South African Journal *of* Science

volume 114
number 1/2

Giraffe tracks in Late Pleistocene aeolianites on the Cape south coast

Palaeodemographics of individuals in Dinaledi Chamber

Mrs Ples and sexual dimorphism in *Australopithecus africanus*

Indigenous knowledge of edible termites in Limpopo Province

ASSAf
ACADEMY OF SCIENCE OF SOUTH AFRICA

Volume 114
Number 1/2
Jan/Feb 2018

South African Journal of Science

eISSN: 1996-7489

Leader

News & Views

Book Review

Scientific Correspondence

Commentary

Research Article

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: admin@sunbloem.co.za

Correspondence and enquiries
sajs@assaf.org.za

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

Cover caption
Ancient giraffe tracks perched above the Indian Ocean east of Still Bay (photo: Jan De Vynck). In an article on page 67, Helm and colleagues explore the unexpected discovery of these fossil giraffe tracks far from the area in which giraffe have previously been known to occur.

Developing young scientists. Really?

Delivering the keynote address at the third Science Forum South Africa on 7 December 2017, Deputy President Cyril Ramaphosa placed considerable emphasis on the importance of developing young scientists as drivers of growth and innovation. To do so is important not just for the well-being of young people (in reaching their dreams), he told his audience, but for the well-being of South Africa and the continent – for the success of the National Development Plan, the United Nations' Sustainable Development Goals, the general enhancement of science and knowledge and (among many other issues) food security.

Two days later, *The Economist* carried a startling cover: a flag-patterned snake, pronouncing 'The corruption of South Africa' and pointing out, in its major leader, that

> *Under President Jacob Zuma, the state is failing. Contracts are awarded through bribes and connections; ruling party members murder each other over lucrative government jobs; crooks operate with impunity.*[1]

And in the time between, on 8 December, the South African High Court in Pretoria ruled that the country's National Director of Public Prosecutions must vacate his position, as his appointment had been made by a 'conflicted' President Zuma. The Court further ruled that the Deputy President must appoint the National Director's successor.

In such a daunting context, what foundations need to be in place to develop young scientists? There are three essentials – fundamental preconditions for ensuring that South Africa is able to develop young scientists (or young economists, or new teachers, for that matter) – which are: a pipeline of well-educated children who will become the next generation of knowledge producers; a set of strong appropriate institutions; and serious investment in research. Do we, as a country, have these three pre-requisites in place?

The pipeline? There is, of course, a pipeline of young people who will leave school well-educated and in line to be scientists, economists, teachers, and other essential role players in the national economy. But it is a severely restricted pipeline that, inevitably, excludes the hundreds of thousands of young people who should be well-educated and should be potential contributors to the country's success but who are not and who will not be. The most recent Progress in International Reading Study (PIRLS), undertaken in 2016, reveals that 78% of South African Grade 4 learners (that is, 10 to 11 year olds) cannot read for meaning – the lowest score in the PIRLS results worldwide. This means that they are unable to locate and retrieve explicitly stated information or make straightforward inferences about events and reasons for actions reported in texts.

Numeracy studies undertaken with Grade 5 and Grade 9 learners the year before the PIRLS research (i.e. 2015) by the Trends in International Mathematics and Science Study are revealing. For Grade 5 learners, South Africa was placed 47th out of 48 participating countries; Grade 9 learners placed South Africa at 38th of 39 countries in the study. What is worse is that the results within South Africa are differentiated by geographical and social factors (translating most often into ethnicity), meaning that the largest proportion of the underperforming students are also the most deserving of opportunities after school. In short, the pipeline is both restricted and discriminatory – and severely ill-suited to developing young people who seek to gain valued skills.

Strong, appropriate institutions? Francis Fukuyama makes the importance of strong institutions in society clear:

> *…if you don't get the politics right – and by politics I don't just mean the short-term political decisions, but the actual institutions around which societies are organised – then you're not going to have economic growth, you are not going to have the right kind of social development and you're not going to have a just society.*[2]

These *actual institutions* are, amongst others, the institutions established under Chapter 9 of the South African Constitution – and, of course, universities. Jonathan Jansen is of the view that South African universities face a range of challenges that, if not addressed, will change their nature for the worse.[3] The issue of fees versus free education (and hence the matter of institutional income) has been so defectively managed at the very highest levels that some universities will face the prospect of no or very limited income for the first quarter of this year. In short, universities face both intellectual and material challenges that do not auger well for their strength unless there are major shifts away from current trends and circumstances.

Serious investment in research? South Africa has one of the lowest levels of public investment in research among comparable countries – in 2015 the expenditure amounted to 0.77% of GDP which accounted for about 43% of gross expenditure on research and development (GERD). By way of comparison, the Turkish GERD stands at 1.06% of GDP while for China the figure is 2.07%. The local figure by contrast is low – and the National Research Foundation (NRF) recently drastically cut its funding for rated researchers, by as much as 90% in some instances, claiming that the funds were never intended to be real research monies but incentives to encourage scientists to apply for rating. Some research projects or plans have been thrown into disarray, students associated with funded research projects will no longer receive support for their degrees next year, and other funders who have given money on the grounds that the NRF is providing some of what is needed will have to be placated. Universities are scrambling for a helpful response, and a wide spread sense of demoralisation and anger has set in.

Funding aimed at expanding serious scientific research and new knowledge, some of which can be applied to improve social and economic conditions in the country therefore remains limited and highly contested. This funding is also then not benefitting a new generation of young scientists.

All told, then, none of the three foundations needed to enable the development of science and scientists is securely in place. Of the three, only one (investing in research and development) falls to the state department – the Department of Science and Technology – that works consistