ocean.

Of further importance is the emerging trend that test sites located along the eastern coast (particularly along the KwaZulu-Natal seashore) are inclined to higher corrosivity, at the same distance range from the ocean, compared to sites located next to the Western and Eastern Cape ocean fronts. This tendency appears to be valid for the 150–1000 m, 1–3 km, 3–10 km, and 10–30 km ranges from the sea. It is just below the 150-m mark that the corrosivity of the atmosphere along the Western Cape coast appears higher in comparison with the Eastern Cape and KwaZulu-Natal shorelines.

The above alteration in the corrosivity of the environment next to the South African coastline is mainly attributable to the varying meteorological (Table 1 and Figure 3), physical (Figure 2) and biome conditions. Concurring with Winter et al.'s[47] climatic regions, the Northern Cape coastline, i.e. from the mouth of the Orange River to Lamberts Bay, is classified as Desert, the Western Cape coast from Lamberts Bay to the mouth of the Breë River as Mediterranean, from the Breë River to Port Elizabeth as Moderate Marine, and the northern parts of the Eastern Cape coastline, i.e. from Port Elizabeth to northern KwaZulu-Natal, as Sub-tropical (Figure 3).[48] Cole et al.[49] state that marine aerosol transport is likely to be favoured in dry environments that exhibit reduced rainfall and low ground coverage, like in the Northern and Western Cape, than in more humid and higher rainfall climates with forest cover. The change in the corrosivity of the atmosphere, as a result of increasing temperatures, rainfall and relative humidity (moving from the western to eastern parts of South Africa), is partly reflected in the Callaghan[1] and Leitch[5] maps but is absent in the HDGASA[6] chart.

The higher corrosion rate of mild steel below the 150-m mark (along the Western Cape shoreline) may in all likelihood be ascribed to the presence of smaller dunes and shrubbery, called fynbos.[50] Fynbos offers less shielding against sea sand and spray, which is whipped up by the high winds from the ocean and dunes, and deposited onto surfaces. Conversely, along the Eastern and KwaZulu-Natal coastlines, the larger and broader leafy sub-tropical plants[50] provide better protection against windborne salts. The presence of lingering mist banks (due to the cold Benguela current), reduced rainfall (no washing effect) and prevailing strong onshore winds (southeaster primarily along the Western Cape, as well as parts of the Eastern Cape coastlines), also play important roles in the corrosivity of this region.[1,18,51] Nixon and Janse van Rensburg[21] reported that along the Northern and Western Cape coastlines, the highest atmospheric corrosivity is typically measured during winter, from about March to September, which corresponds with this region's rainy season. Conversely, next to the eastern coastline, the highest atmospheric corrosion rates are primarily measured during summer.[7]

Just below the Great South African Escarpment, the average corrosivity of the environment in the Western and Eastern Cape measured 7±6 μm/a [95% CI: 0–20 μm/a], with a minimum of about 1.3 μm/a at Droërivier and a maximum of near 12 μm/a at Bedford,[7] corresponding with the difference in the rainfall figures for these locations (Table 1). Moving further inland from the low-lying zones of the Northern, Eastern and Western Cape coastlines, above the Great South African Escarpment (onto the Central Plateau), the conditions change to a desert/semi-desert plateau (the Kalahari Desert and the Karoo). In this region, the corrosion rate of mild steel measured close to 2 μm/a (at De Aar) and near 4 μm/a at Gariep,[7] averaging 3±1 μm/a. This region is best classified as *low* (C2) corrosive, due to the hot arid conditions. From thereon, the corrosivity of the environment increases slightly towards the Free State, measuring approximately 7 μm/a at Dealesville,[7] close to Bloemfontein, with an approximate average precipitation of 390 mm/a (Table 1).

Of significance is that the Kalahari, Karoo and the Free State Province are also known for their salt pans and dry riverbeds. As a result, salt-laden soil that is swept up by the wind and deposited onto metal surfaces may encourage corrosion to take place at lower relative humidity. It can also increase the time of wetness, which is of relevance when considering that the Kalahari Desert and the Karoo experience the highest percentage changes in average rainfall in South Africa, i.e. 26–50%.[47] These regions also display the hottest summers and highest solar irradiation levels in the country.[52,53] Consequently, the variability in the corrosivity of the environment is high. Moreover, studies conducted by Sun et al.[54] demonstrated that soluble salt in surface desert soil might sufficiently lower the relative humidity at which corrosion current density suddenly increases.

From the KwaZulu-Natal coastline towards Gauteng, the change in corrosivity of the atmosphere below and above the Great Escarpment is apparently less extreme compared to that of the Northern, Eastern and Western Cape Provinces (Figure 2). This reduction is likely as the environment changes from a sub-tropical coastal to a moderate, sub-tropical rising rocky (escarpment) terrain that exhibits cold, snowy winters, with hot, rainy summers.[47,55] The change is also observed in Figure 3,[48] which presents the different climatic regions in South Africa.

Proceeding through the lower parts of Mpumalanga, the landscape changes to a temperate Highveld region,[55] classified as *moderately* (C3) corrosive. In this section of Mpumalanga, the average first-year corrosion rate of mild steel measured 29±6 μm/a [95% CI: 25–32 μm/a], suggesting an approximate 26% reduction in the corrosivity of the environment from Empangeni (located in the lowland between the Great Escarpment and the KwaZulu-Natal coastline) towards Ogies, positioned on the Eastern Highveld, likely because of changes in annual precipitation levels (Table 1). The maximum recorded value was near 38 μm/a (at Secunda) and the minimum about 18 μm/a (approximately 20 km north of Belfast).[56] The increased corrosivity of Secunda and Emalahleni (Witbank) may be ascribed to the fact that these areas are some of the most polluted regions in South Africa, due to the presence of a large petrochemical plant (Sasol Synfuels), 11 coal-fired power stations and numerous open-cast coal mines.

Shifting towards the North West, Limpopo and Gauteng Provinces, the corrosivity of the environment decreases further. In the case of Gauteng and closely surrounding areas, the average first-year corrosion rate of mild steel measured 25±12 μm/a [95% CI: 19–32 μm/a] (C2), falling to approximately 12±5 μm/a [95% CI: 9–16 μm/a] (C2) towards the Limpopo River (Zimbabwe) and Botswana border, mainly due to a reduction in precipitation levels.

A graphic representation of the first-year corrosion rates of mild steel, measured at all the corrosion monitoring sites, versus their approximate distances from the ocean, is presented in Figure 4. Based on the plot, the macro corrosive atmosphere of South Africa stabilises, meaningfully, moving inland, with the corrosive effects of coastal environments being inversely related to their distance from the ocean, with an R^2-value of about 0.5 and Pearson product-moment correlation (PPMC) coefficient (Equation 2) of around -0.4, significant at $p \leq 0.05$. Similar graphs have also been reported for sea-salt transport, deposition and corrosion along other coastlines[41,57,58] – all displaying a significant decrease in the corrosivity of the marine environment within 1–2 km from the ocean.

The formula for the PPMC coefficient, r, is:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \qquad \text{Equation 2}$$

where x and y present the data points, and x and y means the averages for array1 and array2, respectively.[59]

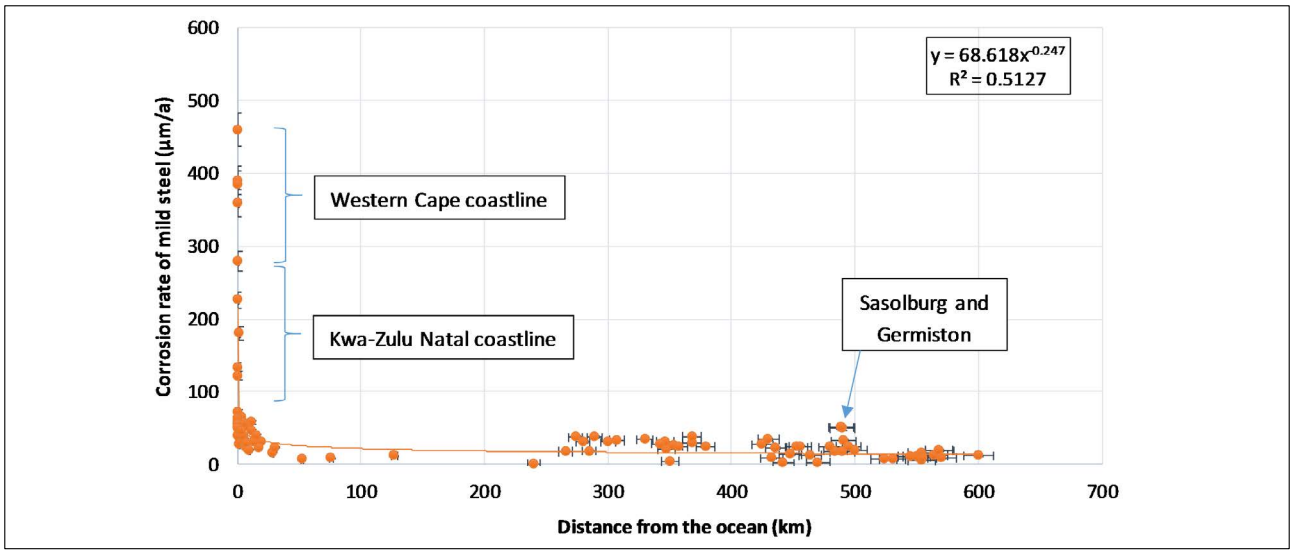


Figure 4: First-year (12-month) corrosion rates of mild steel, measured at numerous sites in South Africa, versus the approximate distances of the sites from the ocean.

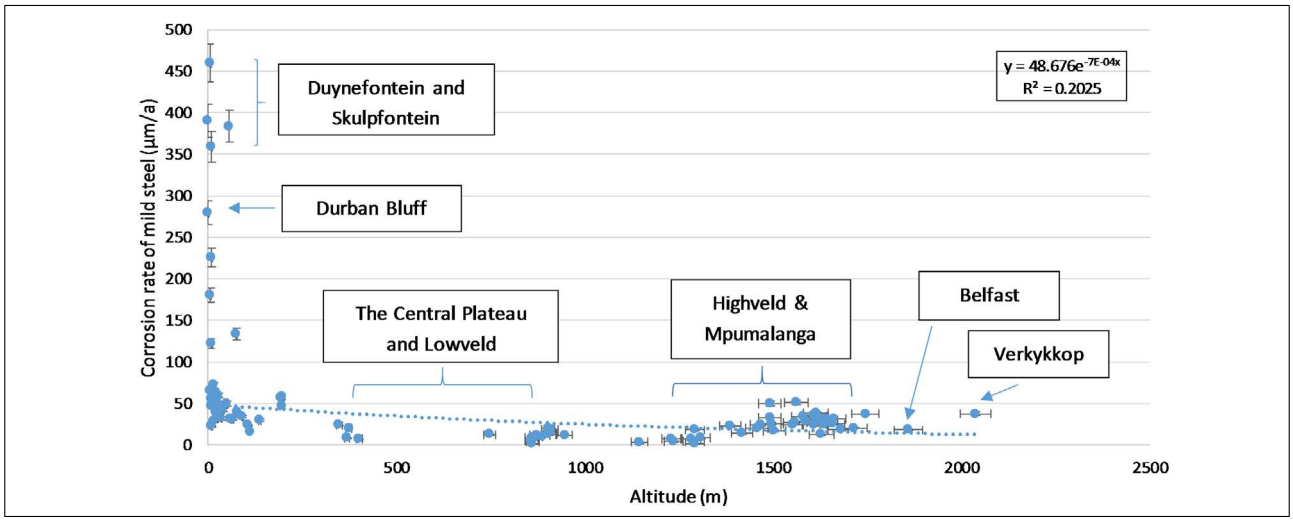


Figure 5: First-year (12-month) corrosion rates of mild steel, measured at numerous sites in South Africa, versus the relative altitudes (elevations above sea level) of the sites.

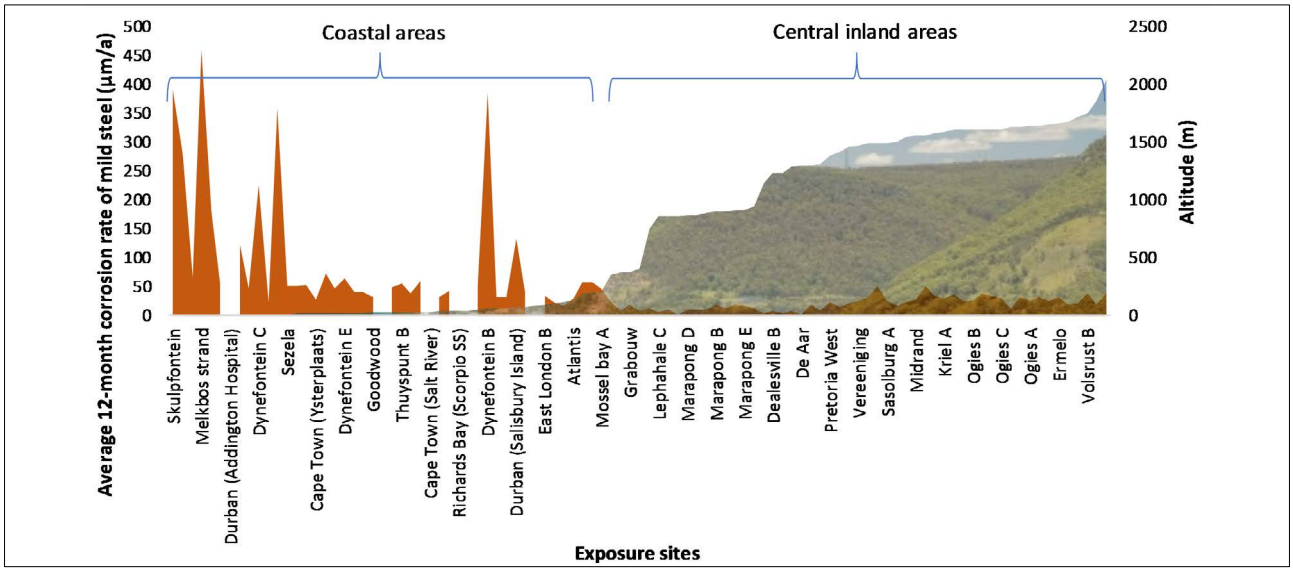


Figure 6: Differences in the first-year 12-month corrosion rates of mild steel at the coastal and central inland sites, versus the relative altitudes (elevations above sea level) of the sites.

In contrast, Figure 5 gives the first-year corrosion rates of mild steel, measured at all the corrosion monitoring sites versus their relative altitudes in metres. According to the graph, the corrosivity of South Africa's atmosphere is also slight to moderately negative related to elevation, exhibiting a PPMC coefficient of -0.4, which is significant at $p \leq 0.05$. The impact of altitude on the corrosivity of the environment is of particular relevance to the coastal and inland industrial areas of the country.

In the sub-tropical Lowveld and semi-desert Karoo regions, with altitude ranges of 500–1000 m, atmospheric corrosivity is notably lower. However, this decrease is because of climatic rather than altitude variations. The differences in the 12-month corrosion rates of mild steel at some of the sites, in contrast with altitude, are also presented in Figure 6.

At central inland locations (Figure 6), it is indicated that atmospheric corrosion is no longer driven by chlorides in the air, but rather by the time of wetness, temperature, pollution (SO_x and NO_x gases), the wind, and the positioning of the metal substrate above ground level.[8] This observation may also apply to regions in and around the central inland and metropolitan areas of South Africa, e.g. the Greater Johannesburg Metropolitan Area, where it has been shown that localised mining, industrial activity, transport and vegetation play essential roles in the elevation of the corrosivity levels of the atmosphere.[8]

Conclusions

Corrosion maps provide valuable information relating to the degradation of metals and alloys in varying atmospheres. Studies on South Africa's macro atmosphere date back as far as 1947, with the scopes of the more recent studies, i.e. those between the mid-1990s and 2018, being significantly broadened to enable the use of the internationally recognised ISO 9223 corrosivity classification system.

Based on assimilated historical (published and unpublished) and new atmospheric corrosion data for South Africa, the atmosphere within the first 150 m from the ocean is classified as *extreme* (CX) corrosive. Between the 150 m and 1000 m marks, the environment is rated mid-C4 (*high*) to mid-C5 (*very high*) corrosive, from 1 km to 30 km *moderate* (C3) to *high* (C4) corrosive, and for most inland locations, *low* (C2) to potentially *high* (C4) corrosive. The highest atmospheric corrosivity is typically measured in the Western Cape, within 150 m from the ocean, and the lowest in the Karoo and the Kalahari Desert.

The variability in the corrosion rate of mild steel was found to decrease by as much as 80% between 150 m and 1000 m from the coastline, which supports the general understanding that the effects of chloride deposition, changing altitude, topography, and onshore wind flow (speed and direction), become less prominent in terms of the atmospheric corrosivity of the environment moving inland.

Acknowledgements

We gratefully acknowledge financial support from Orytech (Pty) Ltd, South African Department of Science and Technology, National Research Foundation (South Africa), University of the Witwatersrand, and Hot Dip Galvanisers Association of Southern Africa. We also gratefully acknowledge the materials support and facilities provided by Orytech (Pty) Ltd and University of the Witwatersrand, including permission to publish from Eskom Holdings SOC Limited and South African Weather Service. General assistance from S.T. van Allemann, V. Etsebeth, M.C. Janse van Rensburg, L.M. Janse van Rensburg, O.A Pheko, T. Mokgomo, C.T. Vermaakt and R. Britz is also greatly appreciated.

Authors' contributions

The study was conceptualised, planned, carried out and written up by D.T.J.v.R., in partial fulfilment of her PhD at the University of the Witwatersrand, under the supervision of L.A.C. and J.v.d.M. Funding was acquired by D.T.J.v.R. from Orytech (Pty) Ltd. and the Hot Dip Galvanizers Association of Southern Africa, and by L.A.C. and J.v.d.M. from the Department of Science and Technology, National Research Foundation and the University of the Witwatersrand.

References

1. Callaghan B. Atmospheric corrosion testing in Southern Africa – results of a twenty-year national programme. Pretoria: Scientia Publishers; 1991. http://hdl.handle.net/10204/10635
2. AECI Paints. Corrosion map of Southern Africa. Johannesburg: AECI Paints; n.d.
3. Leitch J. Corrosivity profile of Southern Africa using ISO 9223 methodology. Paper presented at: The 14th International Corrosion Congress; 1999 September 27 – October 01; Cape Town, South Africa. International Corrosion Council and Corrosion Institute of Southern Africa; 1999. p. 1–10. https://doi.org/10.1108/acmm.1999.12846daa.002
4. Leitch J. The atmospheric corrosivity profile of Southern Africa – an update. In: Proceedings of the 7th International Corrosion Conference; 2003 January; Johannesburg, South Africa. Johannesburg: Corrosion Institute of Southern Africa; 2003.
5. Leitch J. The corrosivity regions of Southern Africa – long term trends and implications of material selection. Paper presented at: The 8th International Corrosion Conference; 2006 November 14–15; Johannesburg, South Africa. Corrosion Institute of Southern Africa and the South African Institute of Mining and Metallurgy; 2006. p. 1–10. https://doi.org/10.1353/afr.2007.0101
6. Hot Dip Galvanizers Association of Southern Africa (HDGASA). Corrosion resistance of hot dip galvanized coatings. Hot Dip Galv Today. 2005;2(2):39–45. https://doi.org/10.3403/30083371
7. Janse van Rensburg D. TX and DX corrosion index map 2009/2010. Research report no. RES/RR/09/31095. Johannesburg: Eskom Holdings SOC Limited; 2010.
8. Janse van Rensburg D. Atmospheric corrosion mapping of South Africa and the Greater Johannesburg Metropolitan Area (GJMA) [thesis]. Johannesburg: University of the Witwatersrand; 2019.
9. King G, Martin K, Moresby J. A detailed corrosivity survey of Melbourne. Highett, Australia: CSIRO – Division of Building Research; 1982.
10. Cole I, Paterson D. Mathematical models of dependence of surface temperatures of exposed metal plates on environmental parameters. Corros Eng Sci Techn. 2006;41(1):67–76. https://doi.org/10.1179/174327806X94045
11. Li Z, Marston N, Jones M. Update of New Zealand's atmospheric corrosivity map – Study report SR 288. Judgeford: BRANZ; 2013.
12. NACE International. International measures of prevention, application, and economics of corrosion technologies (IMPACT) study [document on the internet]. c2016 [cited 2019 Jul 08]. Available from: http://impact.nace.org/documents/Nace-International-Report.pdf
13. Slabbert M. Cost implications of metallic corrosion for the South African economy in the sectors of mining, power generation, shipping, and transportation – Report no. M251. Johannesburg: Mintek; 1986.
14. Rand vs the dollar: 1978 – 2016 [Internet]. BusinessTech. 2016 March 13 [cited 2017 Apr 09]. Available from: https://businesstech.co.za/news/finance/116372/rand-vs-the-dollar-1978-2016/
15. The World Bank. South Africa [webpage on the Internet]. c2017 [cited 2017 Apr 09]. Available from: http://www.worldbank.org/en/country/southafrica/overview
16. Natesan M, Venkatachari G, Palaniswamy N. Corrosivity and durability maps of India [document on the Internet]. c2005 [cited 2015 Jul 24]. Available from: http://krc.cecri.res.in/ro_2005/013-2005.pdf
17. Badea G, Cret P, Lolea M, Setel A. Studies of carbon steel corrosion in atmospheric conditions. Acta Technica Corviniensis – Bull Eng. 2011;Tome IV:p. 25-28.
18. Council for Scientific and Industrial Research (CSIR). Results of the four-year atmospheric exposure programme (Report C. CHEM 330). Pretoria: CSIR; 1975.
19. Gross C, Nixon M. Review of corrosion data for the proposed nuclear sites of the Eastern, Southern and Western Coasts – Eskom report TRR/S93/091. Johannesburg: Eskom Holdings SOC Limited; 1993.
20. ASTM G116-99 – Standard practice for conducting wire-on-bolt test for atmospheric galvanic corrosion. West Conshohocken, PA: ASTM International; 2004.
21. Nixon M, Janse van Rensburg D. Environmental contributions to atmospheric corrosion – Eskom research report TRR/S92/168. Johannesburg: Eskom Holdings SOC Limited; 1992.

22. Nixon M. Environmental contributions to atmospheric corrosion. Paper presented at: The 10th European Corrosion Congress; 1993 July 5–8; Barcelona, Spain. International Corrosion Council (ICC); 1993.

23. Janse van Rensburg D. Environmental contributions to atmospheric corrosion – Eskom research report TRR/S94/194/djvr. Johannesburg: Eskom Holdings SOC Limited; 1994.

24. Colloby D. Environmental contributions to atmospheric corrosion – Eskom report TRR/S95/205. Johannesburg: Eskom Holdings SOC Limited; 1995.

25. Northcott K. Environmental contributions to atmospheric corrosion – Paper no. 364. Paper presented at: The 4th International Corrosion Congress; 1999 September 27 – October 01; Cape Town, South Africa. International Corrosion Council and Corrosion Institute of Southern Africa; 1999. https://doi.org/10.1108/acmm.1999.12846daa.002

26. Gnoinski J, Ramothlola J. Progress report no. 3 – Monitoring of atmospheric corrosion in the Eastern Transvaal Highveld (report no. 940062). Johannesburg: Division of Materials Science and Technology, Council for Scientific Industrial Research; 1994.

27. Doyle D, Godard H. Rapid determination of corrosivity of an atmosphere to aluminium. In: Proceedings of the 3rd International Congress on Metallic Corrosion; 1966; Moscow, Russia. Moscow: MIR Publishers; 1966.

28. ISO 9223. Corrosion of metals and alloys: Corrosivity of atmospheres – classification. Geneva: International Organization for Standardization; 1992.

29. ISO 9226. Corrosion of metals and alloys: Corrosivity of atmospheres – determination of corrosion rate of standard specimens for the evaluation of corrosivity. Geneva: International Organization for Standardization; 1992.

30. SANS 1796. South African National Standard – Application of durable organic powder coatings for architectural aluminium. Pretoria: SABS Standards Division; 2013.

31. Pietersen D, Holtzhausen J, Vosloo W. An investigation into the methodology to develop an insulator pollution severity application map for South Africa. Paper presented at: The AFRICON Conference; 2004 September 15–17; Cape Town, South Africa. IEEE; 2004. https://doi.org/10.1109/africon.2004.1406774

32. Calitz J, Potgieter J. Corrosion of overhead power transmission conductors in marine environments. Trans S Afr Inst Electr Eng. 2005;96(4):306–311.

33. O'Donnell A, White R, Bronkhorst R, le R. Fourie F. The results of an atmospheric exposure programme on agricultural wire in South Africa [document on the Internet]. No date [cited 2016 Jan 02]. Available from: http://www.izasa.org/Documents/Technical/Exposure%20Progamme%20on%20Agricultural%20Wire%20in%20SA%20-%20paper%20046.pdf

34. Janse van Rensburg D. Corrosion index map – Eskom scan report no. RES/SC/05/26612. Johannesburg: Eskom Holdings SOC Limited; 2005.

35. ISO 9226. Corrosion of metals and alloys: Corrosivity of atmospheres – determination of corrosion rate of standard specimens for the evaluation of corrosivity. Geneva: International Organization for Standardization; 2012. https://doi.org/10.3403/30209297

36. ISO 9223. Corrosion of metals and alloys: Corrosivity of atmospheres – classification, determination and estimation. Geneva: International Organization for Standardization; 2012.

37. Saexplorer.co.za. Climate [webpage on the Internet]. No date [cited 2019 Feb 19]. Available from: http://www.saexplorer.co.za/south-africa/map/south_africa_map.asp

38. Cottis R, Graham M, Lindsay R, Lyon S, Richardson J, Scantlebury J, et al. Shreir's corrosion. Volume 2. 4th ed. Amsterdam: Elsevier; 2010. https://doi.org/10.1016/b978-044452787-5.09002-8

39. OpenStax CNX. Natural science – Ecosystems and the environmental balance [webpage on the Internet]. No date [cited 2017 Aug 17]. Available from: http://archive.cnx.org/contents/669116d7-d148-4af9-905d-4dcdf17cde-56@1#graphics1.png

40. Cole I, Paterson D. Holistic model for atmospheric corrosion. Part 5 – Factors controlling deposition of salt aerosol on candles, plates and buildings. Corros Eng Sci Techn. 2004;39(2):125–130. https://doi.org/10.1179/147842204225016949

41. Rozenfeld I. Atmospheric corrosion of metals. Houston, TX: NACE International; 1972.

42. Maps-streetview.com. Grabouw maps – road map, satellite view and street view [webpage on the Internet]. No date [cited 2017 Apr 09]. Available from: https://www.maps-streetview.com/South-Africa/Grabouw/

43. Hernandez FJ, Santana JJ, Souta S, Gonzales S, Morales J. Characterization of the atmospheric corrosion of aluminium in Archipelagic subtropical environments. Int J Electrochem Sci. 2011;6:6567–6580.

44. Del Angel E, Vera R, Corvo F. Atmospheric corrosion of galvanised steel in different environments in Chile and Mexico. Int J Electrochem Sci. 2015;10:7985–8004.

45. Ballance J, Duncan J. Wind-borne transport and deposition of sea-salt in New Zealand. New Zealand J Technol. 1985;1:239–244.

46. Thornton J, Kercher J, Riedel T, Wagner N, Cozic J, Holloway J, et al. A large atomic chlorine source inferred from mid-continental reactive nitrogen chemistry. Nature. 2010;464(7286):271–274. https://doi.org/10.1038/nature08905

47. Winter K, Oelofse C, Bottaro J. Oxford senior atlas vir Suider-Afrika [Oxford senior atlas for southern Africa]. 13th ed. Cape Town: Oxford University Press Southern Africa; 2013. Afrikaans.

48. OpenStax College. Geography [webpage on the Internet]. c2017 [cited 2017 Apr 09]. Available from: http://archive.cnx.org/contents/d5717376-e429-4585-a1ee-98767a736cfd@1/climate-regions

49. Cole I, Paterson D, Ganther W. Holistic model for atmospheric corrosion. Part 1 – Theoretical framework for production, transportation and deposition of marine salts. Corros Eng Sci Techn. 2003;38(2):129–134. https://doi.org/10.1179/147842203767789203

50. Wiegand P, editor. Oxford secondary atlas for South Africa. Cape Town: Oxford University Press; 2007.

51. Barnett W. Walter's corner – the atmospheric corrosion rate is not always what it seems to be! Hot Dip Galv Today. 2006;3(1):36–37.

52. South African Tours and Travel.com. Enjoy South Africa 's climate, delightfully mild and pleasant all year round [webpage on the Internet]. No date [cited 2017 Aug 18]. Available from: http://www.south-africa-tours-and-travel.com/south-africa-climate.html

53. Evwind. Enel brings two new South African PV plants [webpage on the Internet]. No date [cited 2017 Aug 16]. Available from: https://www.evwind.es/2017/02/06/enel-brings-two-new-south-african-pv-plants/58722

54. Sun S, Zheng Q, Wen J, Li D. Atmospheric corrosion of aluminium in the northern Taklamakan Desert environment. Mater Corros. 2009;61(10):852–859. https://doi.org/10.1002/maco.200905422

55. Maskew Miller Longman (Pty) Ltd. Pearson – platinum high school atlas. 6th ed. Cape Town: Maskew Miller Longman; 2016.

56. Nixon M. Environmental contributions to atmospheric corrosion – Eskom interim report TRR/S91/143. Johannesburg: Eskom Holdings SOC Ltd; 1991.

57. Corvo F, Perez T, Dzibb L, Martin Y, Castañeda A, Gonzalez E, et al. Outdoor-indoor corrosion of metals in tropical coastal atmospheres. Corros Sci. 2008;50(1):220–230. https://doi.org/10.1016/j.corsci.2007.06.011

58. Castaneda A, Corvo F, Howland J, Marrero R. Penetration of marine aerosol in a tropical coastal city: Havana. Atmósfera. 2018;31(1):87–104.

59. Microsoft. Microsoft Excel – Pearson function [webpage on the Internet]. No date [updated 2017; cited 2017 Apr 15]. Available from: https://support.office.com/en-us/article/PEARSON-function-0c3e30fc-e5af-49c4-808a-3ef66e034c18?NS=EXCEL&Version=16&SysLcid=1033&UiLcid=1033&AppVer=ZXL160&HelpId=xlmain11.chm60360&ui=en-US&rs=en-US&ad=US

AUTHORS:
Jennifer M. Fitchett[1]
Stefan W. Grab[1]
Heinrich Portwig[1]

AFFILIATION:
[1]School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

CORRESPONDENCE TO:
Jennifer Fitchett

EMAIL:
jennifer.m.fitchett@gmail.com

DATES:
Received: 20 Dec. 2018
Revised: 24 Mar. 2019
Accepted: 26 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Fitchett JM, Grab SW, Portwig H. Progressive delays in the timing of sardine migration in the southwest Indian Ocean. S Afr J Sci. 2019;115(7/8), Art. #5887, 6 pages. https://doi.org/10.17159/sajs.2019/5887

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☒ On request from author(s)
☐ Not available
☐ Not applicable

EDITORS:
John Butler-Adam

KEYWORDS:
phenology; sardine run; sea surface temperature; ENSO; mid-latitude cyclones

FUNDING:
None

Progressive delays in the timing of sardine migration in the southwest Indian Ocean

Phenological shifts represent one of the most robust bioindicators of climate change. While considerable multidecadal records of plant and animal phenology exist for the northern hemisphere, few noteworthy records are available for the southern hemisphere. We present one of the first phenological records of fish migration for the southern hemisphere, and one of the only phenological records for the southwest Indian Ocean. The so-called 'sardine run' – an annual winter migration of sardines, northeast of their summer spawning grounds on the Agulhas Bank off the coast of Durban, South Africa – has been well documented in local newspapers given the importance placed on fishing and fishing-tourism in the region. An analysis of the first arrival dates of sardines reveals a 1.3 day per decade delay over the period 1946–2012. Although this phenological shift reveals a poor association with sea surface temperatures (SST), it coincides with a poleward shift in the position of the 21 °C mean annual SST isotherm – the threshold temperature for sardine populations. The timing of sardine arrivals near Durban corresponds closely with the number of mid-latitude cyclones passing over the Durban coastline during the months of April and May. The strength of the run is strongly associated with ENSO conditions. The complex suite of factors associated with this phenological shift poses challenges in accurately modelling the future trajectory for this migratory event.

Significance:

- The sardine run, a significant event for tourism and fisheries, is occurring progressively later in the year.
- The incidence of failed sardine runs has increased in frequency over the period 1946–2012.
- These changes in fish migration phenology coincide with a poleward shift in the position of the 21 °C mean annual SST isotherm.
- The strength in the sardine run is strongly associated with ENSO conditions.

Introduction

Shifts in the timing of floral and faunal phenological events are cited as one of the most robust bioindicators of climate change.[1] A substantial body of literature has highlighted both advances and delays in phenological events as a direct response to global scale warming over recent decades.[2-5] These meta-analyses have confirmed, most importantly, that such shifts are both location and species specific in nature.[6] This in turn results in mismatches between flowers and pollinators[7,8]; predators and prey[9,10]; and food supply (or food peaks) and demand during breeding and feeding young offspring[11,12]. The importance of a high spatial resolution network of phenological observations spanning a wide range of plant and animal species is thus magnified, both for the region and species, and for the global understanding of phenological responses to climate change.[13]

The timing of annual migrations and the extent of the range shifts captured therein represent an important phenological record due to the interaction of intrinsic and extrinsic cues.[14,15] Given the range shift boundaries that are posed by anthropogenic infrastructural developments, overlapping predator ranges, and food availability, shifts in the timing and extent of annual migration often cannot transpire to the extent required by the intrinsic temperature-related cue of the species. Research on annual migration is hampered by the dynamic nature of the subject being observed.[16] Unlike plants which remain in a fixed location throughout their lifespan, and which can thus be observed daily on an individual basis, migratory events can often only be measured for the migrating population as a whole.[17] Moreover, unless tracking devices are used, the phenological record of the migration event is usually captured using proxies for the appearance of the population at a destination along the migratory route, such as bird and frog calls or evidence of nest construction.[18,19] These proxies, captured over a longitudinal time span, are then compared against the climatic conditions at that destination, to determine the phenological shifts under changing climatic conditions.[2,19]

The 'sardine run' is an annual eastward migration of sardines from the Agulhas Bank off the southern coast of South Africa (Figure 1) in early (austral) winter.[20,21] Sardines are small pelagic fish belonging to the order Clupeiformes, with the South African sardine *Sardinops sagax* being the focus of the current study. South African sardine subpopulations, which thrive under ocean temperatures of 21 °C, are constrained to waters poleward of ~32°S during the summer months, with the exception of the west coast which is influenced by cold, deep water upwelling through Ekman transport, driven by the Benguela current.[21] In winter, as the 21 °C isotherm shifts northwards, the sardines' range is expanded up the east coast of the country.[22] Evidence from coastal sampling suggests that the east coast region of South Africa serves as a spawning ground during the winter months.[23]

This distinct seasonal migration is a feature of the geographical position of South Africa. Situated at the boundary of the subtropics and mid-latitudes, South Africa is influenced by significant seasonal fluctuations. During winter months, the climate of the southern half of the country is controlled by the frequent passage of mid-latitude cyclones, whereas convective systems characterise precipitation in the northern interior during summer months.[24,25] The latitudinal position of the westerlies, and in turn the potential for the northern progression of mid-latitude cyclones[25], more directly influences the oceanographic conditions along the east coast of South Africa through responses in the Agulhas leakage[26]. However, factors encouraging their seasonal migration are poorly understood, particularly as the region remains populated by predators such as sharks, and has a thermally restricted plankton abundance which limits food supply.[20,27] Similar

seasonal migration patterns, range shifts and population size changes in sardines have been reported for Sweden[28,29], Chile[30] and the Pacific Ocean more broadly[31,32]. The role of climate change in altering these population behavioural characteristics has been considered at both global and regional scales[33], including the importance of El Niño Southern Oscillation (ENSO) and the frequency and intensity of mid-latitude cyclones[32].

The sardine run has received considerable media attention for more than 150 years in and near the city of Durban on the east coast of South Africa. The sudden migration of sardines results in favourable fishing conditions in a region otherwise too warm for this species, and the heightened shark, dolphin and penguin activity in the region serves as a tourist attraction.[27,34] Newspapers contain a rich, temporally constrained record of the annual sardine migration, which to date has not been explored. To this end, we investigated this record for the region, over the period 1947–2010. In so doing, we aimed to quantify the phenological shift of the sardine run over the given period, and interrogate a range of ocean–atmospheric factors that may explain any changes in the timing of this phenological event in the context of global climate change related phenological shifts.

Materials and methods

The phenological record of annually northeastward migrating sardines in early (austral) winter was constructed using articles from three newspapers published in the Durban and South Coast region of KwaZulu-Natal Province, South Africa: *South Coast Sun* (1999–2006), *South Coast Herald* (1949–1998, 2006–2012) and the *Natal Mercury* (1852–1949). These newspapers are archived in the National Library of South Africa, and all issues of the newspaper spanning April to August each year were consulted in the archive. The *South Coast Sun* and *South Coast Herald* were weekly publications. Most records of sardine sightings were obtained from the *South Coast Herald*, which was published every Friday. The *Natal Mercury* was printed as a weekly to twice weekly publication until 1878; from 2 January 1878 it became a daily publication (it has since become the *Mercury*). These newspapers record specific days when the run occurred, by referring to the event on a specific date. Given that the sardine run events are notable 'public' or 'social' events of much interest on a given day, there is a relatively high level of accuracy in the dates recorded. However, as with any documentary source, an inherent margin of error exists in both the specificity of the start date, and the reliability of annual recordings.

Early newspaper accounts of the sardine run spanning 1852–1945 are sporadic, and thus cannot be included in any meaningful statistical analysis. These do, however, reflect the prolonged occurrence of this phenological event in the region. More recent newspaper reports include a richer array of descriptions, including the size of the shoal, the human interest, and comparison between events:

> *Hundreds of cars from far and wide poured in and out Port Edward looking for sardines, huge shoals and thousands of birds spotted at Port Edward on Sunday.*
>
> *South Coast Herald,* 30 June 1961

> *Our photographer was at Portobello beach last weekend when the mammoth 1971 sardine run began, already it has been the biggest sardine run in 8 years say some experts, others claim there haven't been so many of the fish since 1959.*
>
> *South Coast Herald,* 25 June 1971

From the newspaper records spanning 1946–2012, all but two years contained mention of the sardine run. From these reports, the first report of the sardine run for each year was captured, together with quotes containing commentary relating to the size of the run. Calendar dates were converted to Julian dates for analysis.[19] The rate of change in the timing of the sardine run was calculated using standard univariate linear regression analysis in the form $y=mx+c$.[19] Commentary pertaining to the size of the run was qualitatively grouped using content analysis.

To determine the role of climatic change in driving the phenological shift, the annual dates of the first recorded sardine runs in Durban were compared against mean sea surface temperatures (SST) at Port St Johns (Figure 1), acquired from the NOAA extended SST database (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html), using Pearson's correlation coefficient.[19] Long-term trends in the latitudinal position of the 21 °C SST isotherm, the threshold condition for sardine range, were qualitatively explored through developing a composite plot of the decadal mean annual sea surface isotherms from the NOAA Extended V4 GrADS images (https://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.v4.html). The 21 °C isotherm was extracted for each decade and these were overlaid for the period 1941–2010.[35,36] To explore the role of mid-latitude cyclone occurrence in determining the Julian date of sardine arrival off the coast of Durban[32], monthly counts of mid-latitude cyclone incursion to, or over, the Durban region were captured from daily synoptic maps produced by the South African Weather Service spanning 0–70°S, 60°W–80°E. A sum of mid-latitude cyclones for the months of April and May was then compared statistically to the arrival dates using Pearson's correlation coefficient, and the range of arrival dates per number of mid-latitude cyclones were compared using five-number summaries (maximum, minimum, first and third quartiles, median and outliers) produced in box-plot format. To explore the relationship between the sardine arrival date and ENSO[32], Multivariate ENSO Index (MEI) values were obtained (https://www.esrl.noaa.gov/psd/enso/mei/) and compared to the arrival dates using Pearson's correlation coefficient. The mean annual MEI values were then displayed as a time series, against which the newspaper-reported occurrences of 'good', 'poor' and 'absent' sardine migration events were plotted, to determine concurrent ENSO and anomalous migration events.

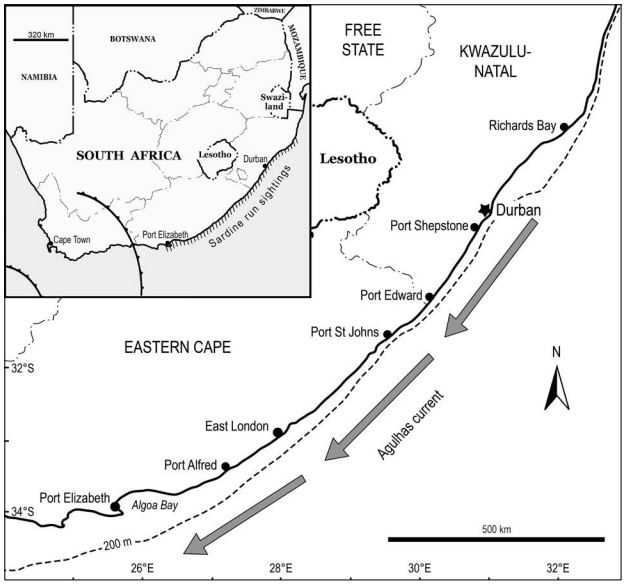


Figure 1: Map of southern Africa indicating the east coast of South Africa along which the sardine runs are sighted (see hashed zone along the coast), and the winter mean trajectory of mid-latitude cyclones (barbed line). The 200-m isobath indicates the extent of the continental shelf.

Results

A progressive delay is noted in the first mention of annual sardine runs in the Durban region, for the period 1947–2012 (Figure 2). This delay in arrival date occurs at a mean rate of 0.13 days per year ($r=0.23$, $p=0.07$, d.f.$=64$), or 1.3 days per decade, and represents a shift in the arrival date from a mean Julian date of 161 (~June 10) for the first decade of the data set to a mean Julian date of 173 (~June 22) for the most recent decade of the data set. The latest arrival dates were recorded for the years 1978 (JD$=204$) and 2006 (JD$=203$), while the earliest arrival dates were recorded for 1949 and 1967 (both JD$=146$) and 1984 (JD$=147$). The variability in the date of arrival has increased over time (Figure 2), from a relatively low standard deviation for the period 1947–1965 ($\sigma=6.2$), with a 204% increase in variability for the

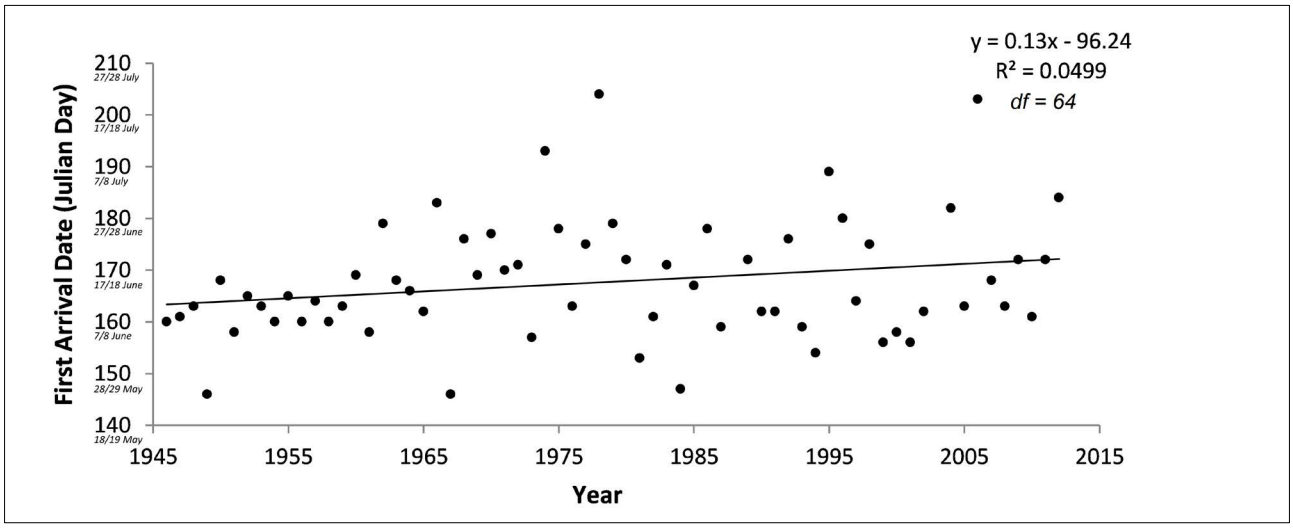


Figure 2: Phenological shift in the start date of the sardine migration in the southwest Indian Ocean over the period 1946–2014.

consecutive period 1966–2014 (σ=12.7). The greatest variability in sardine arrival date is observed for the period 1967–1984 (σ=14.63), with markedly lower variability thereafter, centred around a mean arrival Julian date of 169 (σ=11.77).

Statistically significant time trends in mean monthly SST for the Durban region spanning 1946–2012 were calculated for the months of May, June and July, and the mean winter period at a rate of 0.01 °C/year (Table 1).

Table 1: Time trend in mean monthly sea surface temperature (SST) at Port St Johns for the months of May, June and July, and Pearson's correlation coefficient values for the comparison with sardine arrival date (1946–2012, d.f. = 64)

	May	June	July	Winter mean
SST Time trend	0.01°/year	0.01°/year	0.01°/year	0.01°/year
	$r = 0.58$	$r = 0.64$	$r = 0.55$	$r = 0.65$
	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
Correlation with sardine arrival date	$r = 0.12$	$r = 0.21$	$r = 0.32$	$r = 0.24$
	$p = 0.2$	$p = 0.1$	$p = 0.01$	$p = 0.05$

Weak correlations were observed between the arrival dates of sardines in the Durban region and local mean annual ocean temperatures for the months of May (r=0.12, p=0.3361, d.f.=64), June (r=0.21, p=0.0932, d.f.=64) and July (r=0.32, p=0.0087, d.f.=64) during which the sardine run occurs, with no statistically significant correlation between mean winter SST and the sardine run dates (r=0.24, p=0.05; Table 1). However, concurrent with this phenological shift in arrival dates of migratory sardine populations along the south and east coasts of southern Africa, is a progressive poleward displacement of the 21 °C isotherm from 1951 to 2010 (Figure 3).

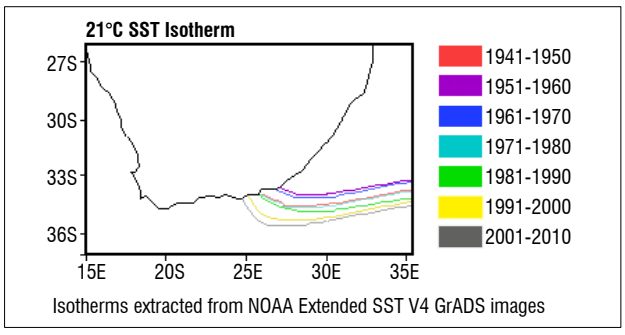


Figure 3: Poleward shift in the 21 °C mean annual sea surface temperature (SST) isotherm over the period 1941–2010.

This displacement is significant as 21 °C is the maximum threshold ocean temperature for sardines. The isotherm has shifted 1.5° poleward since 1951, which equates to a 0.25° latitudinal shift per decade. Notably, the 21 °C isotherm for the period 1941–1950 is located ~0.6° south of the 21 °C isotherm for the periods 1951–1960 and 1961–1970 (Figure 3). This finding may indicate a degree of interdecadal variability in the position of the 21 °C isotherm, although the progressive poleward trend from 1951 onwards would suggest a continuous response to global scale warming during this period.

On average, 10 mid-latitude cyclones affect the Durban region during the months of April and May each year; 15 of the 58 years in the sample were characterised by six mid-latitude cyclones in the region during April and May. A statistically significant relationship exists between the number of mid-latitude cyclones experienced during April and May and the arrival date of sardines in the region (r=0.37, p<0.005, d.f.=67). By classifying sardine arrival dates according to the number of mid-latitude cyclones during the preceding months of April and May, the effect of this discrete variable can be considered. A progressive delay in arrival date corresponds with an increase in the number of mid-latitude cyclones, at a rate of 2.4 days per additional cyclone (Figure 4).

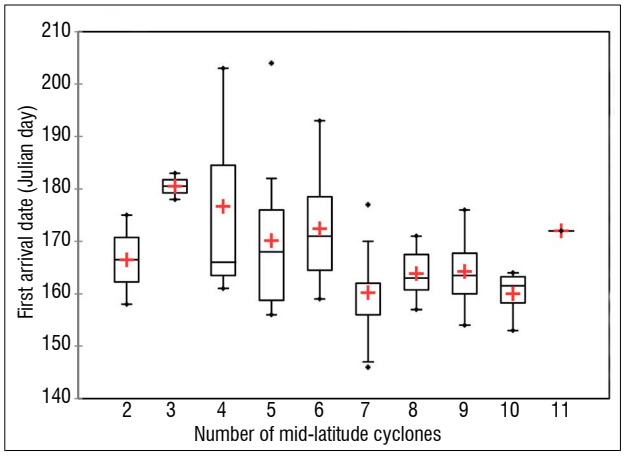


Figure 4: Arrival date of sardines classified by the number of mid-latitude cyclones. Central line represents the median value; crosses indicate the mean score.

A particular exception to this relationship is the occurrence of 11 mid-latitude cyclones in the region during April and May of 1980, with a significantly later first arrival date. In addition, years with only two mid-latitude cyclones in April and May, had notably earlier first arrival dates (Figure 4). These exceptions at the extremes may be indicative of errors

in the attribution of mid-latitude cyclone conditions, particularly in the earlier records.

No statistical correlation exists between the first arrival date of sardines and the MEI score ($r=0.02$, $p=0.4256$). However, a degree of correspondence is observed when plotting the sardine run migration events that were reported in the newspaper articles as explicitly 'good' or 'strong', 'weak' or 'poor', and the instances of no sardine run occurring against mean annual MEI over the period 1946–2012 (Figure 5). Years with a poor run or no run correspond with the majority of the positive MEI scores (El Niño events), whereas years with a good run correspond in most instances with negative MEI scores (La Niña events).

Multiple regression analysis to determine the combined effect of this collection of variables on sardine arrival dates returned a statistically insignificant model capable of explaining only 16.90% of the variance ($p=0.0783$), defined by the equation:

$$\text{Arrival date} = 89.37 - 1.48[\text{mid-latitude cyclone count}] - 5.51[SST_{May}] - 3.80[SST_{June}] + 13.77[SST_{July}] + 0.41[\text{ENSO}].$$

Discussion and conclusion

Phenological shifts in the timing of first observation of migratory species represent a key biometeorological indicator of faunal responses to climate change.[2,14] With the significance of migration timing to inter- and intra-species overlap, it is also one of the phenological shifts most likely to disrupt entire ecosystems following relatively small climatic changes.[10] However, there remain relatively few studies exploring shifts in the timing of migratory fish species[37-40], and in particular that for sardines. Given the importance of this species for global fisheries[41,42], an improved understanding of the temporal and spatial variability in the phenological response to warming atmospheric and oceanic temperatures is imperative[20]. For the southern African sardine run in particular, the poorly understood interannual variability in the timing of the event is frequently cited as a threat to the sustained economic benefit from the event through increased fishing opportunities and tourism.[21,23,34] The long-term progressive delay in the sardine arrival date places this interannual variability into context of longer-term shifts in the phenology, which in turn facilitates better monitoring and modelling of this event. However, the heightened variability in the timing over recent decades, and, in particular, the recent failures of the event pose a concerning outlook for sardine populations in the region.

Phenological shifts, for both plant and animal species, are often related directly to changes in local air temperature.[2,17,18] For marine species, SSTs and ocean–atmospheric interactions have a more direct impact[4], although the same impact can often be simulated using coastal atmospheric temperatures[43]. There has also been recent acknowledgement that phenological shifts are often a response to a wider range of climatic factors, including but not limited to frost, days above a certain threshold temperature, ENSO, and rainfall in the case of terrestrial species[44-46], and photoperiod[47], upwelling dynamics[40], and lunar tidal cycles[48], in addition to a range of intrinsic factors, for oceanic species. This study demonstrates poor correlation between the arrival date of sardines and SST. However, the delay in arrival date occurs concurrently with a poleward shift in the mean annual 21 °C isotherm. The poleward shift in this 21 °C isotherm, representing the threshold temperature boundary for sardine range[21], could explain the trend towards a later migration date, and possible failure of the event all together, along parts of the southeastern African coastline. After such a date, the narrower temporal window of temperatures below 21 °C would be experienced northeast of the sardines' summer habitat.

The association between later migration dates and lower numbers of mid-latitude cyclones in the austral autumn months of April and May further demonstrates the importance of secondary effects to the regional scale warming in constraining sardine arrival dates. Mid-latitude cyclone frequency apparently also controls the magnitude of the range shift of sardines in the North Pacific Ocean, through coupled temperature decreases and an enhanced overturning of surface waters.[32] Long-term changes in the cyclogenesis of these systems through an expansion of the Hadley cell region should be investigated further[49,50], given the significance of these systems for the sardine run. Although advances in spring phenological events are commonly reported as a response to climate change, delays in phenology have also been calculated among a range of plant and animal species even where species and methodology for data collection and analysis have been standardised.[2,6] Menzel et al.[51] argue that the relatively low rate of reporting phenological delays in scientific literature relates to biases in both the analysis and publication of data sets that do not conform to the expected trend. Moreover, in the case of autumn phenological events (which the sardine run represents), recent analyses for the northern hemisphere indicate that a delay may be the more common response, at least among plant species.[52]

While there is no statistical correlation between the arrival date and the MEI, the occurrences of good and poor sardine runs coincide very closely with El Niño and La Niña events, respectively – a similar result to that found for sardine migration patterns in the Pacific Ocean[32] and sardine recruitment off Chile[30]. It is notable, however, that not all of the strongest El Niño events correspond with the failed sardine runs, neither do all of the instances of failed sardine runs correspond with peaks in MEI scores. Thus, phenological shifts in the timing of faunal migrations in the southwest Indian Ocean are driven by a more complex set of ocean–atmospheric variables than that used to account for the more extensively documented changes in plant phenology, including but not limited to a

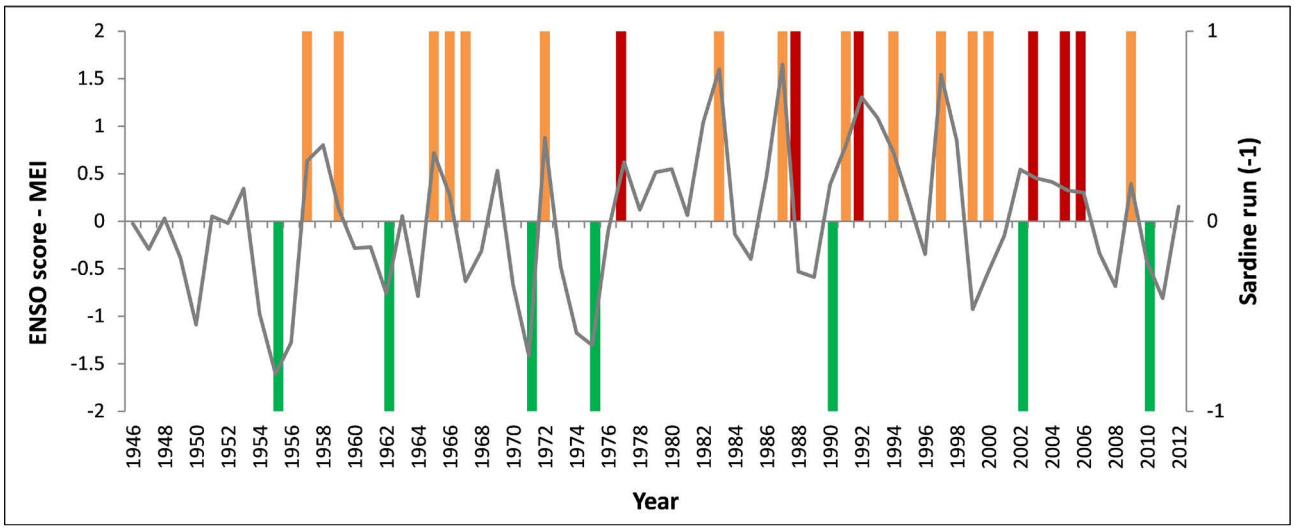


Figure 5: Multivariate ENSO Index (MEI) score (grey line; positive indicating El Niño events, negative indicating La Niña events) and the years of good (green bar, negative *y*-score), poor (orange bar, positive *y*-score) and non-existent (red bar, positive *y*-score) sardine runs.

lagged ENSO effect, mid-latitude cyclones and SST, and are thus more difficult to statistically quantify. An important avenue for future research would include a detailed analysis of the sardine runs during strong El Niño and La Niña events, including total catch size, the experiences of fishers in the region, and a comparison with sub-daily oceanographic and meteorological data through the period of those runs.

Looking forward, three key factors are of concern. The first, in the short term, is the variability in timing of the sardine run, and the consequent lack of predictability which can have a detrimental effect on the fishing and tourism sectors of the Durban region.[21,34] While this study confirms and quantifies the rate of delay in arrival date, this shift is coupled with a significant increase in the variability in arrival dates and recent failure of arrivals. Although a more comprehensive suite of ocean–atmospheric factors driving this shift are presented in this study than in former analyses of sardine run variability, this comprehensiveness does not necessarily afford a greater predictive strength for the timing of migration. Considerable environmental modelling would thus be required, coupled with real-time input of mid-latitude cyclones and the associated surface pressure fluctuations within the region, Agulhas current eddies, and MEI data to provide reliable seasonal forecasting of the arrival date. In the medium term, the increased incidence and last few years of failed runs presented in this study is of concern.[20] It is unclear from the records available whether these incidents of failed runs represent a year in which the population did not migrate from the Agulhas Bank, a run in which the migration did not extend as far northeast as the Durban region, or a run which was thermally restricted to deeper waters, and thus not visible from the coastline.[20] However, should this trend continue, it would heighten the probability that the run may have collapsed altogether, or shifted considerably further south.[53] The delayed timing in the short term and possible collapse of the migration pattern in the long term present a third concern at an ecosystem scale, which relates to the predator–prey mismatches which may ensue.[9,27,53] Improved observation of the concurrent phenological and range shifts among shark populations in the region, and changes in the abundance of phytoplankton, should thus be carefully monitored.[23]

This record highlights the significance of indirect ocean–atmospheric changes under conditions of global warming in constraining phenological and range shifts. This result heightens the importance of understanding phenological shifts among a diverse range of species, and across a large range of terrestrial and marine environments, to better understand the rate of phenological shifts, the intrinsic and extrinsic drivers, and the prospects for the species under sustained warming.

Authors' contributions

H.P. and S.W.G. collected the data. H.P. and J.M.F. conducted the statistical analysis. J.M.F. wrote the first draft of the manuscript. H.P. and S.W.G. provided input on the first draft.

Acknowledgement

We appreciate the sharing of ideas and suggestions provided by Dr Sean O'Donoghue during the early stage of this investigation.

References

1. Schwartz MD. Advancing to full bloom: Planning phenological research for the 21st century. Int J Biometeorol. 1999;42:113–118. https://doi.org/10.1007/s004840050093
2. Parmesan C, Yohe G. A globally coherent fingerprint of climate change impacts across natural systems. Nature. 2003;421(6918):37–42. https://doi.org/10.1038/nature01286
3. Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA. Fingerprints of global warming on wild animals and plants. Nature. 2003;421(6918):57. https://doi.org/10.1038/nature01333
4. Poloczanska ES, Brown CJ, Sydeman WJ, Kiessling W, Schoeman DS, Moore PJ, et al. Global imprint of climate change on marine life. Nat Clim Change. 2013;3:919–925. https://doi.org/10.1038/nclimate1958
5. Chambers LE, Altwegg R, Barbraud C, Barnard P, Beaumont LJ, Crawford RJM, et al. Phenological changes in the southern hemisphere. PLoS ONE. 2016;8(10), e75514, 12 pages. https://doi.org/10.1371/journal.pone.0075514
6. Fitchett JM, Grab SW, Thompson DI. Plant phenology and climate change: Progress in methodological approaches and application. Prog Phys Geog. 2015;39(4):460–482. https://doi.org/10.1177/0309133315578940
7. Hegland SJ, Nielsen A, Lázaro A, Bjerknes AL, Totland Ø. How does climate warming affect plant-pollinator interactions? Ecol Lett. 2009;12(2):184–195. https://doi.org/10.1111/j.1461-0248.2008.01269.x
8. Rafferty NE, Ives AR. Effects of experimental shifts in flowering phenology on plant–pollinator interactions. Ecol Lett. 2011;14(1):69–74. https://doi.org/10.1111/j.1461-0248.2010.01557.x
9. Edwards M, Richardson AJ. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature. 2004;430(7002):881–884. https://doi.org/10.1038/nature02808
10. Durant JM, Hjermann DØ, Ottersen G, Stenseth NC. Climate and the match or mismatch between predator requirements and resource availability. Clim Res. 2007;33(3):271–283. https://doi.org/10.3354/cr033271
11. Visser ME, Holleman LJ, Gienapp P. Shifts in caterpillar biomass phenology due to climate change and its impacts on the breeding biology of an insectivorous bird. Oecologia. 2006;147:164–172. https://doi.org/10.1007/s00442-005-0299-6
12. Saino N, Ambrosini R, Rubolini D, Von Hardenberg J, Provenzale A, Hüppop K, et al. Climate warming, ecological mismatch at arrival and population decline in migratory birds. Philos T Roy Soc B. 2011;278(1707):835–842. https://doi.org/10.1098/rspb.2010.1778
13. Parmesan C. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Glob Chang Biol. 2007;13(9):1860–1872. https://doi.org/10.1111/j.1365-2486.2007.01404.x
14. Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJ, et al. Ecological responses to recent climate change. Nature. 2002;416(6879):389–395. https://doi.org/10.1038/416389a
15. Cotton PA. Avian migration phenology and global climate change. Proc Natl Acad Sci USA. 2003;100(21):12219–12222. https://doi.org/10.1073/pnas.0400920101
16. Alerstam T, Hedenström A, Åkesson S. Long-distance migration: Evolution and determinants. Oikos. 2003;103(2):247–260. https://doi.org/10.1034/j.1600-0706.2003.12559.x
17. Hurlbert AH, Liang Z. Spatiotemporal variation in avian migration phenology: Citizen science reveals effects of climate change. PLoS ONE. 2012;7(2), e31662, 11 pages. https://doi.org/10.1371/journal.pone.0031662
18. Sparks TH, Carey PD. The responses of species to climate over two centuries: An analysis of the Marsham phenological record, 1736-1947. J Ecol. 1995;83(2):321–329. https://doi.org/10.2307/2261570
19. Gibbs JP, Breisch AR. Climate warming and calling phenology of frogs near Ithaca, New York, 1900–1999. Conserv Biol. 2001;15(4):1175–1178. https://doi.org/10.1046/j.1523-1739.2001.0150041175.x
20. Fréon P, Coetzee JC, Van der Lingen CD, Connell AD, O'Donoghue SH, Roberts MJ, et al. A review and tests of hypotheses about causes of the KwaZulu-Natal sardine run. Afr J Mar Sci 2010;32(2):449–479. https://doi.org/10.2989/1814232x.2010.519451
21. O'Donoghue SH, Drapeau L, Dudley SF, Peddemors VM. The KwaZulu-Natal sardine run: Shoal distribution in relation to nearshore environmental conditions, 1997–2007. Afr J Mar Sci. 2010;32(2):293–307. https://doi.org/10.2989/1814232x.2010.501587
22. O'Donoghue SH, Drapeau L, Peddemors VM. Broad-scale distribution patterns of sardine and their predators in relation to remotely sensed environmental conditions during the KwaZulu-Natal sardine run. Afr J Mar Sci. 2010;32(2):279–291. https://doi.org/10.2989/1814232x.2010.501584
23. Connel AD. A 21-year ichthyoplankton collection confirms sardine spawning in KwaZulu-Natal waters. Afr J Mar Sci. 2010;32(2):331–336. https://doi.org/10.2989/1814232x.2010.502638
24. Jury MR, Valentine HR, Lutjeharms JRE. Influence of the Agulhas Current on summer rainfall along the Southeast Coast of South Africa. J Appl Meteorol. 1993;32:1282–1287. https://doi.org/10.1175/1520-0450(1993)032<1282:iotaco>2.0.co;2

25. Roffe SJ, Fitchett JM, Curtis CJ. Classifying and mapping rainfall seasonality in South Africa: A review. S Afr Geogr J. 2019;101(2):158–174. https://doi.org/10.1080/03736245.2019.1573151

26. Biastoch A, Böning CW, Schwarzkopf FU, Lutjeharms JRE. Increase in Agulhas leakage due to poleward shift of southern hemisphere westerlies. Nature. 2009;462:495–498. https://doi.org/10.1038/nature08519

27. Hutchings L, Morris T, Van Der Lingen CD, Lamberth SJ, Connell AD, Taljaard S, et al. Ecosystem considerations of the KwaZulu-Natal sardine run. Afr J Mar Sci. 2010;32(2):413–421. https://doi.org/10.2989/1814232x.2010.502644

28. Alheit J, Hagen E. Long-term climate forcing of European herring and sardine populations. Fish Oceanogr. 1997;6(2):130–139. https://doi.org/10.1046/j.1365-2419.1997.00035.x

29. Alheit J, Pohlmann T, Casini M, Greve W, Hinrichs R, Mathis M, et al. Climate variability drives anchovies and sardines into the North and Baltic Seas. Prog Oceanogr. 2012;96:128–139. https://doi.org/10.1016/j.pocean.2011.11.015

30. Gomez F, Montecinos A, Hormazabal S, Cubillos LA, Correa-Ramirez M, Chavez FP. Impact of spring upwelling variability off southern-central Chile on common sardine (*Strangomera bentincki*) recruitment. Fish Oceanogr. 2012;21(6):405–414. https://doi.org/10.1111/j.1365-2419.2012.00632.x

31. Chavez FP, Ryan J, Lluch-Cota SE, Niquen M. From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. Science. 2003;299:217–221. https://doi.org/10.1126/science.1075880

32. Auth TD, Daly EA, Brodeur RD, Fisher JL. Phenological and distributional shifts in ichthyoplankton associated with recent warming in the northeast Pacific Ocean. Glob Chang Biol. 2018;24(1):259–272. https://doi.org/10.1111/gcb.13872

33. Checkley Jr DM, Asch RG, Rykaczewski RR. Climate, anchovy, and sardine. Ann Rev Mar Sci. 2017;9:469–493. https://doi.org/10.1146/annurev-marine-122414-033819

34. Dicken ML. Socio-economic aspects of boat-based ecotourism during the sardine run within the Pondoland Marine Protected Area, South Africa. Afr J Mar Sci. 2010;32(2):405–411. https://doi.org/10.2989/1814232x.2010.502642

35. Fitchett JM, Grab SW. A 66-year tropical cyclone record for south-east Africa: Temporal trends in a global context. Int J Climatol. 2014;34(13):3604–3615. https://doi.org/10.1002/joc.3932

36. Fitchett JM. Recent emergence of CAT5 tropical cyclones in the South Indian Ocean. S Afr J Sci. 2018;114(11/12):83–88. https://doi.org/10.17159/sajs.2018/4426

37. Sims DW, Wearmouth VJ, Genner MJ, Southward AJ, Hawkins SJ. Low-temperature-driven early spawning migration of a temperate marine fish. J Anim Ecol. 2004;73:333–341. https://doi.org/10.1111/j.0021-8790.2004.00810.x

38. Kaltenberg AM, Emmett RL, Benoit-Bird KJ. Timing of forage fish seasonal appearance in the Columbia River plume and link to ocean conditions. Mar Ecol Prog Ser. 2010;419:171–184. https://doi.org/10.3354/meps08848

39. Jansen T, Gislason H. Temperature affects the timing of spawning and migration of North Sea mackerel. Cont Shelf Res. 2011;31:64–72. https://doi.org/10.1016/j.csr.2010.11.003

40. Asch RG. Climate change and decadal shifts in the phenology of larval fishes in the California Current Ecosystem. Proc Natl Acad Sci USA. 2015;112(30):4065–4074. https://doi.org/10.1073/pnas.1421946112

41. Beckley LE, Van der Lingen CD. Biology, fishery and management of sardines (*Sardinops sagax*) in southern African waters. Mar Freshwater Res. 1999;50(8):955–978. https://doi.org/10.1071/mf99068

42. Botsford LW, Castilla JC, Peterson CH. The management of fisheries and marine ecosystems. Science. 1997;277(5325):509–515. https://doi.org/10.1126/science.277.5325.509 .

43. Morley JW, Batt, RD, Pinsky ML. Marine assemblages respond rapidly to winter climatic variability. Glob Change Biol. 2016;23:2590–2601. https://doi.org/10.1111/gcb.13578

44. Peñuelas J, Filella I, Zhang X, Llorens L, Ogaya R, Lloret F, Comas P, Estiarte M, Terradas J. Complex spatiotemporal phenological shifts as a response to rainfall changes. New Phytol. 2004;161(3):837–846. https://doi.org/10.1111/j.1469-8137.2004.01003.x

45. Crimmins TM, Crimmins MA, Bertelsen DC. Complex responses to climate drivers in onset of spring flowering across a semi-arid elevation gradient. J Ecol. 2010;98(5):1042–1051. https://doi.org/10.1111/j.1365-2745.2010.01696.x

46. Fitchett JM, Grab SW, Thompson DI, Roshan G. Spatio-temporal variation in the phenological response of citrus to climate change in Iran: 1960-2010. Agr Forest Meteorol. 2014;198–199:285–293. https://doi.org/10.1016/j.agrformet.2014.08.010

47. Pankhurst NW, Porter MJR. Cold and dark or warm and light: Variations on the theme of environmental control of reproduction. Fish Physiol Biochem. 2003;28:385–389. https://doi.org/10.1023/b:fish.0000030602.51939.50

48. Samoilys M. Periodicity of spawning aggregations of coral trout *Plectropomus leopardus* (Pisces: Serranidae) on the northern Great Barrier Reef. Mar Ecol Prog Ser. 1997;160:149–159. https://doi.org/10.3354/meps160149

49. Lu J, Vecchi GA, Reichler T. Expansion of the Hadley cell under global warming. Geophys Res Lett. 2007;34(6), L06805, 5 pages. https://doi.org/10.1029/2006GL028443

50. Seidel DJ, Fu Q, Randel WJ, Reichler TJ. Widening of the tropical belt in a changing climate. Nat Geosci. 2008;1(1):21–24. https://doi.org/10.1038/ngeo.2007.38

51. Menzel A, Sparks T, Estrella N, Koch E, Aasa A, Ahas R, et al. European phenological response to climate change matches the warming pattern. Glob Change Biol. 2006;12:1969–1976. https://doi.org/10.1111/j.1365-2486.2006.01193.x

52. Liu Q, Fu YH, Zhu Z, Liu Y, Liu Z, Huang M, et al. Delayed autumn phenology in the northern hemisphere is related to change in both climate and spring phenology. Glob Change Biol. 2016;22(11):3702–3711. https://doi.org/10.1111/gcb.13311

53. Kovach RP, Joyce JE, Echave JD, Lindberg MS, Tallmon DA. Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. PLoS ONE. 2013;8(1), e53807, 10 pages. https://doi.org/10.1371/journal.pone.0053807

AUTHORS:
Kersten Bergstrom[1]
Austin B. Lawrence[2]
Alex J. Pelissero[3]
Lauren J. Hammond[1]
Eliwasa Maro[4]
Henry T. Bunn[5]
Charles M. Musiba[3]

AFFILIATIONS:
[1]Department of Anthropology, Texas A&M University, College Station, Texas, USA
[2]Department of Pathology and Anatomical Sciences, University of Missouri, Columbia, Missouri, USA
[3]Department of Anthropology, University of Colorado Denver, Denver, Colorado, USA
[4]Department of Antiquities, Ministry of Natural Resources and Tourism, Dodoma, Tanzania
[5]Department of Anthropology, University of Wisconsin-Madison, Madison, Wisconsin, USA

CORRESPONDENCE TO:
Kersten Bergstrom

EMAIL:
kersten.bergstrom@tamu.edu

DATES:
Received: 04 Jan. 2019
Revised: 22 Feb. 2019
Accepted: 11 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Bergstrom K, Lawrence AB, Pelissero AJ, Hammond LJ, Maro E, Bunn HT, et al. Aerial map demonstrates erosional patterns and changing topography at Isimila, Tanzania. S Afr J Sci. 2019;115(7/8), Art. #5911, 6 pages. https://doi.org/10.17159/sajs.2019/5911

ARTICLE INCLUDES:
☒ Peer review
☒ Supplementary material

DATA AVAILABILITY:
☒ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☐ Not applicable

EDITOR:
Maryna Steyn

KEYWORDS:
Middle Pleistocene; East Africa; Acheulean/Acheulian; site topography; uncrewed/unmanned aerial vehicle; drone map

FUNDING:
University of Colorado Denver Office of Research Services and CLAS CRISP 2016/2017 Grants

Aerial map demonstrates erosional patterns and changing topography at Isimila, Tanzania

Isimila is a Middle Pleistocene archaeological site located in southern Tanzania. The site is known for large surface assemblages of later Acheulean lithics such as hand axes, cleavers, scrapers and cores. While hominin remains have yet to be discovered at the site, Isimila offers a unique window into Middle Pleistocene *Homo* behaviour. Although Isimila has been studied extensively, the last published map of the site and surrounding area was made available in the 1970s. Here, we present an updated high-resolution map of Isimila. Data for the map were collected during aerial survey with an uncrewed(unmanned) aerial vehicle. With this map, we identified new archaeological localities, erosional patterns, newly exposed geological features and changes in site topography. The map demonstrates patterns of stone tool and raw material distribution that may support previous hypotheses of short-distance raw material transport into the area by hominins. This open-access map establishes a baseline for tracking changes to site topography in the future and serves as a unique tool to enable collaboration between researchers, museum personnel and local populations to better conserve Isimila.

Significance:

- New potential archaeological localities and significant changes to erosional patterns at Isimila were identified.
- The open access map and associated raw data provided enable researchers to track seasonal and erosional changes and anthropogenic effects, and to develop protocols for conservation of this unique site.

Introduction

Isimila is located in the central highlands of southern Tanzania on the Iringa Plateau (Figures 1 and 2) and is preliminarily dated to 330–220 kya.[1] The site was first recognised for its archaeological potential by D.A. Maclennan in 1951.[2,3] Excavation and survey at Isimila have uncovered large quantities of later Acheulean lithics, including large surface assemblages and in-situ occupation areas.[3-5] The first surface collection from Isimila comprised 26 stone tools, including hand axes, cleavers, a backed blade and a Levallois core.[2] In 1954, F. Clark Howell conducted a survey of the Isimila Basin and collected at least 90 hand axes and 50 cleavers, which were described as fresh and unrolled, suggesting they had only recently eroded out of their primary context.[3] Howell[3] noted substantial variation in the 'workmanship', technique, and raw materials in the lithic assemblages, which were proposed to represent both living areas and factory sites of the Late Acheulean.

The Isimila Korongo System consists of northern and southern branches, with a stream running from north to south through the valley. Isimila preserves five layers of consolidated sands numbered from the top (Sands 1) to base layer (Sands 5) overlying an early Pleistocene claycrete. The lower beds (Sands 3–5) are thick and largely continuous throughout the northern branch of the Korongo, while the upper beds (Sands 1 and 2) are thinner and present in only the northernmost parts of the northern branch.[4] The sediments of Isimila are thought to have been deposited during a period of drying during the Middle Pleistocene.[4] The deposition of sandy layers followed by silty clay in the Isimila Formation has been attributed to a cyclic depositional environment by various authors. However, the reconstructions of this environment have differed. The palaeoenvironment of Isimila has been described as lacustrine[6], a shallow pond with some drainage out the northern end of the korongo[4], and riverine[7]. Howell et al.[4] also argued that the clay capping the upper layers of the Isimila Formation may represent an mbuga environment (a seasonal swamp or marsh).

Excavations in Sands 1 uncovered rich concentrations of stone tools throughout, suggesting a dense and largely continuous occupation by Middle Pleistocene *Homo*.[4] 'Crudely finished' tools were interspersed with finely finished hand axes in Sands 1; this combination has been hypothesised to reflect behavioural flexibility in hominins in response to differing environmental conditions.[8(p.351)] Two occupation areas (H20 and J12 trenches) were identified in Sands 2 and had a lower density of artefacts than Sand 1 or 3, suggesting sparse occupation by hominins.[4] Excavations in Sands 3 uncovered a generalised dense occupation, including three occupation areas (trenches H15, K18 and K19).[4] Excavations in Sands 4 and 5 uncovered a number of small implements and fauna.[4,5,9]

Isimila has been compared to Olorgesailie and Kariandusi in Kenya, as well as to Kalambo Falls in Zambia, based on similarities in their chronologies and lithic typologies (Figure 1).[4,5,8,10] Recent discoveries at Olorgesailie yielded some of the earliest known Middle Stone Age (MSA) artefacts in East Africa.[11-13] Moreover, optically stimulated luminescence dating of deposits at Kalambo Falls suggests multiple, temporally distinct occupations beginning as early as 500 kya.[14] Isimila may provide a unique temporal and geographic window into the Acheulean at the Acheulean–MSA transition in East Africa, although new dates are necessary to better contextualise the site. Within Tanzania, the lower beds of Isimila (Sands 3–5) are broadly contemporaneous with the Ngaloba Beds at Laetoli[15], which yielded Laetoli Hominid 18 (LH 18), a partial *Homo* cranium[16,17]. While no hominin remains have been found at Isimila, the region preserves an extensive archaeological sequence ranging from the Middle Pleistocene to the Iron Age.[18] As such, Isimila and the broader region provide a unique window into hominin behaviour, ecology and palaeoenvironments at a critical time period in human evolution and more recent human history.

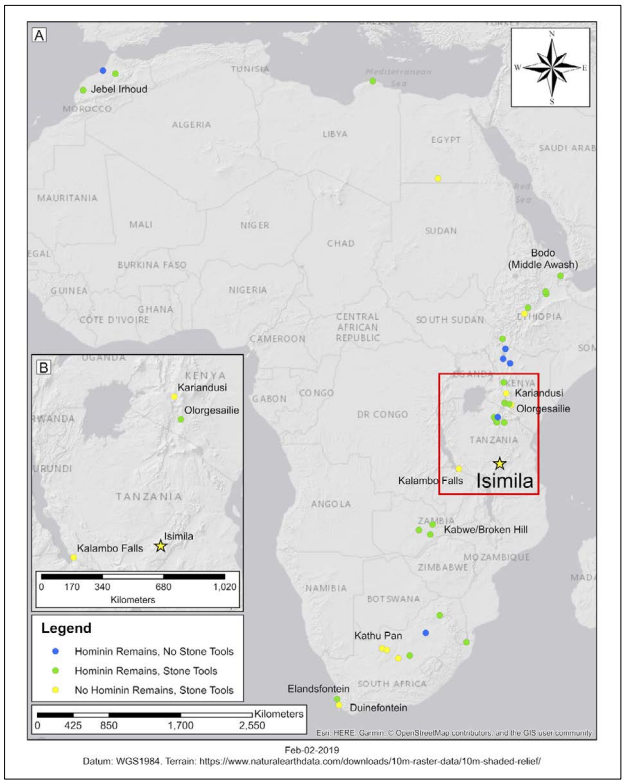


Figure 1: Map of Middle Pleistocene sites in Africa that are either contemporaneous to Isimila or contain similar lithic type/distribution. Blue points indicate sites with hominin remains with no stone tools, green points indicate sites with hominin remains and stone tools, and yellow points indicate sites with stone tools but no hominin remains.[31]

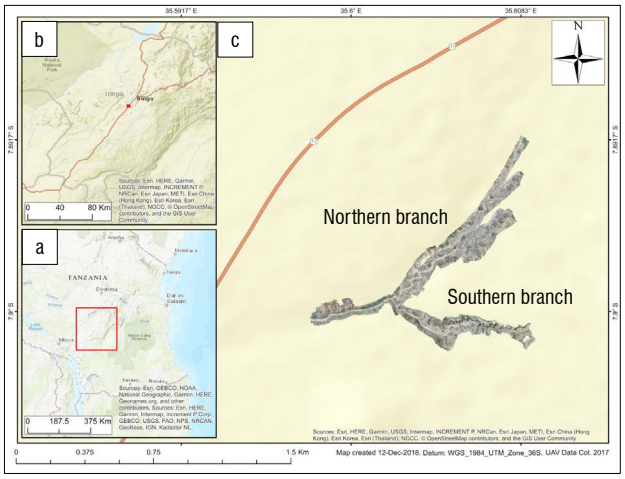


Figure 2: (a) Map showing the location of Isimila within the broader context of East Africa. (b) Map showing Isimila within the Iringa plateau of southern Tanzania. (c) A close-up map of Isimila demonstrating the two primary sections of the Korongo System, labelled 'northern branch' and 'southern branch', following Howell et al.[4]

Methods

A DJI Phantom 4 Pro+ quadcopter (DJI, Shenzen, China) equipped with an onboard high-definition camera optimised for aerial image capture (i.e. a wide-angle, non-fisheye lens; Supplementary table 1) was used for the aerial survey and data capture in July 2017. Previously published maps and a preliminary pedestrian survey were used to plan flight paths (Figure 3). Start and end points were recorded on the ground using a handheld GPS unit. The end point of each flight was used as the starting point for each subsequent flight. In total, 12 survey sessions were conducted at two different altitudes: 6 sessions at 40 m and 6 sessions at altitudes ranging from 10 m to 20 m.

Figure 3: Satellite image indicating flight paths of the uncrewed aerial vehicle in yellow.

The uncrewed/unmanned aerial vehicle (UAV) was piloted manually using its native software (DJI GO 4v. 4.1.18, DJI, 2017) to set the altitude, velocity, camera positioning and capture parameters, and to monitor the flight path during data capture. Live video tracking was used to capture images during flight. The video footage from the UAV was reviewed in the field and used to identify geological features, sedimentary changes and potential areas of interest for pedestrian survey.

Still photos were extracted from video obtained during flight sessions. GPS coordinates and altitude data tracked by the UAV were embedded in metadata for each still image. Blurry or out of focus images were manually removed. Photos were then imported into Agisoft Photoscan Pro (v 1.4.1, Agisoft, 2018); for processing parameters and workflow see Supplementary table 1. Initially, photos were aligned to create a sparse point cloud of tie points. A dense point cloud was then created to reconstruct the three-dimensional parameters of the coverage area (Figure 4).

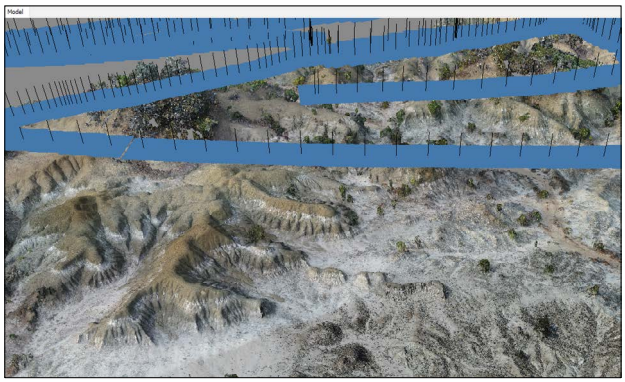


Figure 4: Screen capture from Agisoft Photoscan showing dense point cloud. The blue path represents overlapping photos (overlapping blue rectangles), with the thin, black lines marking the centre point of each photo.

The dense point cloud (Supplementary table 1) was manually edited to remove errant points, areas of heavy noise and unnecessary coverage outside of the basin. A digital elevation model – that is, a three-dimensional representation of the elevation and terrain of the surface (Figure 5a) – was created from the dense point cloud and used to generate the top-down orthomosaic, a series of overlapping georeferenced images used to build a scaled map (Figure 5b, Supplementary table 1), both of which were then imported into ArcMap (v. 10.5, ESRI, 2016), where they were cleaned and legends were added. A hill shade of z-value 1 was added to enhance relief appearance in the Korongo System. An overlay map was created to compare site topography in 1962[4] and that in 2017 (Figure 6). The orthomosaic was digitally aligned to the map from Howell et al.[4] using GNU Image Manipulation Program (v. 2.10.4, GIMP, 2018). Trenches and pits were cross-referenced and plotted using approximate locations.

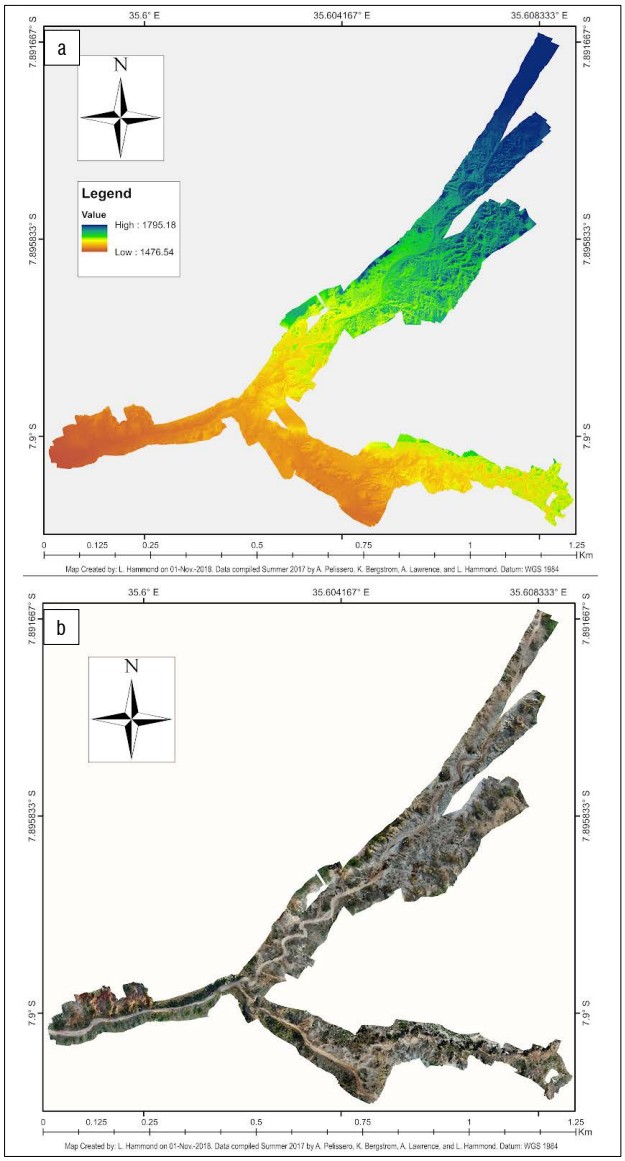


Figure 5: (a) Digital elevation map of Isimila. (b) Orthomosaic map of Isimila.

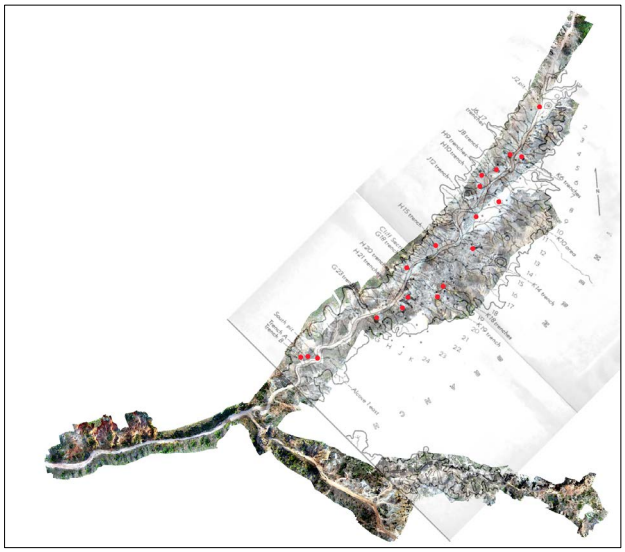


Figure 6: Orthomosaic overlaid with previous map by Howell et al.[4] Approximate locations of previous excavation trenches are marked in red.

Results

The overlaid excavation map (Figure 6) demonstrates shifts in the course of the Isimila stream. A horseshoe-shaped meander in the northern branch which appeared on the original map has been largely eroded away. The previous course of the stream now appears as a large sandy bank on the western side of the northern branch. A new meander is present to the north, cutting directly into exposed tool-bearing beds. Based on comparisons with the original excavation maps, the new meander may be washing over the location of the 1959 H10 trench (Figure 7).[4]

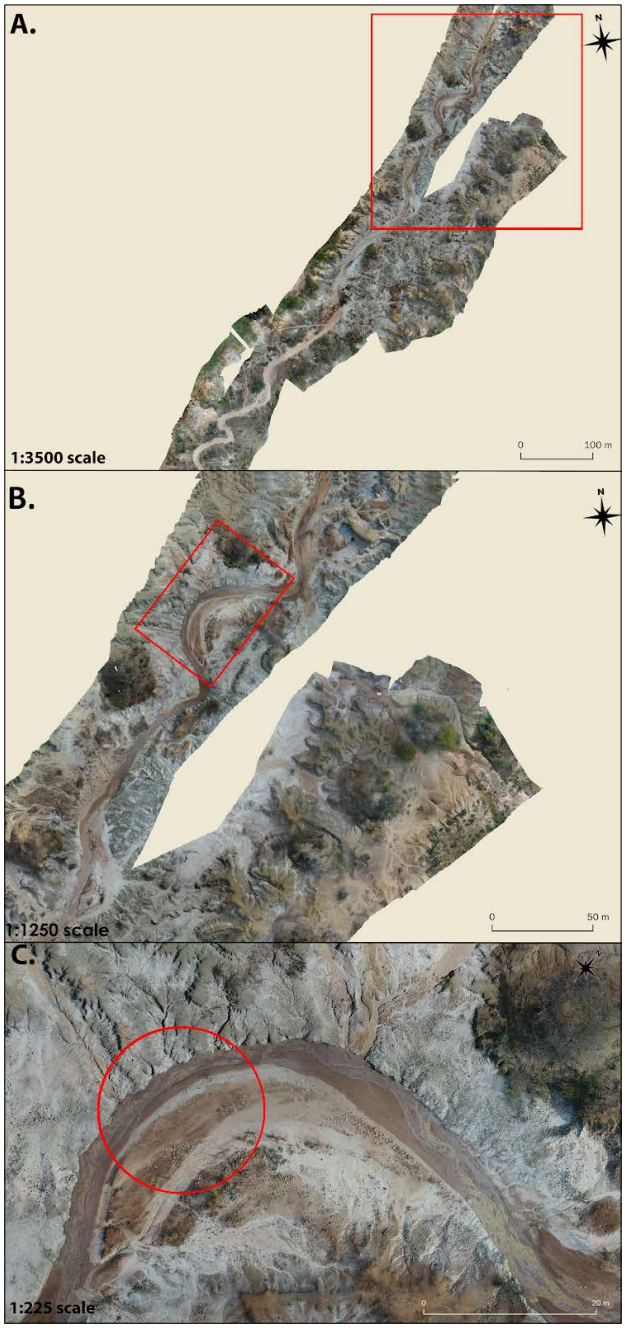


Figure 7: (a) Location within the northern branch of the recent meander outlined in red. (b) Inset of location of recent meander. (c) Detail of recent meander with approximate location of H10[4] trench circled in red.

The aerial survey showed undocumented sediment exposures and geological differences within the basin. In the northern branch, an unexcavated area of dark, ferrous sediments was found to have substantial lithic deposits (Figure 8). Additionally, a new region of lithic-bearing red sediments, dissimilar to those in the central part of the

Korongo, was identified approximately 200 m south of the southernmost extent of the previous maps (Figure 9).

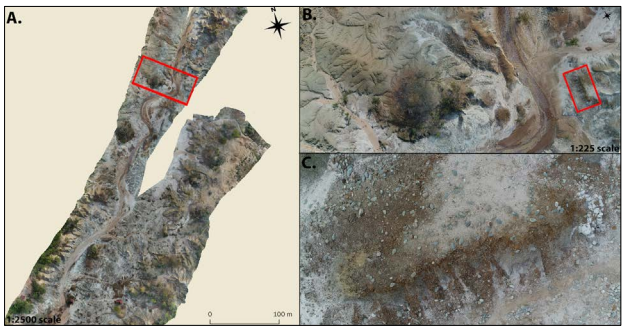


Figure 8: (a) Location within the northern branch of the outcrop with ferrous sediments, outlined in red. (b) Inset of location with ferrous outcrop, outlined in red. (c) Still photo of ferrous sediments with artefacts on the surface taken from the uncrewed aerial vehicle at an altitude of 15 m.

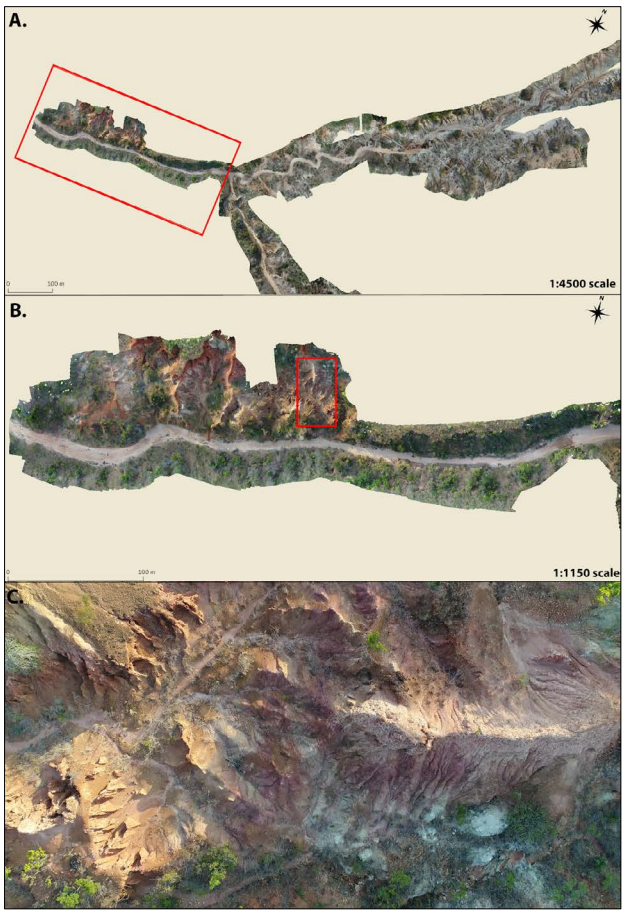


Figure 9: (a) Location of previously unmapped area, outlined in red. (b) Previously unmapped outcrops southwest of the natural junction, outlined in red. (c) Detail of the outcrops from an altitude of 40 m.

The majority of stone tool surface assemblages are located in the central northern branch of the Korongo (Supplementary figure 1). The large concentrations of lithics and debris in this area may be a result of significant erosion from the Isimila stream. While surface assemblages are present outside of this potential floodplain, they cover smaller surface areas. Most previous excavation trenches are located in areas where there are dense accumulations on the surface today. However, the areas of trenches H20 and K14 have fewer lithics on the modern surface, which may be a result of artefacts from these areas being collected during previous excavations (Figure 10).

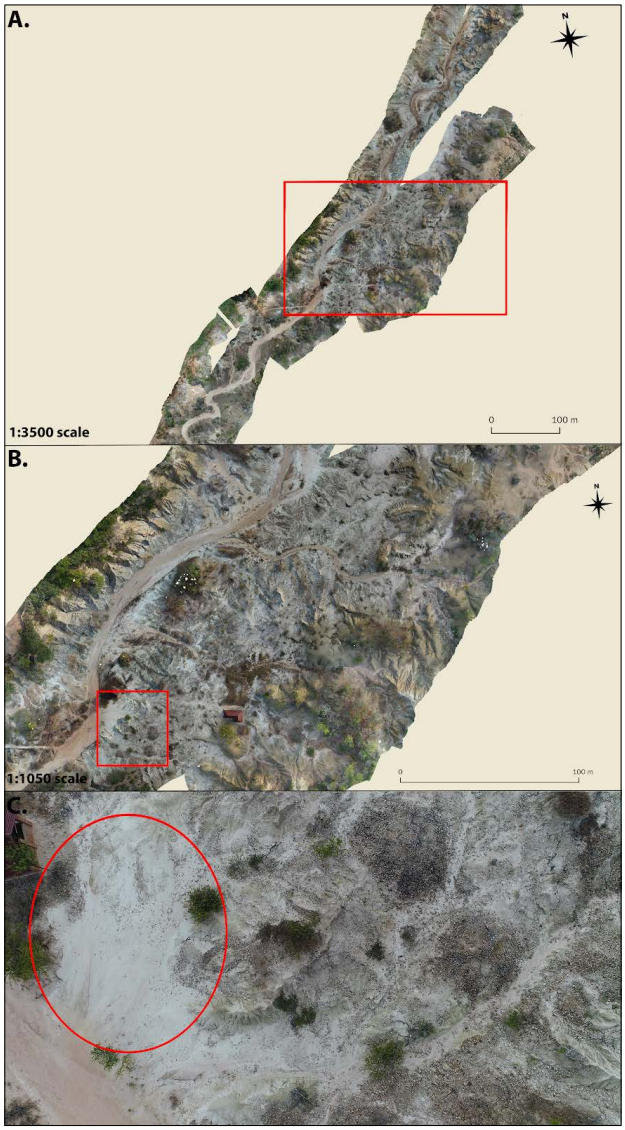


Figure 10: (a) Location within the northern branch of the Howell et al.[4] H20 trenches, outlined in red. (b) Inset of the H20 trenches, outlined in red. (c) Detail of the former site of extensive excavations at the H20 trenches, circled in red. The small structure in the top left corner once contained a partial skeleton of a hippopotamus unearthed in one of the trenches.

Discussion

Uncrewed aerial vehicles provide a higher-resolution alternative to satellite imagery and are more versatile than traditional aerial photogrammetry or mapping.[19] As demonstrated by recent work using UAVs at Olduvai Gorge in Tanzania[20] and in the Turkana Basin, Kenya[21], aerial survey and mapping enhances research by recording new sites and areas of geological and archaeological interest. The high-resolution UAV map of Isimila presented here enables collaborative efforts between research teams to help answer future questions about the site, including aspects of hominin behaviour and its interaction with a shifting palaeoenvironment. Using UAV data, we identified significant changes to surface topography at Isimila over the last half century, including shifts in the course of the Isimila stream and new perspective on the distribution of stone tools and raw materials.

Howell et al.[4] proposed that the close association of stone tools to surrounding debris represented short-distance raw material transport. The orthomosaic presented here shows dense clusters of raw material and

artefacts, possibly supporting the hypothesis of Howell et al.[4] However, the association of artefacts and raw material in clustered surface assemblages in the heavily eroded central portion of the northern branch may be the result of erosional processes. Additionally, new lithic-bearing deposits were identified in previously unmapped southern exposures. If the centre of Isimila, located in the northern branch, was primarily a manufacturing area next to a reliable water source, inhabited sites may be located on the periphery, possibly in the new southern exposures identified here.

Seasonal erosion and changes in the course of the Isimila stream over the last 50 years may have washed away unexcavated lithic deposits. This possibility highlights the need for long-term repeated aerial survey and mapping. Future UAV mapping has the potential to further examine the effects of seasonal erosion and the resulting changes to site topography. Moreover, understanding the effects of natural and anthropogenic change is essential for site conservation. While Tanzania has a lengthy history of issues surrounding archaeological conservation and management,[22-25] UAV mapping has yet to be used as part of a management plan. Although Isimila is a managed archaeological site, conservation risks from human activity, erosion and archaeological excavation persist.[26,27] Annual UAV mapping and collaborative efforts with researchers and the local communities would advance research and conservation efforts in that any changes within the Isimila Korongo System, particularly in terms of sediment starving or erosions, could easily be detected and mitigated.

Conclusions

Isimila is the subject of renewed research, including excavation and extensive survey, by multiple independent research teams.[28-31] The open-access orthomosaic map presented here represents a unique tool for coordinating research between teams working in different parts of the site. The open-access data set presented includes a digital elevation model, orthomosaic, previous excavation overlay map and supplementary material.[32] This work provides a baseline for future work and conservation efforts at Isimila. Additionally, we identify major changes to site topography, erosional effects and new archaeological deposits. In a collaborative effort, we ask fellow researchers to submit GPS data of excavation, surface collection and areas of geological interest to a separate open-access orthomosaic.[33] This map[33] will be updated with new data submissions and will serve as an open-access research tool.

Acknowledgements

We thank the University of Colorado Denver (Office of Research Services and CLAS CRISP 2016/2017 Grants) which made this study possible, Ms Digna Tillya (Director of Antiquities) and Mr Anthony Tibaijuka (Assistant Director, Research) for their support in permitting and providing knowledge of the area, the Antiquities Division of the Ministry of Natural Resources and Tourism for issuing us the Antiquities Excavation Licence, the Commission for Science and Technology (permit no. 2017-234-NA-2016-115), and all the staff at Isimila Stone Age Site. We thank Jonathan Kent, Neffra Matthews, Bonny Ford and Rachael Bible for their valuable comments on earlier drafts. We also thank the students and staff of the 2017 University of Colorado Denver–Tanzanian Field School. Special thanks go to Masoud Kafene, Richard Nzemya, Tony Emmanuel and the insurmountable Faru and Bighorn for always getting us to where we needed to go. We are especially indebted to Dennis Van Gerven and Claudia Blood Van Gerven for their continued support and help on this project. Lastly, we thank the late Simon Mataro for his contributions over the years.

Authors' contributions

K.B.: Conceptualisation, methodology, data collection, data curation, writing – the initial draft, writing – revisions, student supervision, project leadership, project management; A.B.L.: Conceptualisation, data collection, writing – the initial draft, writing – revisions; A.J.P.: Conceptualisation, methodology, data collection, data analysis, data curation, writing – the initial draft, writing – revisions, student supervision, project management; L.J.H.: Methodology, data collection, data analysis, writing – the initial draft, writing – revisions; E.M.: Student supervision, project leadership, funding acquisition; H.T.B.: Writing – revisions, student supervision, funding acquisition; C.M.M.: Conceptualisation, data curation, writing – revisions, student supervision, project leadership, funding acquisition.

References

1. Howell FC, Cole GH, Kleindienst MR, Szabo BJ, Oakley KP. Uranium-series dating of bone from the Isimila Prehistoric Site, Tanzania. Nature. 1972;237(5349):51. https://doi.org/10.1038/237051a0
2. Van Riet Lowe C. A new African Acheul Stage IV site in Tanganyika. S Afr Archaeol Bull. 1951;6(24):94–98. https://doi.org/10.2307/3886803
3. Howell FC. A preliminary note on a prehistoric donga (Maclennan's Donga) in central Tanganyika. S Afr Archaeol Bull. 1955;10(38):43–52. https://doi.org/10.2307/3887057
4. Howell FC, Cole GH, Kleindienst MR. Isimila: An Acheulian occupation site in the Iringa Highlands, Southern Highlands Province, Tanganyika. Actes du IVe Congrès panafricain de préhistoire et de l'étude du quaternaire. 1962:43–80.
5. Cole GH, Kleindienst MR. Further reflections on the Isimila Acheulian. Quat Res. 1974;4(3):346–355. https://doi.org/10.1016/0033-5894(74)90021-0
6. Bishop WW. The Later Tertiary and Pleistocene in Eastern Equatorial Africa. In: Howell FC, Bourliére F, editors. African ecology and human evolution. Chicago, IL: Aldine Publishing Company; 1963. p. 246–275.
7. Hansen CL, Keller CM. Environment and activity patterning at Isimila Korongo, Iringa District, Tanzania: A preliminary report. Am Anthropol. 1971;73(5):1201–1211. https://doi.org/10.1525/aa.1971.73.5.02a00190
8. Kleindienst MR. Variability within the Late Acheulian Assemblage in Eastern Africa. S Afr Archaeol Bull. 1961;16(62):35–52. https://doi.org/10.2307/3886868
9. Coryndon SC, Gentry AW, Harris JM, Hooijer DA, Maglio VJ, Howell FC. Mammalian remains from the Isimila Prehistoric Site, Tanzania. Nature. 1972;237(5353):292. https://doi.org/10.1038/237292a0
10. Howell FC, Clark JD. Acheulian hunter-gatherers of sub-Saharan Africa. In: Howell FC, Bourliére F, editors. African ecology and human evolution. Chicago, IL: Aldine Publishing Company; 1963. p. 458–533.
11. Potts R, Behrensmeyer AK, Faith JT, Tryon CA, Brooks AS, Yellen JE, et al. Environmental dynamics during the onset of the Middle Stone Age in eastern Africa. Science. 2018;360(6384):86–90. https://doi.org/10.1126/science.aao2200
12. Deino AL, Behrensmeyer AK, Brooks AS, Yellen JE, Sharp WD, Potts R. Chronology of the Acheulean to Middle Stone Age transition in eastern Africa. Science. 2018;360(6384):95–98. https://doi.org/10.1126/science.aao2216
13. Brooks AS, Yellen JE, Potts R, Behrensmeyer AK, Deino AL, Leslie DE, et al. Long-distance stone transport and pigment use in the earliest Middle Stone Age. Science. 2018;360(6384):90–94. https://doi.org/10.1126/science.aao2646 1.
14. Duller GAT, Tooth S, Barham L, Tsukamoto S. New investigations at Kalambo Falls, Zambia: Luminescence chronology, site formation, and archaeological significance. J Hum Evol. 2015;85:111–125. https://doi.org/10.1016/j.jhevol.2015.05.003
15. Manega PC. Geochronology, geochemistry and isotopic study of the Plio-Pleistocene hominid sites and the Ngorongoro Volcanic Highland in northern Tanzania [PhD dissertation]. Boulder, CO: University of Colorado at Boulder; 1993.
16. Magori CC, Day MH. Laetoli Hominid 18: An early *Homo sapiens* skull. J Hum Evol. 1983;12(8):747–753. https://doi.org/10.1016/S0047-2484(83)80130-4
17. Day MH, Leakey MD, Magori C. A new hominid fossil skull (L.H. 18) from the Ngaloba Beds, Laetoli, northern Tanzania. Nature. 1980;284(5751):55–56. https://doi.org/10.1038/284055a0
18. Biittner KM, Sawchuk EA, Miller JM, Werner JJ, Bushozi PM, Willoughby PR. Excavations at Mlambalasi Rockshelter: A terminal Pleistocene to recent Iron Age record in southern Tanzania. Afr Archaeol Rev. 2017;34(2):275–295. https://doi.org/10.1007/s10437-017-9253-3
19. Nikolakopoulos KG, Soura K, Koukouvelas IK, Argyropoulos NG. UAV vs classical aerial photogrammetry for archaeological studies. J Archaeol Sci Rep. 2017;14:758–773. https://doi.org/10.1016/j.jasrep.2016.09.004

20. Jorayev G, Wehr K, Benito-Calvo A, Njau J, De la Torre I. Imaging and photogrammetry models of Olduvai Gorge (Tanzania) by unmanned aerial vehicles: A high-resolution digital database for research and conservation of Early Stone Age sites. J Archaeol Sci. 2016;75:40–56. https://doi.org/10.1016/j.jas.2016.08.002

21. Evans A, Sparrow T, Leakey L, Wilson A, Donahue R. Transforming the search for human origins using new digital technologies, low altitude imaging, and citizen science. In: Jennings B, Gaffney C, Sparrow T, Gaffney S, editors. Proceedings of the 12th International Conference of Archaeological Prospection. Bradford, UK: Archaeopress Archaeology; 2017. p. 66–69.

22. Demas M, Agnew N. Decision making for conservation of archaeological sites: The example of the Laetoli hominid trackway, Tanzania. In: Agnew N, Bridgland J, editors. Of the past, for the future: Integrating archaeology and conservation. Proceedings of the Conservation Theme at the 5th World Archaeological Congress; 2003 June 22–26; Washington DC, USA. Los Angeles, CA: The Getty Conservation Institute; 2006. p. 64–72.

23. Libsekal Y. Multiplying and sharing heritage values: Planning conservation and site management at the Acheulean sites of Buya, Eritrea. Conserv Manage Archaeol Sites. 2008;10(3):251–263. https://doi.org/10.1179/175355209X452796

24. Musiba CM, Mabula A, Selvaggio M, Magori CC. Pliocene animal trackways at Laetoli: Research and conservation potential. Ichnos. 2008;15(3–4):166–178. https://doi.org/10.1080/10420940802470383

25. Biittner KM, Willoughby PR. Working with local communities and managing cultural heritage in Iringa Region, Tanzania. S Afr Archaeol Rec. 2012;36:36–39.

26. Bushozi PM. Towards sustainable cultural heritage management in Tanzania: A case study of Kalenga and Mlambalasi Sites in Iringa, Southern Tanzania. S Afr Archaeol Bull. 2014;69(200):136–141. Available from: http://www.jstor.org/stable/43868708

27. Tillya D. Preservation of the Stone Age site of Isimila, Tanzania. Conserv Manage Archaeol Sites. 1996;1(4):243–246. https://doi.org/10.1179/135050396793139015

28. Bushozi PGM. The Acheulean of Isimila, Iringa (South Tanzania). In: The Cradle of Humankind. Madrid: Instituto de Evolución en Africa, IDEA; 2014.

29. Cole J, Bushozi PM, Bite M, McNabb J, Kwekason A. Contextualizing the Stone Age Site of Isimila. Dodoma: Ministry of Natural Resources and Tourism, Tanzania; 2015.

30. Curran SC, Patton PE, Mtelea C. Renewed explorations of the Mid-Pleistocene Site, Isimila, Tanzania. In: Abstracts of the 2018 Paleoanthropology Society Meeting; 2018 April 10–11; Austin, Texas, USA. p. A9.

31. Pelissero AJ, Bergstrom K, Hammond LJ, Lawrence AB, Bunn HT, Musiba CM. Drone mapping of Isimila, Tanzania: The implications for future research into Mid-Pleistocene *Homo* behavior. In: Abstracts of the 2018 Paleoanthropology Society Meeting; 2018 April 10–11; Austin, Texas, USA. p. A26.ss 1.

32. Bergstrom K, Lawrence AB, Pelissero AJ, Hammond L, Maro E, Bunn HT, et al. UAV Map of Isimila, Tanzania [data set]. Zenodo. Version 1. https://doi.org/10.5281/zenodo.1470770

33. Bergstrom K, Lawrence AB, Pelissero AJ, Hammond L, Maro E, Bunn HT, et al. Collaborative UAV-based orthomosaic of Isimila, Tanzania [data set]. Zenodo. Version 1. https://doi.org/10.5281/zenodo.1470781

AUTHORS:
Juliet K. Brophy[1]
Gregory J. Matthews[2]
George K. Thiruvathukal[3]

AFFILIATIONS:
[1]Department of Geography and Anthropology, Louisiana State University, Baton Rouge, Louisiana, USA
[2]Department of Mathematics and Statistics, Loyola University Chicago, Chicago, Illinois, USA
[3]Department of Computer Science, Loyola University Chicago, Chicago, Illinois, USA

CORRESPONDENCE TO:
Juliet Brophy

EMAIL:
jbrophy@lsu.edu

DATES:
Received: 21 Aug. 2018
Revised: 10 Oct. 2018
Accepted: 05 Apr. 2019
Published: 30 July 2019

HOW TO CITE:
Brophy JK, Matthews GJ, Thiruvathukal GK. An analysis of the effect of tooth wear on bovid identification. S Afr J Sci. 2019;115(7/8), Art. #5496, 5 pages. https://doi.org/10.17159/sajs.2019/5496

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☒ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☐ Not applicable

EDITOR:
Maryna Steyn

KEYWORDS:
Bovidae; worn teeth; elliptical Fourier analysis; machine learning

FUNDING:
Louisiana State University

An analysis of the effect of tooth wear on bovid identification

Previous research provides a method for reducing the subjectivity in taxonomic identification of species in the family Bovidae by quantifying the occlusal surface of molar teeth using elliptical Fourier analysis. In this current study, we specifically test what effect medium to late tooth wear has on the identification of bovids when using the form (size and shape) of the occlusal surface to classify specimens. To achieve this, the classification results of teeth with ≥85% of their occlusal surface (training data set) were compared with the results of teeth with <85% of their occlusal surface (test data set) due to wear. In the training data set, all tribes classified correctly >87% of the time with both Alcelaphini and Reduncini classifying correctly >90% of the time. The worn teeth in the test data set classified correctly at lower rates, but all tribes still collectively had a good classification accuracy (>60%) with classification of Alcelaphini and Tragelaphini at >75% and Reduncini at >65%. Hippotragini classified correctly 50% of the time and Neotragini 42%. The one worn Bovini tooth in the test data set was classified as that of a Hippotragini. The classification rates of teeth with medium to late wear were lower than the unworn teeth, but not so low as to suggest that this methodology for identifying bovid teeth is inappropriate for worn teeth, especially when supplementary to other methods.

Significance:

- Worn teeth can be taxonomically identified by performing elliptical Fourier analysis on the occlusal surface of their teeth.
- While teeth with medium to late wear correctly classify at lower rates than relatively unworn ones, the methodology is a valuable supplement to other methods for taxonomically identifying bovid teeth.
- Worn teeth of the tribes Alcelaphini and Tragelaphini classify at the highest rates.

Introduction

Fossil remains from the family Bovidae, such as antelopes and buffalo, are used frequently to reconstruct past environments.[1-4] Bovid teeth, in particular isolated bovid teeth, are some of the most common fossils found in the southern African record. However, taxonomic identification of bovid teeth is often difficult because of overlap in their shape and size. Biasing factors such as sex, age-at-death and degree of occlusal (chewing surface) attrition often result in considerable overlap in absolute and relative tooth size, thereby complicating taxonomic identification.[4] Thus, taxonomic diagnoses of some bovid teeth often do not extend beyond broad levels such as the tribe or family.[3,5-10] Furthermore, the overlap in tooth shape and/or size often leads to interobserver error as researchers cannot reliably compare the faunal lists produced by different analysts. This result is often because of differences in experience, confidence levels in identifications and access to comparative materials. Researchers can, therefore, analyse the same assemblages and report different results. For example, Vrba[6], Wells and Cooke[11], and Reed[12] reported varying identifications and subsequently concluded different palaeoenvironmental reconstructions for Makapansgat, South Africa.

Previous research has provided a method for reducing the subjectivity in bovid identification by quantifying the occlusal surface of bovid teeth and suggests that teeth from closely related species can be reliably distinguished from each other based on an analysis of the form (shape and size) of their occlusal outline.[4,13-15] These previous studies involved the digitisation and extraction of the outlines of the occlusal surface of molars (upper three and lower three) from 20 species. Elliptical Fourier analysis (EFA) was used to approximate each shape as a series of ellipses. The coefficients generated by EFA were then used as features in machine learning algorithms to classify specimens into taxonomic groups. By applying machine learning techniques to the amplitudes generated by EFA for modern bovids, >80% of specimens in each of the six teeth groups classified correctly to tribe.[14] The ultimate purpose of those studies was to develop a methodology to identify fossil representatives of modern counterparts in the fossil record of southern Africa with greater accuracy. These results can then be utilised as a supplement to other defining characteristics of bovid teeth, such as degree of hypsodonty, enamel thickness and rugosity.

Importantly, the teeth used in the aforementioned studies were not separated into different wear stages, although the samples did include worn teeth. The purpose of these studies was solely to produce a reliable, replicable and practical tool for classifying modern and fossil bovid teeth. The goal was thus to avoid separating the teeth in the reference data set into wear stages in order to encompass more natural, biological variation within the data set and to make the program more accessible to a wider range of teeth. While the teeth were not separated into wear stages, the authors of each paper did state that at least 85% of the occlusal surface of the tooth, as determined by someone familiar with bovid teeth, was required to enable use of this method (Figure 1).

Brophy[13] and Brophy et al.[4] specifically investigated whether the average shape of the occlusal surface of a tooth remained consistent over the lifespan of a bovid, regardless of age and attrition. Their research assessed intra-tooth variation by means of computed tomography (CT) using teeth from different bovid tribes and applying EFA to specific increments of CT scan slices from the same tooth. The Fourier-derived amplitudes were considered 'unknowns' and compared with those of known bovid teeth, using linear discriminant analyses. The 'unknown' digitised CT scans were correctly classified to the known species ≥85% of the time.[4]

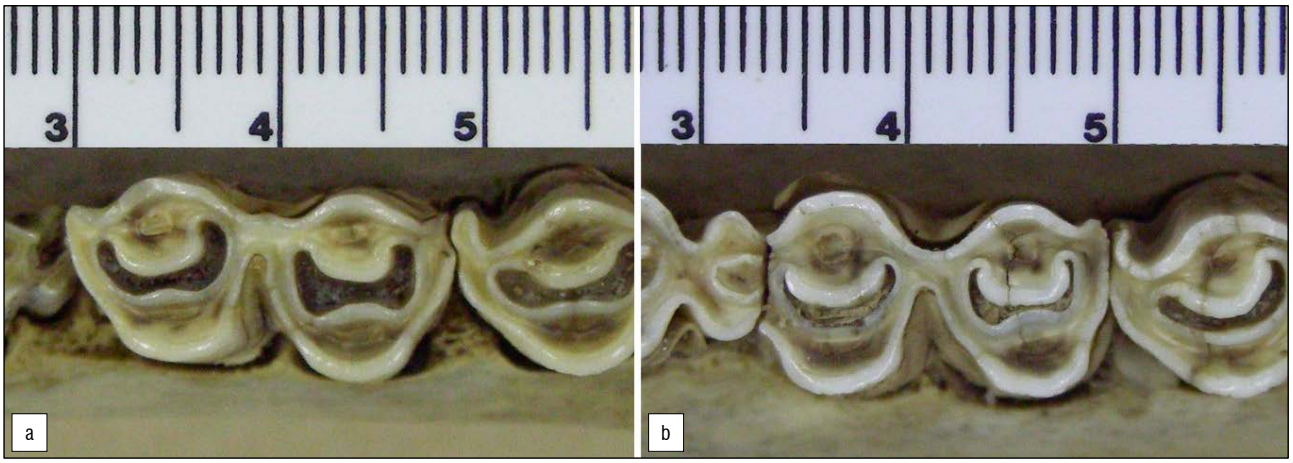


Figure 1: (a) Lower first molar (M_1) with ≥85% occlusal surface and (b) M_1 with medium to late wear, <85% occlusal surface.

The teeth utilised in Brophy[13] and Brophy et al.[4] were not separated into wear stages but were digitised by one of the authors who is familiar with the shape of bovid teeth. The teeth employed in Matthews et al.[15] were also not separated into wear stages but were digitised as Human Intelligence Tasks by Amazon Mechanical Turk workers, or Turkers. These individuals, very likely, had no *a priori* knowledge of bovid teeth other than the video tutorial given to them in order to complete the task. In Matthews et al.[15], the same tooth was digitised three times by Turkers. One author (J.K.B.) reviewed every Turker submission before using it in the project to ensure that the digitised tooth did not include information other than the actual tooth. Teeth were removed from the study if they included information other than the outline of the tooth, as explained by the Human Intelligence Task. Using a random forest algorithm, the classification results based on the teeth digitised by J.K.B. were compared with the Turkers' results. This process was done using the average shape and generalised Procrustes analysis of the three replications of digitisations created by the Turkers. While classification of the J.K.B. outlines outperformed the Turker outlines, the differences were relatively small and in both cases each tooth was classified correctly to tribe ≥80% of the time in leave-one-out cross-validation tests.[15] While the purpose of that study was to determine if the digitisation process could be crowd sourced, the high correct classification results provide support for not separating the teeth into wear stages.

The results of the aforementioned studies indicate that the shape of the tooth throughout an animal's life does not change significantly enough to impede identification of that tooth using the occlusal surface. The findings also support the use of occlusal outlines as reliable indicators of bovid tribe and species. It is important to note that while the overall classification rate is high, in all of these studies some tooth types (e.g. M^2) and taxonomic groups classified with higher accuracy than others. In addition, while worn teeth were included in these studies, heavily worn teeth were not targeted for the sample.

This current study expands on the previous results and specifically assesses the effect medium to late wear (<85% of their occlusal surface) has on the identification of bovid teeth when using the form of the occlusal surface and EFA to classify specimens (see Figure 1 for an example). For the purpose of this paper, medium to late wear includes teeth with (1) enamel rim ranges from thin to missing on at least one side, (2) infundibulum reduced or worn away completely, (3) a small remnant of or missing goat fold and (4) a crown height spanning from severely to completely lost. These categories were adapted from Klein's dental occlusal wear stages for bovid molars.[16]

Essentially, the study was designed to investigate whether a completely unworn or slightly worn (i.e. fully observed) tooth is absolutely necessary to make an accurate identification; in other words, can a tooth classify correctly when it is significantly worn? To achieve this, the classification results of teeth with ≥85% of their occlusal surface (as determined by J.K.B.) were compared with the results of teeth with <85% of their occlusal surface intact, as a result of wear (Figure 1). The expectation was that the classification rates of the worn teeth would be lower than those of the fully observed ones, but not so low as to suggest that this methodology for identifying bovid teeth is not applicable to worn teeth.

Materials and methods

Bovid tooth images were obtained from the University of the Witwatersrand (UW), Ditsong National Museum of Natural History (TM and AZ), and National Museum Bloemfontein (NMB). The teeth were systematically oriented in the same manner with the cervical plane perpendicular to a digital camera so that the occlusal surface could be seen clearly. A levelled scale bar was placed directly next to the tooth at the height of the occlusal surface. Photographs were taken of the three upper and three lower molars, which included 20 species from seven tribes (Table 1). The outlines of the occlusal surfaces for the training data set (≥85% of their occlusal surface intact) were obtained using MLmetrics (see Brophy et al.[4] for protocol). Briefly, this process involved creating outlines of the same tooth type (e.g. M^2) from a given species by manually placing 60 points around the enamel edge according to a template. MLmetrics generated *x*-*y* coordinates for each of the 60 points that were used in the training data set.

A sample of 92 teeth with medium to late wear were chosen for the test sample of this study from six different tribes and 13 species (Table 1). It is important to note that the majority of the test data set was from Alcelaphini species and that the distribution across tooth types is highly heterogeneous; some tribes number more individuals than others. Alcelaphini is typically one of the most common tribes at sites in southern Africa e.g. Elandsfontein[17], Equus Cave[18], Gladysvale[19], Sterkfontein[20] and Plovers Lake[3]; therefore this tribe was targeted in this study.

Each tooth in the test data set for this study was digitised using the freeware GIMP (the GNU Image Manipulation Program; www.gimp.org) according to the same method outline in Matthews et al.[15], briefly described hereafter. The image of a bovid tooth was downloaded in GIMP and an outline of the tooth was created using the lasso function. Next, the outline was converted to a black and white image. The black and white images were then imported into R using the Momocs package.[21] This function extracted *x*- and *y*-coordinates along the edge between the black and white fields in the images. A model was then trained using a data set containing only teeth with ≥85% of their occlusal surface intact, to assess how accurately the worn teeth could be classified.

The shape of each tooth in both the training and test data sets was approximated using EFA with 20 harmonics. Each harmonic generates four components; 80 coefficients in total were used as features in a random forest classification model with 5000 trees to predict tribe membership (see Matthews et al.[14]). Additionally, 20 principal components based on the 80 coefficients were used as possible features in the model. Models were fit separately for each tooth type (M_1, M_2, etc.). The fitted random forest model was used to predict tribe membership for each specimen in the test data set. A confusion matrix was generated which displays which

teeth classified correctly. Tables 2 and 3, respectively, reveal the results of the classification performance of the training data and test data set.

Table 1: Taxonomic list of the teeth used in the training and test data sets

Tribe	Species	Training data	Test data
Alcelaphini			
	Damaliscus dorcas	129	9
	Alcelaphus buselaphus	118	15
	Connochaetes gnou	121	15
	Connochaetes taurinus	126	5
Antilopini			
	Antidorcas marsupialis	147	
Bovini			
	Syncerus caffer	104	5
Hippotragini			
	Oryx gazella	46	5
	Hippotragus niger	87	5
	Hippotragus equinus	53	3
Neotragini			
	Raphicerus campestris	102	5
	Oreotragus oreotragus	60	
	Ourebia ourebi	41	
	Pelea capreolus	39	6
Reduncini			
	Redunca fulvorufula	101	
	Redunca arundinum	113	6
	Kobus leche	107	
	Kobus ellipsiprymnus	119	8
Tragelaphini			
	Tragelaphus scriptus	132	
	Tragelaphus strepsiceros	117	
	Taurotragus oryx	133	10

Table 2: Confusion matrix of the unworn teeth. These teeth had a correct classification accuracy rate of 0.8709.

	Reference						
Prediction	**Alcelaphini**	**Antilopini**	**Bovini**	**Hippotragini**	**Neotragini**	**Reduncini**	**Tragelaphini**
Alcelaphini	514	5	10	17	0	12	13
Antilopini	0	132	0	0	7	0	3
Bovini	0	0	59	4	0	0	1
Hippotragini	1	0	15	120	0	22	0
Neotragini	3	0	0	1	224	4	18
Reduncini	8	8	3	46	11	410	9
Tragelaphini	3	2	19	6	11	5	342

Table 3: Confusion matrix of the worn teeth. These teeth had a correct classification accuracy rate of 0.6447.

	Reference						
Prediction	**Alcelaphini**	**Antilopini**	**Bovini**	**Hippotragini**	**Neotragini**	**Reduncini**	**Tragelaphini**
Alcelaphini	27	0	0	1	0	2	1
Antilopini	1	0	0	0	1	0	0
Bovini	0	0	0	0	0	0	0
Hippotragini	0	0	1	5	0	0	0
Neotragini	0	0	0	0	5	0	0
Reduncini	4	0	0	3	0	8	0
Tragelaphini	4	0	0	1	6	2	4

Table 4 shows the balanced accuracy of the unworn and worn teeth. Balanced accuracy is an average of sensitivity and specificity. Sensitivity is the true positive rate and explains, for example, if a tooth predicted to be an Alcelaphini and was actually an Alcelaphini. Specificity is a true negative rate, which, for example, shows when a tooth that is not an Alcelaphini did not predict to be an Alcelaphini.

Table 4: Balanced accuracy of the classification of teeth by Tribe

	Unworn	Worn
Alcelaphini	0.9673	0.8250
Antilopini	0.9463	N/A
Bovini	0.777	0.5
Hippotragini	0.7991	0.7424
Neotragini	0.9355	0.7083
Reduncini	0.9262	0.7786
Tragelaphini	0.9293	0.8084

Results

In the training data set, all tribes classified correctly more than 87% of the time, with both Alcelaphini and Reduncini classifying over 90% correctly (Tables 2 and 4). As expected, lower rates of classification accuracy were found for the worn teeth, but all of the tribes combined had a classification accuracy of more than 60%, with Alcelaphini (n=36) and Tragelaphini (n=5) both at more than 75% and Reduncini (n=12) at over 65% (Tables 3 and 4). Hippotragini (n=10) classified with a 50% accuracy while the tribe Neotragini (n=12) classified with only 42% accuracy. The one Bovini in the test data set classified as a Hippotragini. While these classification rates are certainly lower than those for the less worn teeth, they are still high enough to prove useful for taxonomic classification.

Discussion

The results of this study suggest that using EFA is a viable, supplemental method for classifying worn bovid teeth, even when there is significant wear. This study highlights how wear can often complicate taxonomic identification. Molars such as the maxillary and mandibular first molars (M_1, M^1) tend to be more difficult to identify because they erupt first and so generally have more wear than other molars. The shape and size of teeth overlap more for some tribes than for others, making identification of these tribes particularly challenging; this overlap is even more exaggerated when the teeth are heavily worn. Any methodology that can assist in narrowing the classification of the taxon of a worn tooth is useful, but the percentages reported here are particularly informative.

In this study, Alcelaphini, Tragelaphini and Reduncini were identified with the highest rates of the six tribes. These results suggest that the form of their teeth do not change significantly throughout their lifetime, regardless of wear, making this methodology particularly useful for these three tribes.

The Hippotragini, Neotragini and Bovini were not identified with as high classification rates, thereby suggesting that their teeth (specifically those teeth with medium to late wear) are more difficult to classify. Half of the Hippotragini teeth were too worn to classify correctly. As a result of attrition, these teeth lost some of the classic features of Hippotragini, resulting in the tooth appearing more similar to those of Reduncini or Alcelaphini. Neotragini teeth overlap in size and, with attrition, look more similar to those of *Tragelaphus scriptus* (bushbuck). Therefore, six of the Neotragini teeth were classified as belonging to Tragelaphini. Finally, although the one Bovini tooth was classified as that of a Hippotragini, there was only one tooth. A larger sample of worn Bovini teeth is needed to demonstrate whether this result is typical of all Bovini teeth. The EFA methodology can aid in identifying teeth from these tribes, but teeth with medium to heavy wear may require additional methods to ratify the identification. Such methodology may involve degree of hypsodonty, enamel thickness, rugosity, and/or associated teeth/horn cores, depending on what is present. Other specimens, in particular isolated teeth, may prove to present too little data to enable classification.

The following four examples provide more background related to the results of this study, that is, reasons for the correct or incorrect classification of teeth in the test data set. All the teeth in these cases exhibited heavy wear and, according to van Zyl[22], would have been at least 37 months old.

The first case is tooth NMB 7440 – a worn lower, left, first molar that was correctly classified as that of an Alcelaphini, *Damaliscus dorcas* (blesbok) (Figure 2). The mesial lobe has been obliterated by wear with no infundibulum, while the distal lobe has retained the infundibulum. The tooth is distorted mesially and distally as a result of interproximal wear from both the fourth premolar and the second molar. The mesial side of the tooth angles mesiobuccally to distolingually. The enamel around the buccal portion of the mesial lobe (protoconid) is also damaged. Distally, the tooth curves from the eruption of the second molar. Regardless, the program was able to correctly classify this tooth to its tribe, genus and species, based on the shape and size of the remaining tooth.

Figure 2: NMB 7440, a mandibular first molar that was correctly classified as an Alcelaphini, *Damaliscus dorcas* (blesbok).

The second case, tooth AZ 1491, is a mandibular second molar that, despite its wear, was classified correctly as a Neotragini, *Raphicerus campestris* (steenbok) (Figure 3). The first and third molars have greatly affected the mesial and distal lobes of this second molar through interproximal wear. The mesial side of the tooth is essentially a straight line, parallel with the tooth row, because of impact with the first molar during eruption. The distal lobe curves as a result of the third molar impact. Despite the wear on the tooth, enough information was present for the program to classify the tooth correctly.

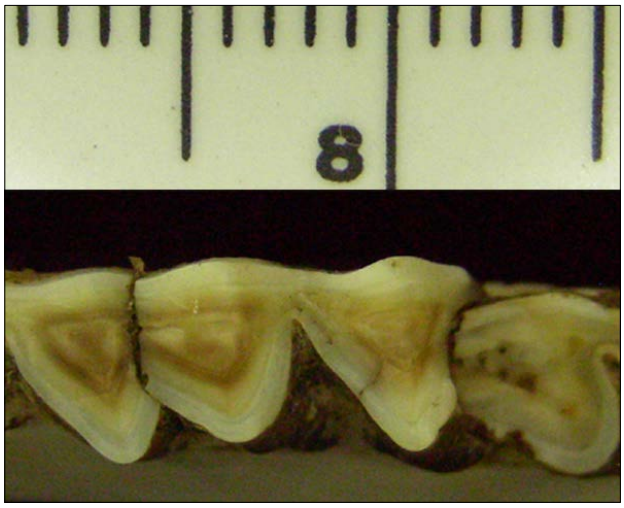


Figure 3: AZ 1491, a mandibular second molar that was classified correctly as a Neotragini, *Raphicerus campestris* (steenbok).

The third case is that of a mandibular first molar, TM 13136, belonging to a Hippotragini, *Hippotragus niger* (sable), which was classified as *Alcelaphus buselaphus* (hartebeest), an Alcelaphini (Figure 4). The mesial lobe of this tooth has been obliterated by wear and is missing the majority of its mesial and lingual enamel. The third molar has impacted the tooth, damaging the enamel, dentine and infundibulum of the distal lobe. Because of this wear, the tooth lacks the characteristics typical of *Hippotragus,* including a strong goat fold and pinching of the lateral/buccal lobes and strong ectostylid.[23] A tooth that has lost this much enamel, together with the change in shape, was difficult for the program to identify. However, without the presence of the surrounding mandible and/or other associated material, this tooth would, arguably, have been difficult to classify by any means.

Figure 4: TM 13136, a mandibular first molar from a Hippotragini, *Hippotragus niger* (sable), that was classified as an Alcelaphini, *Alcelaphus buselaphus* (hartebeest).

The last example of an incorrectly classified tooth is AZ 1576, a mandibular second molar of a Hippotragini, *Oryx gazella* (gemsbok), which was classified as an Alcelaphini, *Alcelaphus buselaphus* (Figure 5). This tooth exhibits late wear. The mesial enamel is worn away, leaving dentine that angles mesiolingually to distobucally. No goat fold is present; only a faint remnant of the parastylid remains. The distal lobe has been damaged by the third molar which has worn away the distolingual (entoconid) enamel and part of the distobuccal (hypoconid) enamel. A weak, barely visible ectostylid remains on the tooth. Because of wear, the tooth has lost some of the classic characteristics of hippotragine teeth and exhibits characteristics of alcelaphine teeth, including rounded lobes and the absence of a goat fold and ectostylid.[23] This tooth was, therefore, difficult to classify using the EFA method.

Figure 5: AZ 1576, a mandibular second molar from a Hippotragini, *Oryx gazella* (gemsbok), that was classified as an Alcelaphini, *Alcelaphus buselaphus* (hartebeest).

Taking into consideration that wear remains an issue, the method presented here could assist in mitigating the challenge of taxonomically identifying worn bovid teeth. Valuable information – such as the number of individual specimens, minimum number of individuals and relative abundance of taxa – is lost when teeth in an assemblage are grouped into broad taxonomic levels due to their poor preservation. It is important to keep in mind that most bovid teeth in the fossil record are isolated. The classifications of the teeth in this study are known because they are complete dentitions in the maxilla/mandible, associated with horn cores and housed in museum collections. In the absence of such a context, teeth are especially difficult to identify. This program, however, provides a supplement to the identification of bovid teeth where ambiguity exists.

Conclusions

Worn teeth are more challenging to classify than unworn or less worn teeth. Elliptical Fourier analysis performed on the form of the occlusal surface of teeth with medium to late wear is a viable method for aiding in taxonomic identification; this finding is despite the fact that worn teeth do not classify at the same high probabilities as relatively unworn teeth. Although some tooth types (e.g. M_1) tend to be more difficult to classify than others, and the teeth of some tribes overlap more in form when they are worn, this method aids in taxonomic classification where ambiguity in their identification exists. This research is particularly important when limited data exist on a specimen, such as an isolated tooth. By identifying more bovid teeth with higher confidence at a site, more individual specimens can be used in faunal lists. These data, in turn, are valuable for reconstructing past environments.

Acknowledgements

We thank the reviewers for taking the time to comment on our paper; Ditsong Museum, Stephanie Potze and Lazarus Kgasi for access to the collections and facilitating research; Bernhard Ziphel, Curator at the University of the Witwatersrand; and James Brink at the National Museum Bloemfontein.

Authors' contributions

J.K.B.: Conceptualisation, methodology, data collection, data analysis, data curation, writing – the initial draft. G.J.M.: Conceptualisation, methodology, data analysis, validation, data curation, writing – revisions. G.K.T.: Conceptualisation, methodology, writing – revisions.

References

1. Bobe R, Eck GG. Responses of African bovids to Pliocene climatic change. Paleobiology. 2001;27(2):1–48. https://doi.org/10.1666/0094-8373(2001)-027<0001:ROABTP>2.0.CO;2
2. Alemseged Z. An integrated approach to taphonomy and faunal change in the Shungura Formation (Ethiopia) and its implications for hominid evolution. J Hum Evol. 2003;44:451–478. https://doi.org/10.1016/S0047-2484(03)00012-5
3. De Ruiter DJ, Brophy JK, Lewis PJ, Churchill SE, Berger LR. Faunal assemblage composition and paleoenvironment of Plovers Lake, a Middle Stone Age locality in Gauteng Province, South Africa. J Hum Evol. 2008;55:1102–1117. https://doi.org/10.1016/j.jhevol.2008.07.011
4. Brophy JK, De Ruiter DJ, Athreya S, DeWitt TJ. Quantitative morphological analysis of bovid teeth and its implications for paleoenvironmental reconstructions in South Africa. J Arch Sci. 2014;41:376–388. https://doi.org/10.1016/j.jas.2013.08.005
5. Vrba ES. Some evidence of the chronology and paleoecology of Sterkfontein, Swartkrans and Kromdraai from the fossil Bovidae. Nature. 1975;254:301–304. https://doi.org/10.1038/254301a0
6. Vrba ES. The fossil record of African antelopes (Mammalia, Bovidae) in relation to human evolution and paleoclimate. In: Vrba ES, Denton GH, Partridge TC, Burckle LH, editors. Paleoclimate and evolution, with emphasis on human origins. New Haven, CT: Yale University Press; 1995. p. 385–424. https://doi.org/10.1017/s0016756897247710
7. Brain CK. The hunters or the hunted. An introduction to African cave taphonomy. Chicago, IL: University of Chicago Press; 1981. https://doi.org/10.1002/ajpa.1330590320
8. Brain CK. Temperature-induced environmental changes in Africa as evolutionary stimuli. In: Vrba ES, editor. Species and speciation. Transvaal Museum Monograph 4. Pretoria: Transvaal Museum; 1985. p. 45–52.
9. Watson V. Composition of the Swartkrans bone accumulations, in terms of skeletal parts and animals represented. In: Brain CK, editor. Swartkrans: A cave's chronicle of early man. Transvaal Museum Monograph 8. Pretoria: Transvaal Museum; 1993. p. 35–74.
10. Klein RG, Avery G, Cruz-Uribe K, Steele TE. The mammalian fauna associated with an archaic hominin skullcap and later Acheulean artifacts at Elandsfontein, Western Cape Province, South Africa. J Hum Evol. 2007;52:164–186. https://doi.org/10.1016/j.jhevol.2006.08.006
11. Wells LH, Cooke HBS. Fossil Bovidae from the limeworks quarry, Makapansgat, Potgietersrus. Paleont Afr. 1956;4:1–55.
12. Reed KE. Using large mammal communities to examine ecological and taxonomic organization and predict vegetation in extant and extinct assemblages. Paleobiology. 1998;32:384–408. https://doi.org/10.1666/0094-8373(1998)024[0384:ULMCTE]2.3.CO;2
13. Brophy JK. Reconstructing the habitat mosaic associated with *Australopithecus robustus*: Evidence from quantitative morphological analysis of bovid teeth [dissertation]. College Station, TX: Texas A&M University; 2011.
14. Matthews GJ, Brophy JK, Luetkemeier MP, Gu H, Thiruvathukal GK. Classification of bovid teeth: A comparison of machine learning techniques for taxonomic classification of teeth from the Family Bovidae. J App Stats. 2018;45(15):2773–2787. https://doi.org/10.1080/02664763.2018.1441381
15. Matthews GJ, Thiruvathukal GK, Luetkemeier MP, Brophy JK. Examining the use of Amazon's Mechanical Turk for edge extraction of the occlusal surface of fossilized bovid teeth. PLoS ONE. 2017;12(7), e0179757, 18 pages. https://doi.org/10.1371/journal.pone.0179757
16. Klein RG. On the taxonomic status, distribution and ecology of the blue antelope, *Hippotragus leucophaeus* (Pallas, 1766). Ann S Afr Mus. 1974;65:99–143.
17. Klein RG, Cruz-Uribe K. The bovids from Elandsfontein, South Africa, and their implications for the age, palaeoenvironment, and origins of the site. Afr Archaeol Rev. 1991;9:21–79.
18. Klein RG, Cruz-Uribe K, Beaumont PB. Environmental, ecological, and paleoanthropological implications of the late Pleistocene mammalian fauna from Equus Cave, Northern Cape Province, South Africa. Quat Res. 1991;36:94–119.
19. Lacruz RS, Brink JS, Hancox PJ, Skinner AR, Herries A, Schmid P, Berger LR. Palaeontology and geological context of a Middle Pleistocene faunal assemblage from the Gladysvale Cave, South Africa. Palaeont Afr. 2002;38:99–114.
20. Reynolds SC, Kibii JM. Sterkfontein at 75: Review of palaeoenvironments, fauna and archaeology from the hominin site of Sterkfontein (Gauteng Province, South Africa). Palaeont Afr. 2011;46:59–88.
21. Bonhomme V, Picq S, Gaucherel C, Claude J. Momocs: Outline analysis using R. J Stat Soft. 2014;56(13):1–24. https://doi.org/10.18637/jss.v056.i13
22. Van Zyl LJ. Ageing criteria for some of the Bovidae in southern Africa [thesis]. Stellenbosch: Stellenbosch University; 1972.
23. Gentry AW. Evolution of African mammals. Cambridge, MA: Harvard University Press; 1978. https://doi.org/10.4159/harvard.9780674431263.c28

AUTHORS:
Damian W. Ponsonby[1]
M. Thabang Madisha[2]
Ute Schwaibold[1]
Desiré L. Dalton[2,3]

AFFILIATIONS:
[1]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa
[2]National Zoological Gardens of South Africa, Pretoria, South Africa
[3]Department of Zoology, University of Venda, Thohoyandou, South Africa

CORRESPONDENCE TO:
Damian Ponsonby

EMAIL:
dw.ponsonby@gmail.com

DATES:
Received: 12 Apr. 2018
Revised: 26 Mar. 2019
Accepted: 18 Apr. 2019
Published: 30 July 2019

HOW TO CITE:
Ponsonby DW, Madisha MT, Schwaibold U, Dalton DL. Genetic diversity of African clawless otters (*Aonyx capensis*) occurring in urbanised areas of Gauteng, South Africa. S Afr J Sci. 2019;115(7/8), Art. #4889, 8 pages. https://doi.org/10.17159/sajs.2019/4889

ARTICLE INCLUDES:
☒ Peer review
☒ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☒ On request from author(s)
☐ Not available
☐ Not applicable

EDITOR:
John Butler-Adam

KEYWORDS:
Aonyx capensis; genetic health; urbanisation; distribution

FUNDING:
None

Genetic diversity of African clawless otters (*Aonyx capensis*) occurring in urbanised areas of Gauteng, South Africa

Genetic diversity is the basis of the evolutionary potential of species to respond to environmental changes. However, restricting the movement of species can result in populations becoming less connected which can reduce gene flow and can subsequently result in a loss of genetic diversity. Urban expansion can lead to the fragmentation of habitats which affects the ability of species to move freely between areas. In this study, the genetic diversity of the African clawless otter (*Aonyx capensis*) in Gauteng (South Africa) was assessed using non-invasive sampling techniques. DNA was extracted from spraint (faecal) samples collected along nine rivers and genotyped using 10 microsatellites to assess population structure and genetic diversity. Samples were grouped based on locality and by catchment to determine whether isolated subpopulations exist. Genetic diversity of *A. capensis* in Gauteng was found to be low (mean observed heterozygosity (*Ho*)=0.309). Analysis of genetic structure provides support for the otter populations being panmictic with high gene flow between populations from different rivers. Results from the study indicate that the movement of *A. capensis* is not affected by physical barriers in urbanised areas. However, because the genetic diversity of the species in the study area is low, these animals may not be able to cope with future environmental changes.

Significance:

- Genetic structure analysis of the sampled Gauteng otter population indicates the population is panmictic; however, a low level of genetic diversity in this population has also been identified and may affect how the population copes with future environmental changes.
- Physical restrictions in urbanised areas do not appear to be affecting movement of the species.

Introduction

Over the past eight decades, urban areas have expanded into surrounding natural environments at a significant rate. This development into previously undisturbed areas has resulted in species being driven out of their habitats in search of suitable environment with less human disturbance. In some cases, species will remain in the urban areas and utilise the novel environment.[1] Many cities include open spaces such as parks and sports fields which provide new habitat for wildlife. However, not all species are suited to living in cities[2,3], and thus a decrease in biotic diversity may occur, whereby only the more resilient (able to recover from adverse conditions) species survive as they possess characteristics allowing them to tolerate the urban setting[1].

Species in urban areas can occur across a broader habitat range which reduces restriction to one specific habitat type, allowing them to move to another area if conditions become unfavourable.[3-6] However, barriers such as roads and fences may prevent movement of some animals between suitable habitats, limiting their movement and reducing their chances of finding shelter, food and mates. A reduction in interactions between unrelated individuals of the same species[7] can lead to reduced genetic diversity and an increase in the level of inbreeding.[8]

Two otter species occur in South Africa: the African clawless otter (*Aonyx capensis*) and the spotted-necked otter (*Hydrictis maculicollis*). The distributions of both species range across most of South Africa and include inland and coastal areas as well as large urbanised areas (such as the current study area), with *A. capensis* having a much greater distribution range than *H. maculicollis*.[9] The IUCN Red List (2016) has categorised both otter species as near-threatened, with habitat degradation posing the highest threat to freshwater environments used by the otters.[10,11] Kubheka et al.[12] demonstrated a decrease in abundance of both otter species along a stretch of the Mooi River in South Africa that has experienced an increase in human activity along its banks in recent years, lending to the urgency to better understand anthropogenic effects on otters. Somers and Nel[13] reported that *A. capensis* has a home range size that varies from 4.9 km to 54.1 km and a core length from 0.2 km to 9.8 km. Their study also indicated that the ranges of male individuals overlapped with those of other male and female individuals, while female otters possibly demonstrated territoriality. However, there is a possibility that the ability of otters to travel great distances in dense urban areas may be hampered by barriers such as buildings, roads, fences and high levels of human activity, which in turn would impact on intraspecific encounters. To date, no studies have focused on the genetic diversity of either of the two otter species, making it impossible to draw conclusions regarding the general genetic health and risks facing these otter species in the future.

The aim of this study was to assess the population genetics of *A. capensis* in a region exposed to varying levels of human disturbance. It was hypothesised that population structuring would reflect division of the local population caused by geographical separation from catchment areas, as well as restriction of movement due to areas of heavy urban development. A study of Hungarian otters demonstrated a level of genetic clustering occurring between to geographically separated river basins.[14] It was also hypothesised that low genetic diversity and inbreeding would be evident as unrelated individuals may not be able to interact and reproduce successfully in urban Gauteng.

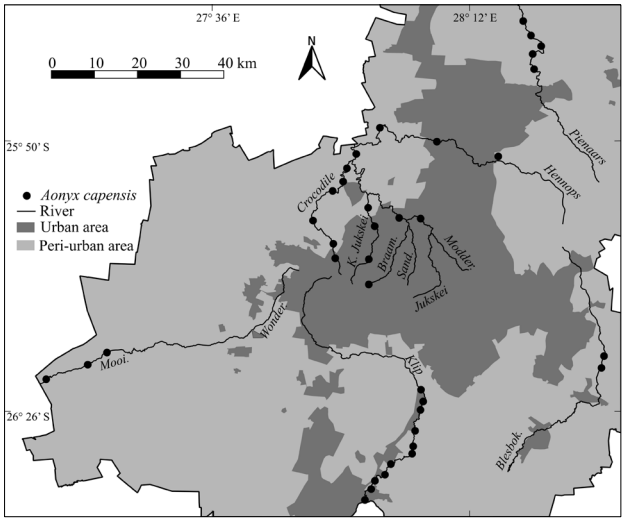
Spraint (faecal) samples were collected and examined from river catchments in the Gauteng Province (South Africa) to determine the level of genetic diversity and structure of the *A. capensis* population, using 10 microsatellite primers developed for *Lutra lutra*, the Eurasian otter). The use of cross-species primers has been conducted

successfully for amplification of alleles in numerous otter and other animal species in situations in which species-specific primers have not yet been developed.[15-19] Gauteng was selected as it represents a complex landscape comprising urban areas surrounded by less transformed peri-urban areas. There are numerous interconnecting rivers within Gauteng that flow through varying levels of urbanisation (residential suburbs, industrial, mining and commercial areas) and natural environments.

Methods

Study area and sample collection

The Gauteng Province of South Africa has three river catchments: Crocodile River west catchment (A), Olifants River primary catchment (B) and Vaal River primary catchment (C). These catchments contain the headwaters of several major river systems.[20] The study focused on nine rivers in the Province which occur in two of the three catchments: Pienaars, Hennops, Jukskei, Klein Jukskei and Crocodile Rivers in Catchment A and Braamfonteinspruit, Mooi River Loop/Wonderfonteinspruit (henceforth Mooi), Klip River and Blesbokspruit in Catchment C. Sampling was conducted from June 2012 to October 2014 and was restricted to autumn and winter as these seasons have much lower rainfall levels, thus reducing the chance of spraints deteriorating due to rain or being washed away by flooded rivers[21], which is a common occurrence in summer. Google Earth[22] and the Resource Quality Information Services river coverage data for South Africa[23] were used to measure the full length of the chosen rivers (Figure 1) and sampling sites were identified at 5-km intervals along each river. Sites were selected at 5-km intervals as this is the shortest home range length of *A. capensis* found by Somers and Nel[24], but due to possible DNA degradation, individuals could not be identified, preventing the estimation of home ranged based on occurrence of multiple spraints from the same individual. A 400 m by 10 m transect was surveyed once only at each 5-km point along both sides of the river for signs of otter presence (footprints, spraints and sightings of animals).



Mooi., Mooi River Loop; Wonder., Wonderfonteinspruit; K. Jukskei, Klein Jukskei River; Braam., Braamfonteinspruit; Modder., Modderfonteinspruit

Figure 1: Rivers surveyed and collection sites of *Aonyx capensis* spraints in relation to peri-urban and urban areas.

Spraints occurred in various forms: small deposits of anal jelly, a single cigar-shaped faecal deposit, a solitary pile of faeces (comprising three or four cigar-shaped faeces), or a site with numerous piles of faeces. Otter spraints can be easily identified based on a pungent fishy smell that can be detected several metres away, as well as by the characteristic presence of pieces of crab carapace in the spraints[21]). Each spraint sample (anal jelly, single cigar-shaped faeces or solitary pile of faeces) was collected separately in re-sealable plastic bags, and a solitary pile of spraints was considered one sample. At spraint sites, care was taken to select spraint piles (each one collected separately) that were not in contact with neighbouring spraint piles. Multiple spraints were collected separately from spraint sites, as previous studies have shown that multiple individuals[21,25], as well as both otter species (*A. capensis* and *H. maculicollis*)[21], use the same spraint sites on occasion. Spraints were collected regardless of their age (except in the case of extremely weathered spraints that had deteriorated significantly). The Global Positioning System (GPS) coordinates were recorded at every location at which spraints were found using a handheld Garmin eTrex VistaCX GPS device (Garmin, Olathe, USA). Figure 1 shows the locations where positive signs were found. Samples were stored at -10 °C prior to DNA extraction.

DNA extraction and species identification

DNA was extracted from 211 spraint samples using the QIAGEN QIAamp DNA Stool Mini Kit (Qiagen, Hilden, Germany)[26] according to the manufacturer's instructions for isolation of DNA from stool for human DNA analysis.[27] Species identification was conducted using developed partial *CytB* primers.[28] A homology search was done on all sequences obtained using the BlastN function on the US National Center for Biotechnology Information (NCBI) online database. Control sample DNA for *A. capensis* and *H. maculicollis* was extracted from reference tissue samples obtained from the South African National Zoological Gardens Biomaterials Bank (Biobank). These reference samples were collected from roadkill specimens from various locations across South Africa.

Amplification and genotyping

Ten microsatellite markers developed for studies of *L. lutra*[29] were used for genotyping analysis: Lut435, Lut453, Lut457, Lut604, Lut615, Lut701, Lut715, Lut782, Lut818 and Lut832. These markers have been shown to be polymorphic in up to six otter species (including *A. capensis*), but not in other carnivores.[30] Optimisation of the primers was conducted at various annealing temperatures (Ta) to ensure amplification of the correct fragment, with the subsequent temperature (Ta) deemed the most effective based on number of successful amplifications of the correct fragment size. Amplification was carried out using a 15 μL reaction volume containing 7.5 μL of Platinum master mix (1X), 3 μL of forward and reverse primer (10 pmol), 2.5 μL of double distilled water and 2 μL template DNA (~20 ng). The cycling conditions for polymerase chain reaction (PCR) amplification were: 5 min at 95 °C initial denaturation, 38 cycles for 30 s at 95 °C, 30 s at 45–52 °C and 30 s at 72 °C, followed by extension at 72 °C for 20 min. The PCR was carried out in the Bio-Rad T100 Thermal Cycler (Bio-Rad Laboratories, Inc., Hercules, USA). PCR products were run against GenescanTM 500 LIZ™ (Applied Biosystems, Inc., ABI, Foster City, USA) internal size standard on an ABI 3130 Genetic Analyzer. Samples were genotyped using GeneMapper v.4.0.[30] For each sample, PCR reactions were conducted once and then repeated four times, resulting in each sample being amplified five separate times. Genotyping was conducted using a comparative method in which alleles obtained for each sample were compared, and the most frequently observed alleles for each locus were selected for each sample. Allelic peaks were scored based on height and occurrence in prescribed binning areas based on the range of each marker. In cases presenting multiple allelic peaks, the highest peak was chosen as the first allele. The second allele was selected if it was no less than half the height of the first allele, fell into a prescribed bin, and was of a reasonable distance of base pairs apart from the first allele selected (see Supplementary figures 1 and 2 for visual representation of genotype scoring).

Microsatellite analysis

In order to exclude possible errors, MICROCHECKER version 2.2.3[31] and FreeNA[32] was used to detect the presence/absence of null alleles and allelic dropout. GenAlEx 6.5[33,34] was used to test for deviations from Hardy–Weinberg equilibrium. Linkage disequilibrium was determined using the online version of Genepop 4.2 (Genepop on the web[35]). Duplicate samples of individuals were identified using the probability of identity in GenAlEx 6.5.[33,34] Matching profiles indicating duplicate sampling of the same individual were excluded from further analysis to prevent redundancy. However, genetic profiles are dependent on the quality of DNA extracted, which can be compromised in non-invasive samples. Some samples were older than others, which may have impacted the quality of DNA extracted. If an individual defecated several times along a study river, the presence of null alleles due to low-quality DNA would

greatly affect the genetic profile obtained for that individual. A single locus difference will render a genetic profile unique, requiring multiple repeats to be conducted to increase the accuracy of allele detection. Genetic diversity was assessed using GenAlEx 6.5[33,34] to determine the number of alleles (Na), expected heterozygosity (*He*) and observed heterozygosity (*Ho*).

Population structure

Due to areas of heavy urbanisation, and large distances between study rivers restricting movement of otters, each river was defined as a potential population, resulting in nine theoretical populations. As the study rivers occur in two catchment areas, these were considered individual populations for the catchment analysis portion of this study. GenAlEx 6.5[33,34] was used to determine population differentiation (F_{ST}) and for analysis of molecular variance (AMOVA). In addition, F_{ST} was calculated following balancing for null alleles with FreeNA.[32] In order to assess the genetic partitioning across Gauteng river otter populations, two different approaches were used based on multilocus genotypes. A Bayesian clustering analysis was conducted using the statistical program STRUCTURE version 2.3.4[36] for the assignment of individuals to groups based on genetic similarity. STRUCTURE was run with and without LOCPRIOR using 100 replications at each value for *K* (*K*=1-12) for the 'per river' analysis and for the catchment analysis (*K*=1-4). The values used for *K* for 'per river' analysis took into account the possible nine populations designated to each study river, and an extra three populations in case more than nine independent populations occurred. If 12 populations were detected, the value for *K* would be increased further to accurately detect the possible number of populations. The *K* value for catchment analysis included the two actual catchments and two extra potential populations as the large areas of the catchments may be occupied by more than two populations. The runs were conducted with a burn-in period of 100 000 repeats followed by 1 000 000 repeats of the Markov chain Monte Carlo. The result files from each run (with LOCPRIOR and without LOCPRIOR) were uploaded to the web-based STRUCTURE-HARVESTER[37] program which uses likelihood methods to assume the correct number of genetic clusters (*K*). In addition, the genetic distance was calculated and a principal coordinates analysis (PCoA) was conducted for the data using GenAlEx version 6.5.[33,34] Nei's genetic distance was also compared to geographical distance between populations using the computer program IBD for Windows (version 1.52).[38] IBD (running 5000 randomisations) was used to calculate Mantel tests to highlight any significant relationships between genetic and geographical distance and estimate regression values.

Relatedness analysis

Pairwise relatedness was calculated between individuals per river, with each river considered as a separate population, using GenAlEx version 6.5.[33,34] Results were obtained for three different relatedness tests: Ritland[39] estimator, Lynch and Ritland[40] estimator, and Queller and Goodnight[41] estimator. The mean of the three results obtained for each pairwise comparison was used to create a box-and-whisker plot for each river. This analysis was restricted to the Blesbokspruit, Crocodile, Jukskei, Klein Jukskei, Klip and Pienaars Rivers as we did not obtain sufficient numbers of samples for an adequate analysis from the Braamfonteinspruit, Mooi and Hennops River. The same procedure was conducted for the comparison between catchments, with Catchment A comprising samples from the Pienaars, Jukskei, Klein Jukskei and Crocodile Rivers, while Catchment C included the Blesbokspruit and Klip River. If the median occurs at or below zero, individuals within the population are not highly related, whereas if the median is above zero, individuals in the population are considered related.

Results

Of the total 211 samples collected, 171 spraint samples were identified as being from *A. capensis* (except for two samples, relatedness analysis indicated that these were all unique individuals), while 8 were identified to be from *H. maculicollis*. A total of 32 samples remained unidentified to species, possibly because sample DNA was too degraded for successful amplification or was not present in a sufficient quantity in the sample. Due to the low number of samples identified as *H. maculicollis*, population genetic assessments were conducted only for *A. capensis* in the study presented here.

Marker assessment

Aonyx capensis samples from two catchments in Gauteng (South Africa) were genetically analysed using 10 microsatellite markers. Sample distribution included 14 samples from Blesbokspruit, 2 samples from Braamfonteinspruit, 48 samples from Crocodile River, 3 samples from Hennops River, 16 samples from Jukskei River, 15 samples from Klein Jukskei River, 37 samples from Klip River, 6 samples from Mooi and 30 samples from Pienaars River. The sample collection comprised the first genetic analysis of *A. capensis* in South Africa. Summary statistics calculated using GenAlEx 6.5[33,34] indicated that all loci were polymorphic in each population (Supplementary table 1). All loci were affected by null alleles in all populations following analysis in GenAlEx 6.5[33,34] and FreeNA.[32] Genotypes obtained were corrected using MICROCHECKER and three markers (Lut604, Lut782 and Lut818) showed a high presence of null alleles (mean >0.45) and were thus excluded from further analysis. Using probability of identity, no matching profiles were identified, consequently, the home range of individuals could not be estimated. All markers appeared to be significantly linked based on Genepop analysis, which may be due to the presence of non-amplified alleles (null alleles). Markers from Blesbokspruit, Crocodile, Jukskei, Klein Jukskei, Klip and Pienaars Rivers deviated from the Hardy–Weinberg equilibrium. The observed deviations may be from null alleles, low levels of observed heterozygosity at all loci and/or differences in sample sizes between rivers.

Genetic analysis: Populations defined by river

Genetic assessments were then carried out for each river referred to here as 'per river' analyses. All loci were polymorphic with the number of alleles ranging from 4 to 27 and averaging 9 alleles per locus. Genetic diversity estimates by observed and expected heterozygosity and the number of alleles within each river were moderate to high. The mean expected heterozygosity (*He*) was 0.730 with a mean observed heterozygosity (*Ho*) of 0.344 (Table 1).

Table 1: Genetic variation estimates (mean±s.e.) for (a) 'per river' analysis and (b) catchment analysis

a)

River	*Ho*	*He*	*Na*	*Ne*
Blesbokspruit (*n*=14)	0.406 ± 0.044	0.753 ± 0.027	6.9 ± 0.526	4.47 ± 0.449
Crocodile (*n*=48)	0.312 ± 0.051	0.879 ± 0.026	17.4 ± 1.796	10.388 ± 1.279
Jukskei (*n*=16)	0.289 ± 0.044	0.805 ± 0.028	8.6 ± 0.806	6.107 ± 0.805
Klein Jukskei (*n*=15)	0.319 ± 0.05	0.854 ± 0.013	10.0 ± 0.715	7.460 ± 0.767
Klip (*n*=37)	0.266 ± 0.033	0.879 ± 0.015	14.4 ± 1.185	8.989 ± 0.702
Pienaars (*n*=30)	0.292 ± 0.042	0.888 ± 0.019	16.3 ± 2.05	11.205 ± 1.614
Mean ± s.e.	0.314 ± 0.044	0.843 ± 0.021	12.267 ± 1.18	8.103 ± 0.936

b)

Catchment	*Ho*	*He*	*Na*	*Ne*
A (*n*=114)	0.311 ± 0.033	0.905 ± 0.016	25.5 ± 2.684	12.938 ± 1.792
C (*n*=57)	0.308 ± 0.026	0.873 ± 0.014	16.8 ± 1.191	8.65 ± 0.824

Ho, mean observed heterozygosity; He, mean expected heterozygosity; Na, mean number of alleles per locus: Na = sum of all alleles detected per river/number of loci; Ne, mean number of effective alleles: Ne = 1/(sum of squared population allele frequencies)

All analyses were conducted in GenAlEx version 6.5.[33,34]

Braamfonteinspruit, Mooi and Hennops results have been excluded due to small sample size.

In all instances, *Ho* was lower than *He* and values for *Ho* varied per river with Klip River being the lowest (*He*=0.266) and Blesbokspruit being the highest (*Ho*=0.406). Upon using each river as a potential population, STRUCTURE HARVESTER identified *K*=3 (Figure 2) as the most likely number of subpopulations, although no significant population structure was observed. A low mean genetic differentiation (F_{ST}=0.037) between all rivers is shown in Table 2a. The F_{ST} values were lower (F_{ST}=0.01) but similar when applying the Excluding Null Alleles (ENA) method in FreeNA (Table 2b). Populations along the Crocodile and Pienaars Rivers show the lowest differentiation (F_{ST}=0.014 and F_{ST}=0.001). Populations from all rivers displayed private alleles at all loci, with the Crocodile and Pienaars River populations showing the highest number with eight private alleles each. No significant relationship was observed between genetic and geographical distance (Table 3) at the river population level through Mantel tests (r^2=0.267; p=0.8732).

Table 2: Genetic differentiation between otter populations grouped according to the river along which spraint samples were collected, (a) including null alleles using Weir and Cockham analysis[60] and (b) excluding null alleles using FreeNA[32]

a)

	Blesbokspruit	Crocodile	Jukskei	Klein Jukskei	Klip
Crocodile	0.038				
Jukskei	0.063	0.043			
Klein Jukskei	0.051	0.028	0.058		
Klip	0.039	0.015	0.047	0.032	
Pienaars	0.043	0.014	0.041	0.029	0.020

b)

	Blesbokspruit	Crocodile	Jukskei	Klein Jukskei	Klip
Crocodile	0.027				
Jukskei	0.023	0.009			
Klein Jukskei	0.020	0.005	0.011		
Klip	0.026	0.002	0.011	0.009	
Pienaars	0.025	0.001	0.004	0.005	0.004

Table 3: Nei's genetic distance (measured in GenAlEx version 6.5[33,34]) and geographical distance (km) between river populations. Geographical distance is displayed above the diagonal, genetic distance below the diagonal.

	Blesbokspruit	Crocodile	Jukskei	Klein Jukskei	Klip	Pienaars
Blesbokspruit	–	77	61	66	50	83
Crocodile	0.365	–	17	14	66	60
Jukskei	0.613	0.562	–	6	61	50
Klein Jukskei	0.551	0.463	0.880	–	60	56
Klip	0.371	0.246	0.682	0.550	–	108
Pienaars	0.437	0.231	0.559	0.513	0.362	–

Relatedness: Populations defined by river and catchment

Pairwise relatedness comparisons between individuals within each river population indicated that the mean relatedness for each river is low as the median of the box-and-whisker plots for each river falls below zero. However, the Bleskbokspruit had two maximum outliers, which may be the result of two spraints collected from the same individual. Overall relatedness of individuals in both Catchments A and C was low based on the box-and-whisker plot (Figure 3).

Genetic analysis: Populations defined by catchment area

Due to sample size differences (small sample size of Braamfonteinspruit, Mooi, and Hennops River), which resulted in limitations, some analyses could not be performed in the 'per river' analyses. These rivers were subsequently clustered depending on the water catchment to which they belong (Catchment A – Pienaars, Hennops, Jukskei, Klein Jukskei, Crocodile Rivers; Catchment C – Braamfonteinspruit, Mooi, Klip River and Blesbokspruit) and genetic assessments for each of the two catchments (A and C) were conducted. When separated into catchment areas, all loci were polymorphic, with the number of alleles ranging from 9 to 39 and averaging 21 alleles per locus. Expected heterozygosity within all groups (*He*) was 0.889 and observed heterozygosity (*Ho*) was 0.309; this difference may be due to the use of non-species-specific markers or genotypic error. There was a significant deviation from the Hardy–Weinberg equilibrium ($p<0.001$) for all markers, which may indicate genotyping error and resulting underestimation of heterozygosity. However, genetic differentiation (F_{ST}=0.01) between the two catchments (A and C) was low and non-significant ($p\geq0.05$).

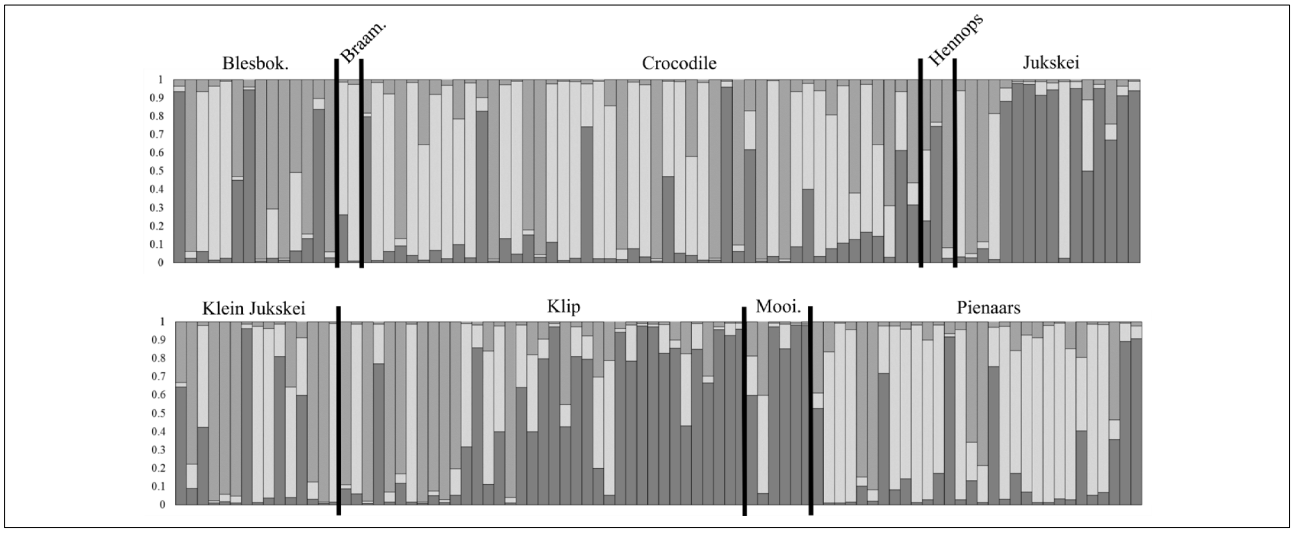


Figure 2: Plots of assignment probabilities from STRUCTURE for the 'per river' analysis showing the posterior probability of assigning each individual to each of the inferred clusters. Each individual is represented by a vertical bar and each shade refers to a different cluster. Average cluster membership for $K = 3$.

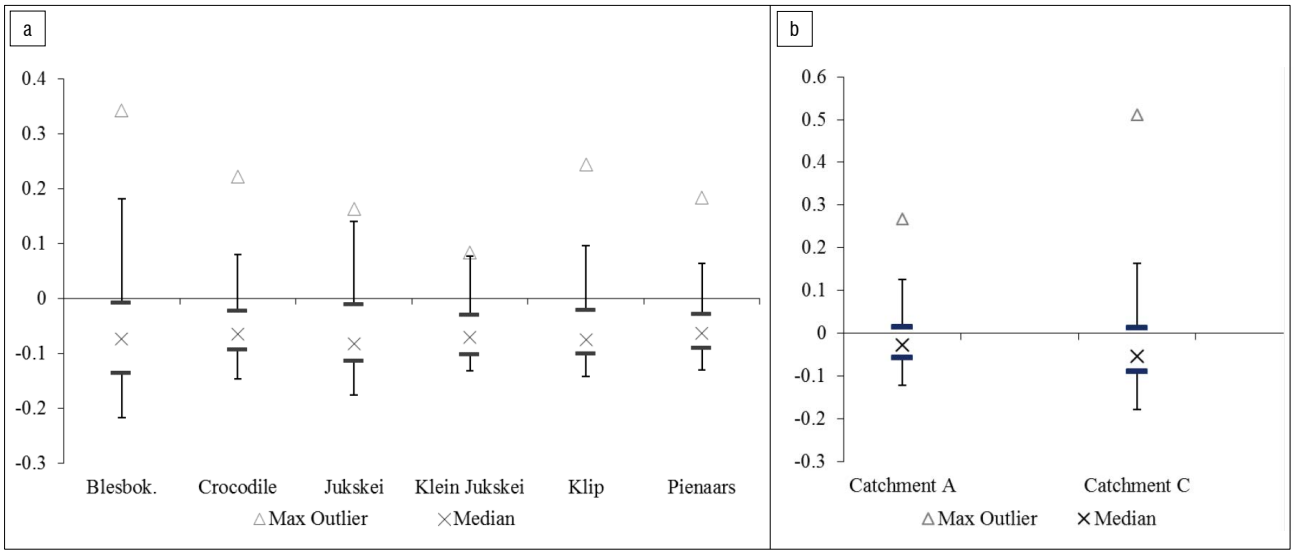


Figure 3: Box-and-whisker plots depicting the relatedness within each (a) river population and (b) catchment population. Overall relatedness is low for all populations, indicating that interbreeding is not considerably high in the populations.

Results from STRUCTURE Harvester identified $K=2$ as the most likely number of genetic clusters for the catchment analysis (Figure 4a,b). No significant population sub-structuring could be observed, with allele frequencies being somewhat similar, although more frequent in other rivers. This finding could be attributed to high gene flow but also shows that some rivers may be more favoured than others. Although STRUCTURE analysis supports the presence of two subpopulations, this was not observed in the PCoA, which clearly illustrates no significant clustering occurring (Figure 5). Private alleles were observed in all 10 loci for Catchment A, with 100 private alleles occurring in the Catchment A population. Of the 10 loci, 7 had private alleles, totalling 13 alleles for the Catchment C population.

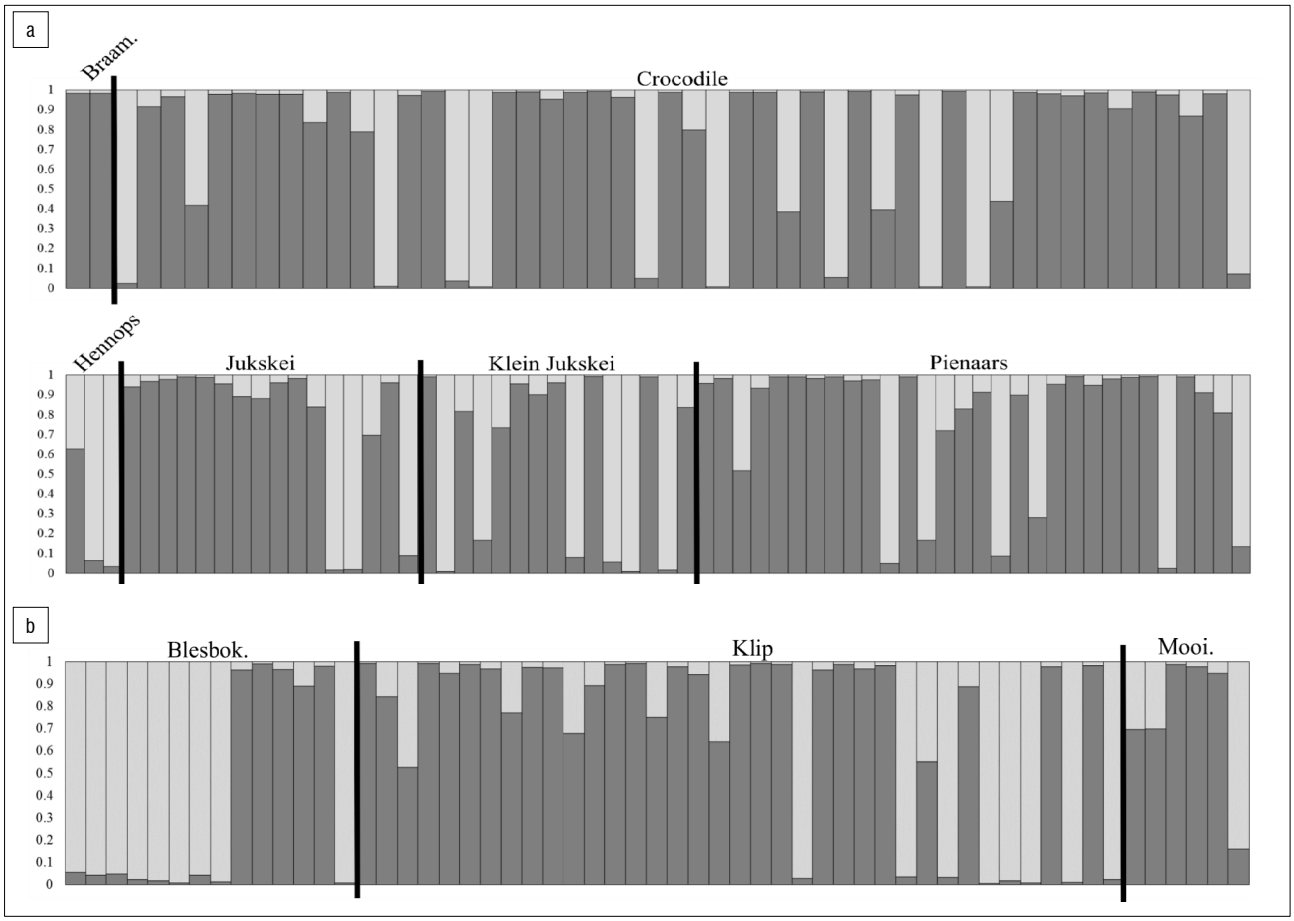


Figure 4: Bayesian assignment probabilities for (a) Catchment A samples at $K=2$ and (b) Catchment C at $K=2$. Each vertical bar represents an individual, which is divided into K shades representing estimated membership fractions in K clusters. The black vertical lines separate individuals into the nine rivers along which samples were found. No definite structure appears to occur within the overall provincial population.

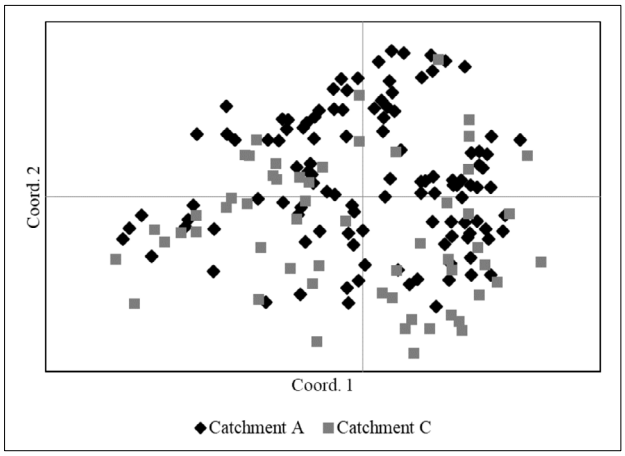


Figure 5: Principal coordinates analysis (PCoA) for the two water catchment areas assessed in Gauteng, South Africa.

Discussion

A relatively high level of genetic diversity is considered fundamental for species survival.[42] To achieve this diversity, high levels of gene flow within a population is required, but can be difficult where the landscape presents barriers such as cities, mountain ranges, valleys and large rivers.[43] Thus, human-mediated activities may have had an effect on patterns of genetic structure and diversity in *A. capensis* samples from two catchments in the Gauteng Province (South Africa). The genetic diversity across all the sampled river populations was low for observed heterozygosity (*Ho*=0.309), with a high expected heterozygosity (*He*=0.889). Historical data for the otter populations in Gauteng are, however, not available for direct comparison to assess whether genetic diversity has increased or decreased. Low genetic diversity introduces several negative effects for a population such as inbreeding, susceptibility to diseases, and reduced genetic fitness. All these factors combined can eventually lead to population decline. Previous studies have shown an increase in diversity after species were reintroduced into the areas, or from repatriation or ingress of species from adjacent areas, following initial declines.[44-46] Thus, the observed low genetic diversity in the Gauteng *A. capensis* population may be because of a history of extirpation and recolonisation, as has been identified in other mustelid species.[47,48] This answer is the most logical as there is no evidence in the literature indicating reintroduction of *A. capensis* to the area. It has been reported that genetic diversity decreases along a path of range expansion.[49,50] A similar pattern has been observed in the Minnesota river otter population from Central North America for which a decrease in heterozygosity was observed from the core population.[52]

The assessment of the population genetic structure of the otters occurring in Gauteng revealed no sub-structuring between the two populations/groups sampled within the two catchments as supported by a non-significant genetic differentiation (F_{ST}=0.01). These results provide evidence of high levels of gene flow between groups sampled in Gauteng which is further supported by the low relatedness coefficient value (0.048). Although STRUCTURE identified three genetic clusters for the populations defined by river analysis and two genetic clusters for the populations defined by catchment analysis, this does not seem to be the case when considering the genetic distance between individuals within the two catchments (Figure 5). Cluster analysis programs such as STRUCTURE tend to introduce uncertainty to results obtained in situations in which the study groups present low levels of divergence.[52] The minimum number of genetic clusters that can be assigned by STRUCTURE is two, thus resulting in one homogenous population being labelled as *K*=2, or two different groups. Lack of sub-structuring between the populations/groups was supported by the PCoA. Although F_{ST} values were moderate for the populations defined by river analysis (F_{ST}=0.13), the value was reduced when the ENA method was applied (F_{ST}=0.001), providing support that this value may be overestimated due to the presence of null alleles.

The presence of null alleles may have influenced the overall outcome of the study and could be attributed to the use of primers designed for different species and possible degraded DNA from faecal samples. Null alleles refer to alleles at any given locus that constantly fail to amplify and as such cannot be detected by PCR or subsequent analysis. They usually occur due to mutations in the flanking regions where the primers anneal for amplification, resulting in poor or no amplification at the affected locus.[53] The presence of null alleles does not necessarily impact the outcomes of population genetic analyses – their presence tends not to have significant consequences in analyses that use average probabilities (as opposed to individual parentage analyses), but they may cause overestimation of F_{ST} and genetic distances, as well as underestimation of observed heterozygosity, and may slightly lower the power of assignment tests (such as STRUCTURE).[13,53,54]

The overall low genetic diversity of the Gauteng otter population is possibly linked to the rapid expansion of urbanised areas outward into previously undisturbed environment at an exponential rate due to a human population increase. The rapid expansion would have affected the established riparian habitats scattered throughout the province, driving species outward to less disturbed habitats, or possibly resulting in the extirpation of more sensitive species.[55] The emigration of species from the area would result in more resources becoming available for opportunistic species able to adapt to the novel urban environment, which could lead to conflict over resources with native species remaining in delineated areas.[56-58]

Another explanation for the low genetic diversity could be related to the home range of otters, which can be extensive, ranging from 4.9 km to 54.1 km^2[4], and may be even larger. Coyotes in developed areas have been found to possess home ranges double that of individuals in less developed areas as well as having dens in less developed forested areas,[3] and it is possible that otters in urban areas may also be increasing the size of their home range to improve chances of finding food and mates. *A. capensis* present in Gauteng may have core ranges (areas with increased frequency of activity, usually where refugia are located) outside of the province from which the animals venture into Gauteng to forage. This practice is seen in urban mammals that can navigate and utilise matrix habitats like those seen in urban areas (discussed in Baker and Harris[59]). The lack of holts (otter refuges) observed during surveys is possible evidence of this being the situation with *A. capensis* in Gauteng. A larger breeding population may occur further north along the Crocodile River, which may have undergone range expansion into the Hennops River and subsequent tributaries with headwaters occurring in the city of Johannesburg.[51] This range expansion could explain the lower levels of genetic diversity in the tributary rivers (Jukskei River and Klein Jukskei). The low genetic differentiation between samples from Pienaars River and Crocodile River is interesting as the rivers are a considerable distance apart in Gauteng, but they share a confluence to the north of Gauteng. This may be considered further evidence for a larger breeding population further north along the Crocodile River which has divided and moved into Gauteng. Otter movement does not seem to be hindered by physical barriers as there was no evidence of sub-structuring occurring, relatedness was low, and there was evidence of high gene flow. These results suggest that urbanisation has not led to fragmentation of the population due to disruption of gene flow, which may indicate the otter population in Gauteng is successful (surviving and reproducing viable offspring). However, further sampling must be conducted to confirm that their genetic health is improving.

This analysis represents the first genetic analysis of a South African otter species to date, and additional studies in the future would be required to assess changes in genetic diversity and differentiation. In addition, future studies should be conducted throughout the otters' distribution range. This is imperative to assist in the assessment of the otter population and the effect urbanisation has had on the ecology of the otters. Future studies could provide evidence of a recovering population with good genetic health, which would support the hypothesis that otters can adapt to urbanisation and associated human activity.

Authors' contributions

D.W.P: Research design; fieldwork and sample collection; analysis of samples in laboratory; data analysis; and writing. M.T.M.: Analysis

of samples in laboratory; statistical analysis of samples; writing and reviewing article drafts. U.S.: Research supervision, writing and reviewing article drafts. D.L.D.: Analysis of samples in laboratory; statistical analysis of samples; writing and reviewing article drafts.

References

1. McKinney ML. Urbanisation, biodiversity, and conservation. BioScience. 2002;52:883–890.
2. Maciusik B, Lenda M, Skorka P. Corridors, local food resources, and climatic conditions affect the utilisation of the urban environment by the black-headed gull *Larus ridibundus* in winter. Ecol Res. 2010;25:263–272. https://doi.org/10.1007/s11284-009-0649-7
3. Gese EM, Morey PS, Gehrt SD. Influence of the urban matrix on space use of coyotes in the Chicago metropolitan area. J Ethol. 2012;30:413–425. https://doi.org/10.1007/s10164-012-0339-8
4. Bino G, Dolev A, Yosha D, Guter A, King R, Saltz D, Kark S. Abrupt spatial and numerical responses of overabundant foxes to a reduction in anthropogenic resources. J Appl Ecol. 2010;47:1262–1271. https://doi.org/10.1111/j.1365-2664.2010.01882.x
5. Herr J, Schley L, Roper TJ. Socio-spatial organisation of urban stone martens. J Zool. 2009;277:54–62. https://doi.org/10.1111/j.1469-7998.2008.00510.x
6. Gosselink TE, Piccolo KA, Van Deelen TR, Warner RE, Mankin P. Natal dispersal and philopatry of red foxes in urban and agricultural areas of Illinois. J Wildl Manag. 2010;74(6):1204–1217. https://doi.org/10.2193/2009-108
7. Bascompte J, Solé RV. Habitat fragmentation and extinction thresholds in spatially explicit models. J Anim Ecol. 1996:465–473. https://doi.org/10.2307/5781
8. Amos W, Worthington WJ, Fullard K, Burg TM, Croxall JP, Bloch D, et al. The influence of parental relatedness on reproductive success. Proc R Soc Lond B Biol Sci. 2001;268:2021–2027. https://doi.org/10.1098/rspb.2001.1751
9. Skinner JD, Chimimba CT. The mammals of the southern African sub-region. 3rd ed. London: Cambridge University Press; 2005.
10. Jacques H, Reed-Smith J, Somers MJ. *Aonyx capensis*. In: The IUCN Red List of Threatened Species [online]. 2015:e.T1793A21938767. https://doi.org/10.2305/iucn.uk.2015-2.rlts.t1793a21938767.en
11. Reed-Smith J, Jacques H, Somers MJ. *Hydrictis maculicollis*. In: The IUCN Red List of Threatened Species [online]. 2015:e.T12420A21936042. https://doi.org/10.2305/iucn.uk.2015-2.rlts.t12420a21936042.en
12. Kubheka SP, Rowe-Rowe DT, Alletson JD, Perrin MR. Possible influence of increased riparian activity (stream modification and agricultural intensification) on abundance of South African otters. Afr J Ecol. 2013;51:288–294. https://doi.org/10.1111/aje.12033
13. Somers MJ, Nel JAJ. Habitat selection by the Cape clawless otter (*Aonyx capensis*) in rivers in the Western Cape Province, South Africa. Afr J Ecol. 2004;42:298–305. https://doi.org/10.1111/j.1365-2028.2004.00526.x
14. Lehoczky I, Dalton DL, Lanszki J, Sallai Z, Madisha MT, Nupen LJ, et al. Assessment of population structure in Hungarian otter populations. J Mammal. 2015;96:1275–1283. https://doi.org/10.1093/jmammal/gyv136
15. Beheler AS, Fike JA, Dharmarajan G, Rhodes OE Jr, Serfass TL. Ten new polymorphic microsatellite loci for North American river otters (*Lontra canadensis*) and their utility in related mustelids. Mol Ecol Notes. 2005;5:602–604. https://doi.org/10.1111/j.1471-8286.2005.01005.x
16. Pickles RSA, Groombridge JJ, Zambrana Rojas VD, Jordan WC. Cross-species characterisation of polymorphic microsatellite loci in the giant otter (*Pteronura brasiliensis*). Mol Ecol Resour. 2009;9:415–417. https://doi.org/10.1111/j.1755-0998.2008.02232.x
17. Guertin DA, Ben-David M, Harestad AS, Elliott JE. Fecal genotyping reveals demographic variation in river otters inhabiting a contaminated environment. J Wildl Manag. 2012;76:1540–1550. https://doi.org/10.1002/jwmg.439
18. Brzeski KE, Gunther MS, Black JM. Evaluating river otter demography using noninvasive genetic methods. J Wildl Manag. 2013;77:1523–1531. https://doi.org/10.1002/jwmg.610
19. Trinca CS, Jaeger CF, Eizirik E. Molecular ecology of the neotropical otter (*Lontra longicaudis*): Non-invasive sampling yields insights into local population dynamics. Biol J Linnean Soc. 2013;109:932–948. https://doi.org/10.1111/bij.12077
20. Gauteng Department of Agriculture and Rural Development (GDARD). Gauteng Provincial Environmental Management Framework (GPEMF): Environmental Management Framework report. Johannesburg: Department of Agriculture and Rural Development, Gauteng Province; 2014.
21. Rowe-Rowe DT. Survey of South African otters in a freshwater habitat, using sign. S Afr J Wildl Res. 1992;22:49–55.
22. Google. Google Earth version 7.1.2.2041. 7 November Gauteng, South Africa. 26°11'47.78"S 28°2'31.77"E. Eye alt 385 metres. DigitalGlobe; 2013.
23. South African Department of Water and Sanitation (DWS). The resource quality information services: South Africa 1:500 000 rivers. Pretoria: DWS; 2012. Available from: http://www.dwa.gov.za/iwqs/gis_data/river/All.zip
24. Somers MJ, Nel JA. Movement patterns and home range of Cape clawless otters (*Aonyx capensis*), affected by high food density patches. J Zool. 2004;262:91–98. https://doi.org/10.1017/s095283690300445x
25. Ben-David M, Blundell GM, Kern JW, Maier JAK, Brown ED, Jewett SC. Communication in river otters: Creation of variable resource sheds for terrestrial communities. Ecology. 2005;86:1331–1345. https://doi.org/10.1890/04-0783
26. QIAGEN. Isolation of DNA from stool for human DNA analysis. QIAamp® DNA stool handbook. Chatsworth, CA: QIAGEN Inc.; 2010. https://doi.org/10.1520/jfs2004428
27. McElwee B. The use of molecular scatology to study river otter (*Lontra canadensis*) genetics [dissertation]. Rochester, NY: Rochester Institute of Technology; 2008.
28. Madisha MT, Ponsonby D, Schwaibold U, Kotzé A, Jansen R, Brettschneider H, et al. Differentiation of two South African otter species (*Aonyx capensis* and *Lutra maculicollis*) from spraint based on partial *CytB* primer sets. Glob Ecol Conserv. 2015;4:8–13. https://doi.org/10.1016/j.gecco.2015.05.001
29. Dallas JF, Piertney SB. Microsatellite primers for the Eurasian otter. Mol Ecol. 1998;7:1248–1251.
30. Applied Biosystems. GeneMapper software version 4.0. Foster City, CA: Applied Biosystems; 2005.
31. Van Oosterhout C, Hutchinson WF, Wills DP, Shipley P. MICRO-CHECKER: Software for identifying and correcting genotyping errors in microsatellite data. Mol Ecol Notes. 2004;4:535–538. https://doi.org/10.1111/j.1471-8286.2004.00684.x
32. Chapuis MP, Estoup A. Microsatellite null alleles and estimation of population differentiation. Mol Biol Evol. 2007;24:621–631. https://doi.org/10.1093/molbev/msl191
33. Peakall R, Smouse PE. GENALEX 6: Genetic analysis in Excel. Population genetic software for teaching and research. Mol Ecol Notes. 2006;6:288–295. https://doi.org/10.1111/j.1471-8286.2005.01155.x
34. Peakall R, Smouse PE. GENALEX 6.5: Genetic analysis in Excel. Population genetic software for teaching and research – an update. Bioinformatics. 2012;28:2537–2539. https://doi.org/10.1093/bioinformatics/bts460
35. Rousset F. Genepop'007: A complete reimplementation of the Genepop software for Windows and Linux. Mol Ecol Resour. 2008;8:103–106. https://doi.org/10.1111/j.1471-8286.2007.01931.x
36. Pritchard JK, Stephens M, Donnelly P. Inference of population structure using multilocus genotype data. Genetics. 2000;155:945–959.
37. Earl DA, VonHoldt BM. STRUCTURE HARVESTER: A website and program for visualizing STRUCTURE output and implementing the Evanno method. Conserv Genet Resour. 2012;4:359–361. https://doi.org/10.1007/s12686-011-9548-7
38. Bohonak AJ. IBD (Isolation by distance): A program for analyses of isolation by distance. J Hered. 2002;93:153–154. https://doi.org/10.1093/jhered/93.2.153
39. Ritland K. Estimators for pairwise relatedness and individual inbreeding coefficients. Genet Res. 1996;67:175–185. https://doi.org/10.1017/s0016672300033620
40. Lynch M, Ritland K. Estimation of pairwise relatedness with molecular markers. Genetics. 1999;152:1753–1766. https://doi.org/10.2307/2409206
41. Queller DC, Goodnight KF. Estimating relatedness using genetic markers. Evolution. 1989;43:258–275.
42. Allendorf FW, Luikart G. Conservation and the genetics of populations. Oxford: Blackwell Publishing; 2007.

43. Serrouya R, Paetkau D, McLellan BN, Boutin S, Campbell M, Jenkins DA. Population size and major valleys explain microsatellite variation better than taxonomic units for caribou in western Canada. Mol Ecol. 2012;21:2588–2601. https://doi.org/10.1111/j.1365-294x.2012.05570.x

44. Williams BW, Scribner KT. Effects of multiple founder populations on spatial genetic structure of reintroduced American martens. Mol Ecol. 2010;19:227–240. https://doi.org/10.1111/j.1365-294x.2009.04455.x

45. Pickles RSA, Groombridge JJ, Zambrana Rojas VD, Van Damme P, Gottelli D, Ariani CV, et al. Genetic diversity and population structure in the endangered giant otter, *Pteronura brasiliensis*. Conserv Genet. 2012;13:235–245. https://doi.org/10.1007/s10592-011-0279-9

46. Zigouris J, Dawson FN, Bowman J, Gillett RM, Schaefer JA, Kyle CJ. Genetic isolation of wolverine (*Gulo gulo*) populations at the eastern periphery of their North American distribution. Conserv Genet. 2012;13:1543–1559. https://doi.org/10.1007/s10592-012-0399-x

47. Larson S, Jameson R, Etnier M, Jones T, Hall R. Genetic diversity and population parameters of sea otters, *Enhydras lutris*, before fur trade extirpation from 1741–1911. PLoS ONE. 2012;7, e32205, 10 pages. https://doi.org/10.1371/journal.pone.0032205

48. Hapeman P, Latch EK, Fike JA, Rhodes OE, Kilpatrick CW. Landscape genetics of fishers (*Martes pennanti*) in the Northeast: Dispersal barriers and historical influences. J Hered. 2011;102:251–259. https://doi.org/10.1093/jhered/esr001

49. Excoffier L, Ray N. Surfing during population expansions promotes genetic revolutions and structuration. Trends Ecol Evol. 2008;23:347–351. https://doi.org/10.1016/j.tree.2008.04.004

50. Latch EK, Heffelfinger JR, Fike JA, Rhodes OE. Species-wide phylogeography of North American mule deer (*Odocoileus hemonus*): Cryptic glacial refugia and postglacial recolonization. Mol Ecol. 2009;18:1730–1745. https://doi.org/10.1111/j.1365-294x.2009.04153.x

51. Brandt JR, Brandt AL, Ammer FK, Roca AL, Serfass TL. Impact of population expansion on genetic diversity and structure of river otters (*Lontra canadensis*) in central North America. J Hered. 2014;105:39–47. https://doi.org/10.1093/jhered/est069

52. Manel S, Gaggiotti OE, Waples RS. Assignment methods: Matching biological questions with appropriate techniques. Trends Ecol Evol. 2005;20:136–142. https://doi.org/10.1016/j.tree.2004.12.004

53. Dakin EE, Avise JC. Microsatellite null alleles in parentage analysis. Heredity. 2004;93:504–509. https://doi.org/10.1038/sj.hdy.6800545

54. Carlsson J. Effects of microsatellite null alleles on assignment testing. J Hered. 2008;99:616–623. https://doi.org/10.1093/jhered/esn048

55. McKinney ML. Urbanisation as a major cause of biotic homogenisation. Biol Conserv. 2006;127:247–260.

56. Bonier PRM, Martin PR, Wingfield JC. Urban birds have broader environmental tolerance. Biol Lett. 2007;3:670–673. https://doi.org/10.1098/rsbl.2007.0349

57. Matthysen E. Density-dependent dispersal in birds and mammals. Ecography. 2005;28:403–418. https://doi.org/10.1111/j.0906-7590.2005.04073.x

58. Lowry H, Lill A, Wong B. Behavioural responses of wildlife to urban environments. Biol Rev.2013;88:537–549. https://doi.org/10.1111/brv.12012

59. Baker PJ, Harris S. Urban mammals: What does the future hold? An analysis of the factors affecting patterns of use of residential gardens in Great Britain. Mamm Rev. 2007;37:297–315. https://doi.org/10.1111/j.1365-2907.2007.00102.x

60. Weir BS, Cockerham CC. Estimating F-statistics for the analysis of population structure. Evolution. 1984;38:1358–1370. https://doi.org/10.1111/j.1558-5646.1984.tb05657.x

AUTHORS:
Samson N. Ugwu[1]
Christopher C. Enweremadu[1]

AFFILIATION:
[1]Mechanical and Industrial Engineering, University of South Africa, Johannesburg, South Africa

CORRESPONDENCE TO:
Christopher Enweremadu

EMAIL:
enwercc@unisa.ac.za

DATES:
Received: 19 Sep. 2018
Revised: 08 May 2019
Accepted: 08 May 2019
Published: 30 July 2019

HOW TO CITE:
Ugwu SN, Enweremadu CC. Biodegradability and kinetic studies on biomethane production from okra (*Abelmoschus esculentus*) waste. S Afr J Sci. 2019;115(7/8), Art. #5595, 5 pages. https://doi.org/10.17159/sajs.2019/5595

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☒ Not applicable

EDITOR:
Teresa Coutinho

KEYWORDS:
biodegradability; methane production; kinetics; anaerobic digestion

FUNDING:
National Research Foundation (South Africa); The World Academy of Science (TWAS)

Biodegradability and kinetic studies on biomethane production from okra (*Abelmoschus esculentus*) waste

Emerging from the energy crisis of 2008 in South Africa, climate change concerns and the global desire to reduce high ozone-depleting emissions, renewable energy sources like biogas are gaining wide acceptance in most localities for heating and electricity. The paucity of feedstock varieties is a major challenge plaguing the sustainability of this sector. Biomethane potential, biodegradability and degradation kinetics of organic substrates are essential for assessing the suitability of feedstocks for methane generation and the overall performance of the anaerobic digestion process in biogas plants. Waste from the vegetable okra (*Abelmoschus esculentus*) is a novel substrate; its biodegradability and degradation dynamics in biomethane production are largely unstudied, and were therefore the aims of this research. The substrate was digested for 25 days at the mesophilic condition and the biomethane potential data were recorded. Measured data of methane yield and the elemental composition of the substrate were used to fit five models (modified Gompertz, Stannard, transference function, logistic and first-order models) to predict degradation parameters and determine biodegradability of the substrate, respectively. Low lag phase (0.143 d), positive kinetic constant (0.2994/d) and the model fitness indicator (<10) showed that transference and first-order kinetic models predicted the methane yield better than did other growth functions. The experimental methane yield was 270.98 mL/gVS, theoretical methane yields were 444.48 mL/gVS and 342.06 mL/gVS and model simulation ranged from 267.5 mL/gVS to 270.89 mL/gVS. With a prediction difference of 0.03–1.28%, all growth functions acceptably predicted the kinetics of *A. esculentus* waste. The findings of this study offer information on this novel substrate important for its use in large-scale biogas production.

Significance:

- Growing interest in biogas technology as an alternative energy source for both South African rural dwellers and industries, has mounted enormous pressure on known feedstocks, and instigated the search for novel substrates.
- Our study shows that okra waste is a viable feedstock for biogas production.
- The suitability of the first-order kinetic model over other models in predicting okra waste degradation was highlighted.

Introduction

Global concerns regarding the depletion rate of fossil fuel sources, their adverse impacts on the environment and the need to reduce the emission of greenhouse gases, have necessitated overwhelming interest in unconventional energy sources from biomasses and wastes.[1-3] Biogas technology is a renewable energy type, which combines sustainable waste management and efficient biofuel production.[4] This waste-to-energy (biogas) process is an established technology, but it has been underexploited in most developing climes like South Africa. According to the South African Biogas Industry Association[5] and Damm and Triebel[6], more than 2.328 million households (about 25% of all families in South Africa) use local fossil fuel sources like charcoal and firewood to meet their energy demands. The high cost and unavailability of electricity in most informal and rural settlements has increased both the demand for and development of biogas technologies.[7]

Anaerobic digestion is a clean energy recovery process of biogas production through the biological degradation of organic wastes in the absence of oxygen for the generation of methane.[8] This biomass degradation by microbes reduces the volume of waste and involves four phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis.[2,8,9]

According to Bharathiraja et al.[9], the low cost, availability and novelty of feedstocks are the incentives needed for more investment in biogas production. This has necessitated the aggressive search for future energy crops with potential for ensuring feedstock security, optimisation of existing biomass feedstocks as well as the technological enhancement of feedstock digestion processes.[9] Various efforts towards discovering novel biomass for biogas have been made. Adiga et al.[10], Patil et al.[11], Bai-Hang et al.[12] and Visva Bharati et al.[13] studied the enhancement of water hyacinth for biogas production. Anongnart et al.[14], Rodriguez et al.[15] and Kroger and Muller-Langer[16] noted that both micro- and macro-algae is a viable substrate for biogas production. Housagul et al.[17] and Aguilar-Aguilar et al.[18] investigated the use of glycerol from biodiesel industries, singly and in combination, for biogas production, while Li et al.[19] attempted to co-digest 33–53% spent cooking oil with food waste. Other novel substrates investigated include meadow grasses[20] and vegetables[21].

In countries such as China, over 200 million tons of about 700 million tons of vegetables produced annually ends up as residues and waste.[22] Okra (*Abelmoschus esculentus*) waste is a vegetable waste-type, which is largely novel and has thus far been unexploited for biogas production. Okra is mainly grown in Africa and India (96% of worldwide production[23]). Okra waste – like that of other vegetables and fruits – accounts for 40–50% of the 48.4%

total food waste globally, a significant volume across its processing value chain.[23] Duman et al.[24] stated that Turkey produces over 36 000 tons of okra per year and that the utilisation of okra waste has been studied as part of Turkey's development plan and vision. Okra and its stems are high in crude fibre, protein and fat; dired okra has about 25% crude fibre and 18% protein.[25] According to Alam and Khan[26], the entire crop waste contains 67.5% a-cellulose, 15.4% hemicellulose, 7.1% lignin, 3.4% pectin and 3.9% fat and waxes. Based on this composition, okra has high biomethane potential.

Biochemical methane potential (BMP), according to Raposo et al.[27] and Jingura and Kamusoko[28], is a simple but reliable procedure for determining maximum methane volume produced per gram of the substrate's volatile solid and indicates rate and extent of conversion of biodegradable organics to methane in an anaerobic digestion set-up. There are both experimental and theoretical BMP methods. Although the BMP of okra has not been studied, other vegetables and food wastes have been studied using Buswell's and modified Dulong's equations[29,30] with the elemental (carbon, hydrogen, nitrogen, sulphur and oxygen) compositions of substrates[22,30,31].

Kinetic modelling is an accepted method[32] to show the specific parameters of system performance. Experimental data are used in kinetic studies and results from these studies are often applied under the same conditions to estimate operational efficiencies of scaled-up reactors. Various kinetic model types, particularly first-order kinetic models, have been successfully used to simulate anaerobic digestion processes. Akin to the phase of bacterial growth, the rate of biomethane production showed a rising limb and a decreasing limb, which were indicated by exponential and linear equations.[19,33] In the past, numerous researchers have predicted biomethane production potential using modified Gompertz, logistic and first-order kinetic models[2,10,11,34,35], as well as sigmoidal models and other statistical models[19,33,36].

The variation in the characteristics of okra waste from place to place, based on agronomical differences and storage conditions before digestion, necessitates the evaluation of its kinetic properties. Fitting kinetic functions to the cumulative methane production curves obtained from the BMP process enables information on anaerobic process performance to be gathered. This information includes: whether the maximum methane yield (Bo) was attained, the maximum rate of methane production (R_{max}), the degradation rate constant (K) and the lag phase (λ) duration.[33] The accuracy of biogas yield prediction in the model is dependent on the substrate that is used as the feedstock.

This study was motivated by the huge amount of okra waste and its perceived high biomethane potential. We assessed the biodegradability and degradation kinetics of okra waste using both Buswell's and Dulong's theoretical BMP equations, and investigated the elemental composition of the substrate to the BMP assay and used the measured BMP data in five identified growth functions (modified Gompertz, Stannard, transference, logistic and first-order models). We also determined the suitability of these models for anaerobic digestion of okra waste.

Materials and method

Substrate and inoculum characterisation

Pods (fruits) of okra (*A. esculentus*) waste were collected from Organic Farm in Centurion (Gauteng Province, South Africa) and mechanically pretreated. Inoculum from an active digester at the University of Johannesburg was degassed and acclimatised at 37 °C before use.[31] The total solids (TS), volatile solids (VS), ash content and moisture content were measured using the standard gravimetric method (Method 1684 of the US EPA for Total, Fixed and Volatile Solids in Water, Solids, and Biosolids). The carbon (C), hydrogen (H), oxygen (O), sulfur (S) and nitrogen (N) contents were determined using a CHNS elemental analyser. Elemental composition (C, H, N, S) of the samples was determined using a LECO CHNS-932 combustion analyser (TruMac, Argon, LECO Corporation, St. Joseph, MI, USA) at 1050 °C, with sulfamethazine as a standard substrate in accordance with Raposo et al.[27]. Oxygen content was calculated by assuming C + H + O + N + ash = 99.5% (on a VS basis).[37] pH was measured using a pH meter (HI 9828 Multi-parameter, Hanna Instruments). All characterisation results are shown in Table 1.

Table 1: Proximate and ultimate analyses of samples

Properties	Inoculum	*Abelmoschus esculentus*
Initial pH	8.08±0.02	8.13±0.01
Final pH	7.68±0.01	8.15±0.02
Moisture content %	98.50±0.01	92.36±4.402
Ash content %	0.03±0.00	15.87±0.006
Total solids (TS) %	1.50±0.01	7.82±0.005
Volatile solids (VS) %	1.02±0.04	6.90±0.001
VS of TS %	68±0.01	88.36±4.402
Removed VS of TS %	89.5±0.00	76.06±0.12
Carbon% TS	NT	39.30±0.012
Hydrogen% TS	NT	5.39±0.003
Oxygen% TS	NT	35.74±0.003
Nitrogen% TS	NT	3.21±0.003
C/N ratio	NT	12.24±0.003

NT, not tested

Biomethane potential

The biomethane potential of okra waste process was performed in triplicate using the BMP assay (AMPTS II, Bioprocess Control, Sweden) with 500-mL reaction bottles at Bioprocess Laboratory, Mechanical and Industrial Engineering, University of South Africa, Florida Campus (Johannesburg, South Africa) as shown in Figure 1. Each reactor was filled to 400 mL of the total volume with the addition of 27.55 g okra based on 6.90% VS, 370.94 mL of inoculum (inoculum to substrate ratio was 2:1) and 1.51 mL of distilled water. Nitrogen gas (Afrox Gas, South Africa) was used to flush out oxygen from the reactors. The reactors were operated at mesophilic temperature (37±1 °C) for 25 days. The entire test was performed as stipulated by the AMPTS II standard operation manual. Results were retrieved from the data logging platform of the reactors and used for the calculation of daily biogas production, production rate and cumulative methane production, as shown in Table 2 and Figure 2.

Figure 1: Biomethane potential assay with the data acquisition system.

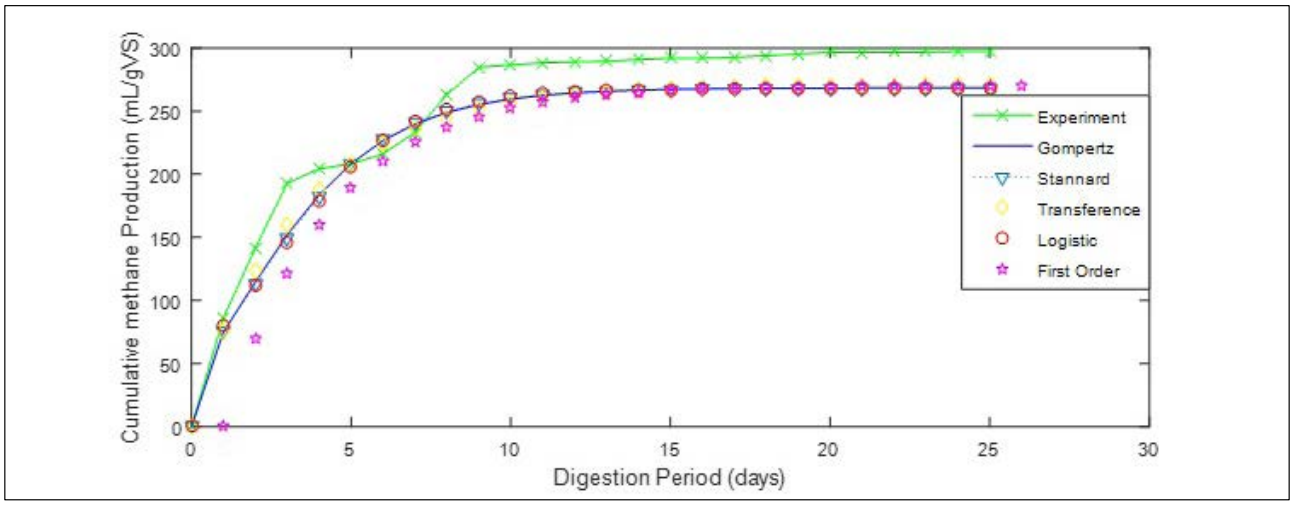


Figure 2: Cumulative biogas production based on experimental and kinetic modelling results.

Table 2: Summary of key energy production parameters

Parameter	Result
BMP (mL/gVS)	270.98
TBMP (mLCH_4/gVS)	444.48
$TBMP_{E*}$ (mLCH_4/gVS)	342.06
E* (MJ/kg) on %TS	14.63
E* (MJ/kgVS) on 88.36 %VS	12.93
BD (%)	60.97
BD_{E*} (%)	79.22
Substrate formula	$C_{14.3}H_{23.4}O_{9.8}N_1$

BMP, biomethane potential; TBMP, theoretical biomethane potential; E, energy; BD, biodegradability

Theoretical biomethane potential and biodegradability

Methane production potential and biodegradability of okra were estimated using two theoretical biomethane potential (TBMP) approaches – Buswell and modified Dulong formulae – based on okra's elemental composition.[29,30] The energy value of feedstock E* (okra) and its theoretical biomethane potential ($TBMP_{E*}$) were estimated using the modified Dulong equation. Boyles (modified Buswell) equation was used to determine the TBMP[38] and biodegradability was calculated as shown in Equations 1 to 5. TBMP was predicated based on the following assumptions[3]: ideal microbial condition and total substrate digestion; complete mixing and constant temperature; substrate composition limited to only C, H, O, N, S and output in the form of CH_4, CO_2, NH_3.

$$E^* = 337(C) + 1419\left(H - \tfrac{1}{8}O\right) + 93(S) + 23.26(N) \quad \text{Equation 1}$$

$$TBMP_{E^*} = \frac{E^*\ (base\ on\ \%VS)}{37.78} \quad \text{Equation 2}$$

$$C_nH_aO_bN_c + \left(n - \tfrac{a}{4} - \tfrac{b}{2} - \tfrac{3c}{4}\right)H_2O \rightarrow \left(\tfrac{n}{2} + \tfrac{a}{8} - \tfrac{b}{4} - \tfrac{3c}{8}\right)CH_4 + \left(\tfrac{n}{2} - \tfrac{a}{8} + \tfrac{b}{4} + \tfrac{3c}{8}\right)CO_2 + cNH_3 \quad \text{Equation 3}$$

$$TBMP = \frac{22400\left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{ac}{8}\right)}{12n + a + 16b + 14c} \quad \text{Equation 4}$$

$$BD_{CH4} = \frac{BMP}{TBMP} \times 100 \quad \text{Equation 5}$$

where E* is the energy value of the substrate (MJ/Kg); methane energy content = 37.78 MJ/m^3 at STP; CHONS = carbon, hydrogen, oxygen, nitrogen, sulfur (% TS); TBMP is the theoretical biomethane potential at STP ; and BD_{CH4} is the anaerobic biodegradability (%).

Kinetic models for biogas production

Non-linear regression analysis was performed using the curve-fitting tool in Matlab R2015b to evaluate the growth functions (modified Gompertz, Stannard, transference, logistic and first-order kinetic models) shown in Equations 6 to 10. The average measured cumulative methane production was used to evaluate the models; the model parameters and the goodness of fit are shown in Table 2 and Figure 2.

Modified Gompertz $$B = B_o Exp\left\{-Exp\left[\frac{R_{max}\cdot e}{B_o}(\lambda - t)\right] + 1\right\}$$ Equation 8

Stannard $$B = B_0\left\{1 + Exp\left[-\frac{(1+kt)}{p}\right]\right\}^{-p}$$ Equation 9

Transference $$B = B_0\left\{1 - Exp\left[\frac{R_{max}}{B_o}(t - \lambda)\right]\right\}$$ Equation 10

Logistic $$B = \frac{B_o}{\left\{1 + Exp\left[\frac{4R_{max}}{B_o}(t - \lambda) + 2\right]\right\}}$$ Equation 11

First-order $$B = B_0(1 - Exp(-kt))$$ Equation 12

where B is cumulative specific methane production (mL/gVS); B_o is maximum specific methane production potential (mL/gVS); R_{max} is the maximum specific methane production rate (mL/gVS- d); e is Exp(1)=2.718282; λ is the lag phase in days; k is the methane production rate constant (day^{-1}); t is digestion time (days); and p is slope of growth.

The kinetics of biogas production were evaluated using the five growth functions to determine the following parameters: B_o, B_0, k, λ, p, R^2, Adjusted R^2, R_{max} and root mean square error (RMSE). The entire experiment was performed in triplicate and the average of the three values was used. Minitab 15 was used for all statistical analyses and all inferences are at a 95% confidence.

Results and discussion

The ultimate and proximate properties of okra waste are shown in Table 1. A mass of 27.55 g was determined based on 7.8157 %TS and 6.8945 %VS. Although a high substrate VS/TS ratio of 88.36% was recorded, 76.06% of the substrate was removed during the anaerobic digestion process. This finding is in agreement with Li et al.[31] who reported a high VS/TS to be desirable for biogas yield. The waste showed a C/N ratio of 12.24, which was outside the ideal range of 15–30, thus necessitating co-digestion or nutrient enrichment.[31]

The experimental BMP assay gave a digestion period of 25 days, as shown in Figure 2. Okra waste resulted in a methane yield of 270.98 mL/gVS, which concurs with other reports of low yields from lignocellulosic vegetable wastes.[22,31] Theoretical biomethane potential (TBMP) and

Table 3: Kinetic parameters of average cumulative methane production curves

Parameter	Modified Gompertz	Stannard	Transference	Logistic	First-order
Measured biogas yield, $B_{(t)}$ (mL/gVS)	270.98	270.98	270.98	270.98	270.98
Predicted biogas yield, $B_{(P)}$ (mL/gVS)	268.38	267.99	270.89	267.50	270.15
Difference between $B_{(t)}$ and $B_{(p)}$ (%)	0.95	1.1	0.03	1.28	0.31
B_o (mL/gVS)	268.4	268.0	271.1	267.5	270.3
R_{max} (mL/gVS)	39.93	–	77.2	34.38	–
Lag phase, λ (days)	0.872	–	0.143	1.24	–
Degradation rate, K (per day)	–	1.449	–	–	0.2994
P	–	3.269	–	–	–
R^2	0.963	0.957	0.983	0.946	0.982
Adjusted R^2	0.96	0.953	0.982	0.941	0.981
RMSE	13.67	14.7	9.209	16.54	9.378

biodegradability (BD_{CH4}) calculated using Equations 1 to 5 using elemental and energy content of the substrate are shown in Table 2. TBMP based on elemental composition (444.48 mL/gVS) was higher than that obtained based on energy content (342.06 mL/gVS). BD_{CH4} based on elemental composition (60.97%) was lower than that based on energy content (79.22%). Raposo et al.[27] reported that $BD_{CH4}<70\%$ is considered an outlier or invalid. In view of this finding, TBMP based on energy content better satisfied the criterion. The low BD_{CH4} seen in elemental TBMP is consistent with the biodegradability of lignocellulosic vegetables.[22,31]

The measured and predicted methane production results, as well as the determined parameters, are shown in Figure 2 and Table 2. The cumulative measured biogas was 270.8 mL/gVS; the models predicted cumulative biogas to be 267.38, 267.99, 270.89, 267.50 and 270.15 mL/gVS, respectively, for modified Gompertz, Stannard, transference, logistic and first-order models. These values are consistent with the assertion of Raposo et al.[27], who recommended that the difference between B_o and B_t should not be more than 10%, above which this kinetic model is deemed invalid for predicting anaerobic digestion processes.

The lag phase (λ) of the growth functions, which is the time required for bacteria to adapt and start biogas production, is given in Table 3 and Figure 2. The values are 0.872, 0.143 and 1.24 for modified Gompertz, transference and logistic models, respectively. The low λ values found in this study are in line with the report of Talha et al.[39], who stated that lower lag phase is dependent on the activeness of the adapted inoculum and biodegradability of the organic part of the okra waste.

Most lignocellulosic substrates have cellulose as their main polymer component (about 68% in the case of okra). The hydrolysis rate of cellulose is normally the rate-limiting step, and the biomethane production rate is denoted by k.[40,41] The k-value of substrates can be determined via product formation (biomethane production or VFAs) and substrate depletion (VS, COD or DOC) methods.[42] In this study, biomethane production (the product formed) was used to compute the k-values of both Stannard and first-order models of 1.449/day and 0.2994/day, respectively. The k-values obtained were both high and positive, which, according to Dudek et al.[41], could be because of the higher bioavailability of cellulose, which results in a faster rate of biogas production.[34,35] This observation is in agreement with that of Veeken and Hamelers[43], namely that biomethane production represents the hydrolysis rate of bioavailable substrate which decreases with decreasing VS and can be best described with first-order kinetics.

Transference and first-order models best predicted okra waste digestion, with a prediction difference of 0.03% and 0.31%, respectively. This finding is consistent with the report of Kafle and Chen[36], who showed that the first-order kinetic model was found to be the best model for predicting BMP. Li et al.[19] reported that the transference model performed better than the modified Gompertz model. The statistical indicators of model fitness (as shown in Table 3), ranged from 0.946 to 0.983, 0.941 to 0.982 and 9.209 to 16.54 for R^2, Adj. R^2 and RMSE, respectively. In line with the report of Budiyono and Sumardiono[35], an RMSE value of <10 shows good model prediction. Based on this criterion, only transference and first-order kinetic models were within the accepted limit.

Conclusions

Experimental biomethane potential, biodegradability and degradation kinetics of okra waste were evaluated in this study using five growth functions. It was also shown that both energy content and elemental composition evaluation methods could be reasonably used to calculate TBMP and BD_{CH4} of okra waste. The goodness of fit, good predicted methane yield and lowest percentage prediction difference as observed showed that both transference and first-order models performed better than the other models evaluated. The positive kinetic constant and lower lag phase confirmed the high rate of degradation. Based on the goodness of fit, the logistic model performed the worst. Based on the substantial cumulative BMP yield of this novel substrate, further studies aimed at improving its biodegradability will be desirable.

Acknowledgements

This research was conducted with the financial assistance of the National Research Foundation (South Africa) and The World Academy of Sciences (TWAS) (grant NRF-TWAS-SFH160606168084). We thank Dr Masebinu for giving us the inoculum and Organic Farmers (Centurion, South Africa) for the okra waste.

Authors' contributions

S.N.U. was responsible for conceptualisation; methodology; data collection; data analysis; validation; initial draft. E.C.C. was responsible for project leadership and management; writing revisions and student supervision.

References

1. Shafiiee S, Topal E. When will fossil fuel reserves be diminished. Energy Policy. 2009;37:181–189. https://doi.org/10.1016/j.enpol.2008.08.016
2. Deepanraj B, Sivasubramanian V, Jayaraj S. Experimental and kinetic study on anaerobic digestion of food waste: The effect of total solids and pH. J Renew Sustain Energy. 2015;7(6), Art. #063104, 12 pages. https://doi.org/10.1063/1.4935559
3. Achinas S, Euverink GJW. Theoretical analysis of biogas potential prediction from agricultural waste. Resour Efficient Technol. 2016;2(3):143–147. https://doi.org/10.1016/j.reffit.2016.08.001

4. Ding HH, Chang S, Liu Y. Biological hydrolysis pretreatment on secondary sludge: Enhancement of anaerobic digestion and mechanism study. Bioresour Technol. 2017;244:989–995. https://doi.org/10.1016/j.biortech.2017.08.064

5. South African Biogas Industry Association (SABIA). Paper presented at: National Biogas Conference, Standards and Regulations; 2015 March 05; South Africa. Available from: www.energy.gov.za/files/biogas/2015-Biogas-Conference/Day-1/SABIA-Standards-and-Regulations-25March2015.pdf

6. Damm O, Triebel R. A synthesis report on biomass energy consumption and availability in South Africa. A report prepared for ProBEC [document on the Internet]. c2008 [cited 2008 Feb 10]. Available from: http://dev.ecoguineafoundation.com/uploads/5/4/1/5/5415260/biomass_energy_consumption_availability_sa.pdf

7. Muvhiiwa R, Hildebrandt D, Chimwani N, Ngubevana L, Matambo T. The impact and challenges of sustainable biogas implementation: Moving towards a bio-based economy. Energy Sustain Soc. 2017;7(20):1–11. https://doi.org/10.1186/s13705-017-0122-3

8. Lim JS, Manan ZA, Alwi SRW, Hashim H. A review on utilization of biomass from rice industry as a source of renewable energy. Renew Sustain Energy Rev. 2012;16(5):3084–3094. https://doi.org/10.1016/j.rser.2012.02.051

9. Bharathiraja B, Sudharsana T, Jayamuthunagai J, Praveenkumar R, Chozhavendhan S, Iyyappan J. Biogas production – A review of composition, fuel properties, feedstock and principles of anaerobic digestion. Renew Sustain Energy Rev. 2018;9(C):570–582. https://doi.org/10.1016/j.rser.2018.08.010

10. Adiga S, Ramya R, Shankar BB, Patil JH, Geetha CR. Kinetics of anaerobic digestion of water hyacinth, poultry litter, cow manure and primary sludge: A comparative study. In: Proceedings of the 2nd International Conference on Biotechnology and Environment Management. Int Proc Chem Biol Environ Eng. 2012;43:73–78.

11. Patil JH, Raj MA, Muralidhara PL, Desai SM, Raju GKM. Kinetics of anaerobic digestion of water hyacinth using poultry litter as inoculum. Int J Environ Sci Dev. 2012;3(2):94–98. https://doi.org/10.7763/ijesd.2012.v3.195

12. Bai-Hang Z, Jie C, Han-Qing Y, Zhen-Hu H, Zheng-Bo Y, Jun L. Optimization of microwave pretreatment of lignocellulosic waste for enhancing methane production: Hyacinth as an example. Front Environ Sci Eng. 2017;11(6):17. https://doi.org/10.1007/s11783-017-0965-z

13. Visva Bharati B, Vaibhav VG, Ajay SK. Microbial pretreatment of water hyacinth for enhanced hydrolysis followed by biogas production. Renew Energy. 2018;126:21–29. https://doi.org/10.1016/j.renene.2018.03.028

14. Anongnart W, Rameshprabu R, Kanda W, Yuwalee U. Potential improvement of biogas production from fallen teak leaves with co-digestion of microalgae. 3 Biotech. 2018;8(123):1–18. https://doi.org/10.1007/s13205-018-1084-7

15. Rodriguez C, Alaswad A, El-Hassan Z, Olabi AG. Waste paper and macroalgae co-digestion effect on methane production. J Energy. 2018;154(44):119–125. https://doi.org/10.1016/j.energy.2018.04.115

16. Kroger M, Muller-Langer F. Review on possible algal-biofuel production processes. Biofuels. 2012;3(3):333–349. https://doi.org/10.4155/bfs.12.14

17. Housagul S, Sirisukpoka U, Boonyawanich S, Pisutpaisal N. Biomethane production from co-digestion of banana peel and waste glycerol. In: Proceedings of the International Conference on Applied Energy – ICAE2014. Energy Procedia. 2014;61:2219–2223. https://doi.org/10.1016/j.egypro.2014.12.113

18. Aguilar-Aguilar FA, Nelson DL, Pantoja LA, Santos AS. Study of anaerobic co-digestion of crude glycerol and swine manure for the production of biogas. Rev Virtual Quim. 2017;9(6):2383–2403. https://doi.org/10.21577/1984-6835.20170142

19. Li Y, Jin Y, Borrion A, Li J. Influence of feed/inoculum ratios and waste cooking oil content on the mesophilic anaerobic digestion of food waste. Waste Manage. 2018;73:156–164. https://doi.org/10.1016/j.wasman.2017.12.027

20. Tsapekos P, Kougias PG, Egelund H, Larsen U, Pedersen J, Angelidaki I. Mechanical pretreatment at harvesting increases the bio-energy output from marginal land grasses. Renew Energy. 2017;111(C):914–921. https://doi.org/10.1016/j.renene.2017.04.061

21. Gaibor-Chávez J, Niño-Ruiz Z, Velázquez-Martí B, Lucio-Quintana A. The viability of biogas production and determination of bacterial kinetics in anaerobic co-digestion of cabbage waste and livestock manure. Waste Biomass Valor. 2019;10(8):2129–2213. https://doi.org/10.1007/s12649-018-0228-7

22. Yan H, Zhao C, Zhang J, Zhang R, Xue C, Liu G, et al. Study on biomethane production and biodegradability of different leafy vegetables in anaerobic digestion. AMB Express. 2017;7(1):27. https://doi.org/10.1186/s13568-017-0325-1

23. FAOSTAT. Okra, production quantity (tons) – for all countries. Rome: Food and Agriculture Organization of the United Nations; 2016. Available from: www.fao.org/faostat/en/#data/QC

24. Duman N, Kocak ED, Merdan N, Mistik I. Nonwoven production from agricultural okra wastes and investigation of their thermal conductivities. IOP Conf Ser Mater Sci Eng. 2017;254, 192007. https://doi.org/10.1088/1757-899x/254/19/192007

25. Olaniyan AM, Omoleyomi BD. Characteristics of okra under different process pretreatments and different drying conditions. J Food Proc Tech. 2013;4:237. https://doi.org/10.4172/2157-7110.1000237

26. Alam MS, Khan GM. Chemical analysis of okra bast fiber (*Abelmoschus esculentus*) and its physico-chemical properties. J Text Apparel Tech Manag. 2007;5(4), 9 pages. Available from: https://textiles.ncsu.edu/tatm/wp-content/uploads/sites/4/2017/11/Alam_Khan_full_229_07.pdf

27. Raposo F, Fernández-Cegrí V, De la Rubia MA, Borja R, Beline F, Cavinato C, et al. Biochemical methane potential (BMP) of solid organic substrates: Evaluation of anaerobic biodegradability using data from an international interlaboratory study. J Chem Tech Biotech. 2011;86(8):1088–1098. https://doi.org/10.1002/jctb.2622

28. Jingura RM, Kamusoko R. Methods for determination of biomethane potential of feedstocks: A review. Biofuel Res J. 2017;14:573–586. https://doi.org/10.18331/brj2017.4.2.3

29. Buswell AM, Mueller HF. Mechanism of fermentation. Ind Eng Chem.1952;44:2441–2460.

30. Browne JD, Murphy JD. Assessment of the resource associated with biomethane from food waste. Appl Energy. 2013;104:170–177. https://doi.org/10.1016/j.apenergy.2012.11.017

31. Li Y, Zang R, Liu G, Chen C, He Y, Liu X. Comparison of methane production potential, biodegradability, and kinetics of different organic substrates. Bioresour Technol. 2013;149:565–569. https://doi.org/10.1016/j.biortech.2013.09.063

32. Kafle GK, Kim SH. Kinetic study of the anaerobic digestion of swine manure at mesophilic temperature: A lab scale batch operation. J Biosyst Eng. 2012;37:233–244. https://doi.org/10.5307/jbe.2012.37.4.233

33. Ware A, Power N. Modeling methane production kinetics of complex poultry slaughterhouse wastes using sigmoidal growth functions. Renew Energy. 2017;104:50–59. https://doi.org/10.1016/j.renene.2016.11.045

34. Kafle GK, Kim SH, Shin BS. Anaerobic digestion treatment for the mixture of Chinese cabbage waste juice and swine manure. J Biosys Eng. 2012;37(1):58–64. https://doi.org/10.5307/jbe.2012.37.1.058

35. Budiyono IS, Sumardiono S. Kinetic model of biogas yield production from vinasse at various initial pH: Comparison between modified Gompertz model and first order kinetic model. Res J Appl Sci Eng Technol. 2014;7(13):2798–2805. https://doi.org/10.19026/rjaset.7.602

36. Kafle GK, Chen L. Comparison of batch anaerobic digestion of five different livestock manures and prediction of biochemical methane potential (BMP) using different statistical models. Waste Manag. 2016;48:492–502. https://doi.org/10.1016/j.wasman.2015.10.021

37. Rincón B, Heaven S, Banks CJ, Zhang Y. Anaerobic digestion of whole crop winter wheat silage for renewable energy production. Energy Fuels. 2012;26(4):2357–2364. https://doi.org/10.1021/ef201985x

38. Boyle WC. Energy recovery from sanitary landfills – a review. In: Microbial energy conversion: The proceedings of a seminar. Oxford: Pergamon Press; 1976. p. 119–138. https://doi.org/10.1016/b978-0-08-021791-8.50019-6

39. Talha Z, Hamid A, Guo D, Hassan M, Mehryar E, Okinda C, et al. Ultrasound assisted alkaline pre-treatment of sugarcane filter mud for performance enhancement in biogas production. Int J Agric Biol Eng. 2018;11(1):226–231.

40. Mao C, Wang X, Feng Y. Process performance and kinetic characteristic of anaerobic digestion focusing on swine manure content. In: Proceedings of the 2nd International Conference on Sustainable Development (ICSD 2016). Advances in Engineering Research Series. Paris: Atlantis Press; 2016. p. 81–84. https://doi.org/10.2991/icsd-16.2017.16

41. Dudek M, Swiechowski K, Manczarski P, Koziel JA, Białowiec A. The effect of biochar addition on the biogas production kinetics from the anaerobic digestion of brewers' spent grain. Energies. 2019;12, Art. #1518, 22 pages. https://doi.org/10.3390/en12081518

42. Angelidaki I, Sanders W. Assessment of the anaerobic biodegradability of macropollutants. Rev Environ Sci Bio Technol. 2004;3:117–129. https://doi.org/10.1007/s11157-004-2502-3

43. Veeken A, Hamelers B. Effect of temperature on hydrolysis rates of selected biowaste components. Bioresour Technol. 1999;69(3):249–254. https://doi.org/10.1016/s0960-8524(98)00188-6

AUTHOR:
Jacques Bezuidenhout[1]

AFFILIATION:
[1]Faculty of Military Science, Stellenbosch University, Stellenbosch, South Africa

CORRESPONDENCE TO:
Jacques Bezuidenhout

EMAIL:
jab@ma2.sun.ac.za

DATES:
Received: 12 Nov. 2018
Revised: 13 Mar. 2019
Accepted: 13 Mar. 2019
Published: 30 July 2019

HOW TO CITE:
Bezuidenhout J. Estimation of radon potential through measurement of uranium concentrations in granite geology. S Afr J Sci. 2019;115(7/8), Art. #5768, 4 pages. https://doi.org/10.17159/sajs.2019/5768

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☐ All data included
☒ On request from author(s)
☐ Not available
☐ Not applicable

EDITORS:
Nicolas Beukes
Yali Woyessa

KEYWORDS:
soil uranium; indoor radon concentrations; in-situ measurements; radon exhalation rate; radon potential map; Cape Granite Suite

FUNDING:
None

Estimation of radon potential through measurement of uranium concentrations in granite geology

The geology of an area can be used as a predictor for radon potential. Granite rock typically contains a high concentration of uranium and subsequent elevated emanation of radon gas. The geology of the western part of the Western Cape Province in South Africa is dominated by granite bedrock but very few studies on radon have been conducted in this area. Uranium concentrations were consequently measured on a large granite hill in the Saldanha Bay area of the Western Cape and a relationship between indoor radon and uranium concentrations was used to model radon potential on the outcrop. Results from granite rich environments in India were modelled in order to extract a relationship between indoor radon concentrations, radon exhalation rates and uranium concentrations. Radon exhalation rates greater than 0.35 Bq/m^{2}h were predicted and estimated indoor radon concentrations in excess of 400 Bq/m^3 were also predicted for the hill. The modelled results were compared with indoor radon measurements taken in the town of Paarl in the Western Cape, which sits on the same granite bedrock formation. The predicted radon potential correlated well with the physical measurements.

Significance:

- Extensive in-situ uranium measurements were conducted by utilising a self-developed gamma-ray detection instrument (the GISPI) by means of a unique method.

Introduction

The dominant naturally occurring nuclides are uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). These nuclides are all of primordial origin. Uranium and thorium decay through long chains of progeny before reaching stable nuclides. Radium (^{226}Ra) is a long-lived daughter in the progeny of uranium and is followed by radon (^{222}Rn). Radon has a half-life of 3.82 days and occurs as a gas at atmospheric conditions. Radon readily escapes the parent material and distributes fairly easy. Radon gas has been identified as the dominant contributor to human exposure to radiation; the World Health Organization has reported that radon is the second largest carcinogen in lung cancer, second only to cigarette smoke.[1] According to the International Commission for Radiological Protection and the International Atomic Energy Agency, concentrations of radon in dwellings are recommended to be below 300 Bq/m^3.

Granite typically contains high concentrations of naturally occurring nuclides. The elevated concentrations of uranium in granite subsequently contribute to high concentrations of radon. Because of these high radon concentrations, people living in granite rich environments would also be exposed to higher concentrations of radon. Risk assessment studies based on radon potential in such areas are essential.[2] The geology of the western part of the Western Cape Province of South Africa is dominated by the so-called Cape Granite Suite. The western terrane of the Cape Granite Suite stretches from Saldanha Bay in the northwest through the town of Paarl to Franschhoek in the southeast.[3] Several other towns and villages have also developed amongst the exposed granite outcrops of this terrane. Research has further established that the upper layers of soil in the alluvial fans at some of these granite outcrops mainly consist of weathered granite rock.[4] The emanation of radon in the greater part of this area has never been investigated. The aim of this study was therefore to model, estimate and compare radon potential in the western part of the Western Cape in order to determine the possible exposure and risk to the local population in towns in the area.

Method

Study area and measurements

A large granite outcrop named Baviaansberg was selected as the study area. Baviaansberg was selected as it is relatively undisturbed by human activities and lies on the same granite complex as the town of Paarl, making comparison possible. The study area was firstly demarcated into measurement squares over a 1:50 000 map of the area. The centre of each square in the grid was predetermined with a fishnet grid function of ArcMap software. The size of each square within the grid was 48.6 m (latitudinal) and 47.6 m (longitudinal). These centres were used as measuring positions but they were shifted within the square if the position was obscured by rocks. A measuring time of 5 min was allocated for the Global Positioning System (GPS) position acquisition and gamma-ray detection. These two measurements were made concurrently within the 5-min period, which was adequate time to acquire data for both measurements. All the measurements were taken during the dry summer months to prevent any effect of moisture on gamma radiation.[5]

Equipment

The system used for in-situ measurements was similar to that used previously.[4] A 7.62 cm x 7.62 cm sodium iodide (NaI(Tl)) scintillation crystal was coupled to a scintiSPEC Multi-Channel Analyser (MCA) that was manufactured by FLIR®.[6] The scintiSPEC MCA was connected to a Trimble Yuma Rugged tablet computer[7] via a USB cable. The Yuma was equipped with an on-board GPS that provided position in the field. The scintiSPEC MCA was operated by means of winTMCA32 software with 1024 energy channels, also developed by FLIR®. The detection set-up is displayed in Figure 1. The radiation data were stored in energy spectra and the accompanying GPS positions were also noted.

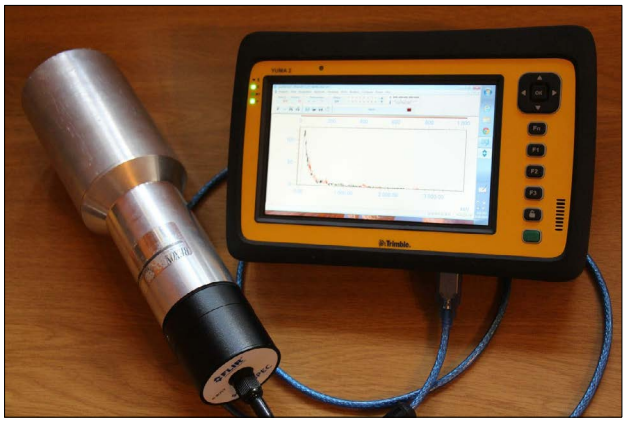


Figure 1: The NaI(Tl) scintillation detector with a 7.62 x 7.62 cm crystal coupled to the scintiSPEC Multi-Channel Analyser and connected to the Trimble Yuma Rugged tablet computer via the USB connection.

Calibration and analyses

Regular energy calibrations were performed on the system using ^{137}Cs, ^{60}Co and the known naturally occurring radionuclides. The instrument was also monitored for energy drift, which could occur due to variations in the ambient temperature. Efficiency calibration spectra were acquired at calibration pads of the Nuclear Energy Corporation of South Africa.[8] The calibration pads consist of three solid concrete cylinders, uniformly mixed with potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th), respectively. The measuring equipment was used to obtain standard spectra at the pads for each of the three nuclides. These spectra were then fitted to the in-situ spectra and a full spectrum analysis method (described by Hendriks et al.[9] and Geyser[10]) was followed in order to extract the natural occurring nuclide concentrations. A uranium concentration map was then constructed from the data. The statistical uncertainty was determined by applying the Poisson statistical distribution to the data. The average statistical uncertainty was estimated at 23.9%.

Construction of a radon potential map

Radon potential in the study area was estimated by linking the indoor radon concentrations to the measured uranium concentrations in the soil on Baviaansberg. Smethurst et al.[11] noted that the relationship between indoor radon and uranium concentrations depends on the characteristic of the geographical locations. The Tusham Ring Complex and the Himachal Pradesh region of India were consequently selected to determine these relationships because of the geographical similarity of these regions to the study area.

The relation between the indoor radon concentration and the radon exhalation rate (E_A) was extracted by using measured data from the Himachal Pradesh region of India[12] (Figure 2).

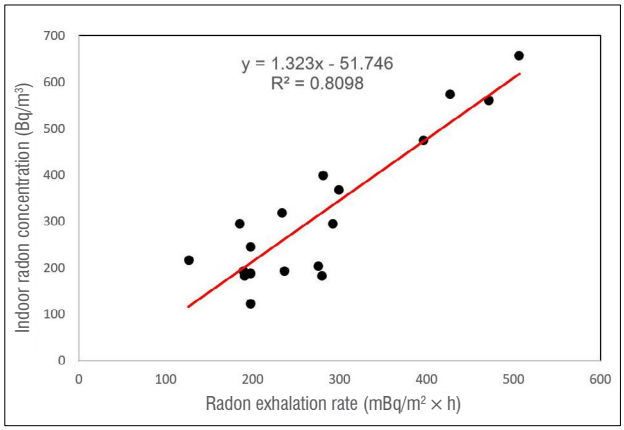


Figure 2: Indoor radon concentration as a function of radon exhalation rate measured from the Himachal Pradesh region.

This relationship was then applied to radon exhalation rates of the Tusham Ring Complex[13] and the indoor radon concentrations were estimated for the Complex. The estimated indoor radon concentrations were plotted against measured uranium concentrations in the granitic soil and rock of the Tusham Ring Complex and a relationship between these parameters was extracted (Figure 3a). The uranium concentrations in this study were determined by applying the fission track registration technique to soil samples.[14]

The extracted relationships between indoor radon concentrations and uranium concentrations from the Himachal Pradesh and Tusham Ring Complex were compared with radon build-up calculations that were done on the radon exhalation rates of the Tusham Ring Complex. The radon exhalation rate and the uranium concentrations of rock and soil were measured in the Tusham Ring Complex by Singh et al.[13] The radon exhalation rates and the uranium concentrations of soil samples were determined using the can[15] and fission track registration techniques, respectively. These measured radon exhalation rates were used to estimate indoor radon concentrations through the same method that was applied by Al-Jarallah[16]. A cuboid volume (3 m x 3 m x 2 m) was used as standard for the estimation. The estimated indoor radon concentrations were then plotted as a function of the uranium concentrations and a linear relationship was extracted (Figure 3b). This relationship compared reasonably well with the one that was extracted from the Himachal Pradesh measurements.

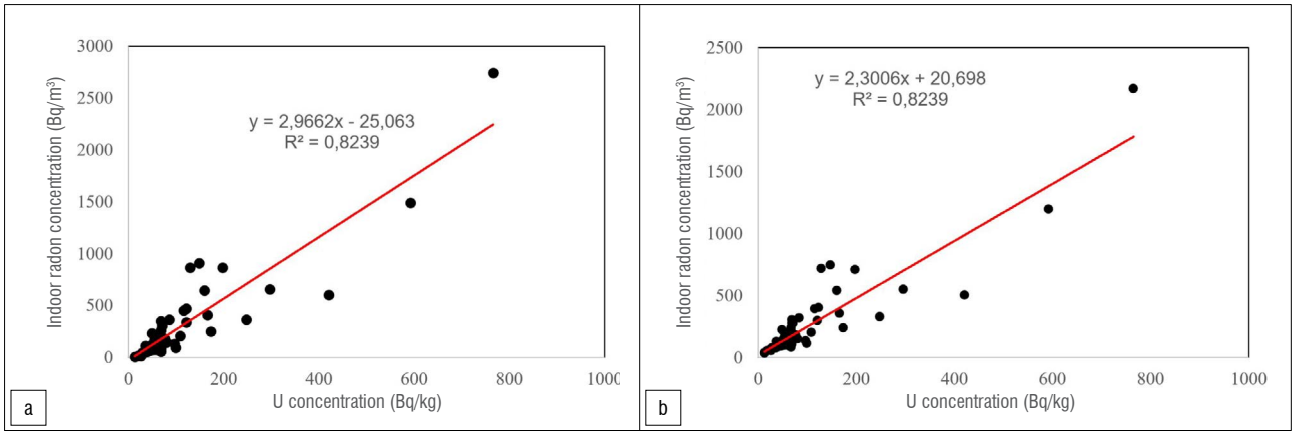


Figure 3: Indoor radon concentration as a function of uranium concentration in the Tusham Ring Complex of India. Indoor radon concentrations were (a) estimated from radon exhalation rates by means of the relationship identified from Figure 2 and (b) calculated from radon exhalation rates for the Tusham Ring Complex.

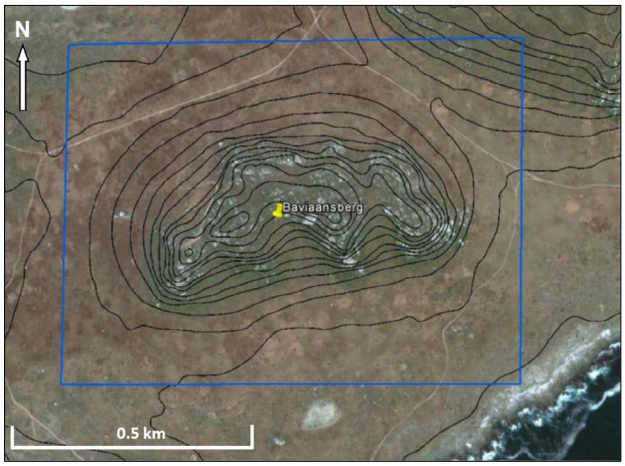


Figure 4: Google Earth image of Baviaansberg, with the topography map overlaid. The study area is indicated by a blue square.

The result that was extracted from the calculations with the standard volume compared well with the result from the empirical data. The initial relationship that was extracted from the empirical data was therefore used to relate the indoor radon concentrations and the uranium concentrations of the study area. This relationship was employed to estimate indoor radon potential, similarly to the method used by Smethurst et al.[11] The uranium concentrations and indoor radon potentials were interpolated and mapped using ArcGIS and QGIS software. The results for the study area were compared to indoor radon measurements taken in Paarl.

Results and discussion

The topography of Baviaansberg is overlaid on a Google Earth image in Figure 4. It is evident that the steeper slopes are mainly confined to the southern side of the hill, most likely as a result of the dominant southerly onshore winds of the region. These steeper slopes are also characterised by exposed granite outcrops which are observable as white spots on the Google Earth image. Smaller granite outcrops are also visible on the northern, less steep slopes on the hill.

Figure 5 shows an overlay of interpolated uranium concentrations on a topographic map. The interpolation between the measured points was done by means of kriging. High concentrations of uranium are mainly confined to the steeper slopes, but some elevated concentrations also occur on the nearby flatter areas.

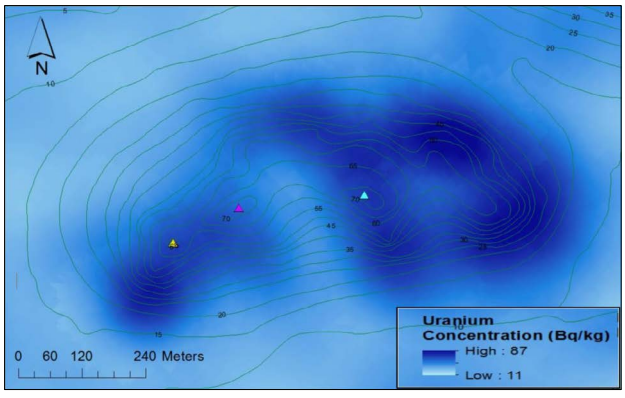


Figure 5: Uranium concentration overlaid on a topographic map of Baviaansberg.

The estimated radon concentrations were interpolated by means of a heat map and overlaid on a Google Earth image of Baviaansberg (Figure 6). High radon potential coincided mainly with the steepest slopes of the hill, when compared to the topographic overlay. This high radon potential also corresponds to the areas within the vicinity of exposed granite outcrops. The dark red areas in Figure 5 are areas where the radon exhalation rate is estimated to be higher than 0.35 Bq/m^{2}h. If there were buildings in these areas and they were occupied similarly to those in Himachal Pradesh and Tusham in India, it is estimated that the indoor radon might exceed 400 Bq/m^3.

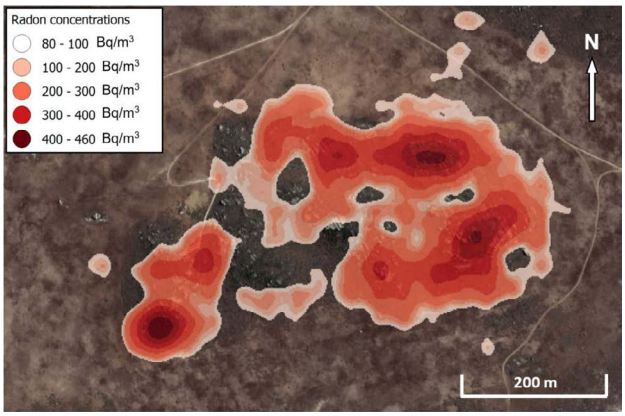


Figure 6: Heat map of the estimated radon potential overlaid on a Google Earth image of Baviaansberg.

The areas of high radon potential, however, also consistently extend beyond the granite outcrops into the less steep foot of the hill. The summit of Baviaansberg and the surrounding area demonstrate no elevated radon potential. It has been previously[4] shown that some slopes of the hills in the area consist of granitic soils, most probably due to weathering of the parent rock and subsequent aeolian and alluvial disposition in its proximity. This geology would explain the high estimated radon potential below the granite outcrop in the study area. The radon potential was directly related to the uranium concentrations, irrespective of soil type. It should, however, be noted that finer grained soil would more readily support radon escape because of its larger exposed active areas.

Granite outcrops found in Paarl are similar to those found in the study area and the granite in Paarl and Baviaansberg originates from the same geological unit.[17] Results of the measurements that were performed in the granite rich areas of Paarl are given in Table 1.[2] These results show that in about 6% of the houses in Paarl, indoor radon concentrations exceed 300 Bq/m^3. This finding correlates well with the estimated radon potential on Baviaansberg, which predicted that 5.7% of the points would exceed 300 Bq/m^3. It is therefore reasonable to conclude that similar levels of radon potential would occur in other towns in the area and that a possible radon hazard does exist. This conclusion, however, needs to be confirmed with more indoor radon measurements, which are planned for various towns in the region. The method that is described in this study for the estimation of radon potential can be used elsewhere to rapidly and remotely identify areas subjected to possible radon hazards.

Table 1: A distribution of the indoor radon concentrations in the granite areas of Paarl[2]

Radon concentration (Bq/m^3)	Fraction of houses
<100	0.44
100 – 200	0.42
200 – 300	0.08
300 – 400	0.03
>400	0.03

References

1. Pavia M, Bianco A, Pileggi C, Angelillo F. Meta-analysis of residential exposure to radon gas and lung cancer. Bull World Health Organ. 2003;81(10):732–738.
2. Lindsay R, Newman RT, Speelman WJ. A study of airborne radon levels in Paarl houses (South Africa) and associated source terms, using electret ion chambers and gamma-ray spectrometry. Appl Radiat Isot. 2008;66(11):1611–1614. https://doi.org/10.1016/j.apradiso.2008.01.022

3. Scheepers R, Armstrong RA. New U-Pb SHRIMP zircon ages of the Cape Granite Suite: Implications for the magmatic evolution of the Saldania Belt. S Afr J Geol. 2002;105:241–256. https://doi.org/10.2113/1050241

4. Bezuidenhout J. Mapping of historical human activities in the Saldanha Bay Military Area by using in situ gamma ray measurements. Scientia Militaria. 2012;40(2):89–101. https://doi.org/10.5787/40-2-998

5. Jones WK, Carroll TR. Error analysis of airborne gamma radiation soil moisture measurements. Agric Meteorol. 1983;28:19–30. https://doi.org/10.1016/0002-1571(83)90020-1

6. FLIR Systems Inc. [webpage on the Internet]. Nashua, NH: FLIR Systems [updated 2018; cited 2018 Sep 06]. Available from: http://www.flir.com/

7. Trimble Inc. [webpage on the Internet]. Sunnyvale, CA: Trimble Inc. [updated 2018; cited 2018 Sep 06]. Available from: http://www.trimble.com

8. Corner B, Toens PD, Richards DJ, Van As D, Vleggaar CM. The Pelindaba facilities for calibrating radiometric field instruments. No. PEL-268. Pretoria: Atomic Energy Board; 1979.

9. Hendriks PH, Limburg J, De Meijer RJ. Full-spectrum analysis of natural gamma-ray spectra. J Environ Radioact. 2001;53(3):365–380. https://doi.org/10.1016/S0265-931X(00)00142-9

10. Geyser AP. The influence of geographical factor on the distribution of natural radionuclides [MMil thesis]. Stellenbosch: Stellenbosch University; 2017.

11. Smethurst MA, Watson RJ, Baranwal VC, Rudjord AL, Finne I. The predictive power of airborne gamma-ray survey data on the locations of domestic radon hazards in Norway: A strong case for utilizing airborne data in large-scale radon potential mapping. J Environ Radioact. 2017;166:321–340. https://doi.org/10.1016/j.jenvrad.2016.04.006

12. Singh S, Kumar A, Singh B. Radon level in dwellings and its correlation with uranium and radium content in some areas of Himachal Pradesh, India. Environ Int. 2002;28:97–101. https://doi.org/10.1016/S0160-4120(02)00012-0

13. Singh H, Singh J, Singh S, Bajwa BS. Radon exhalation rate and uranium estimation study of some soil and rock samples from Tusham ring complex, India using SSNTD technique. Radiat Meas. 2008;43:459–462. https://doi.org/10.1016/j.radmeas.2008.04.060

14. Fleischer RL, Price PB, Walker RM. Nuclear tracks in solids: Principles and applications. Berkeley, CA: University of California Press; 1975. p. 489–495.

15. Khan AJ, Prasad R, Tyagi RK. Measurement of radon exhalation rate from some building materials. Nuclear Tracks Radiat Meas. 1992;20:609–610. https://doi.org/10.1016/1359-0189(92)90013-L

16. Al-Jarallah M. Radon exhalation from granites used in Saudi Arabia. J Environ Radioact. 2001;53:91–98. https://doi.org/10.1016/S0265-931X(00)00110-7

17. Clemens JD, Stevens G. The Saldanha Bay Volcanic Complex: Clarifying the Cambrian geology of the Postberg - Saldanha Area, West Coast, South Africa. S Afr J Geol. 2016;119(2):347–358. https://doi.org/10.2113/gssajg.119.2.347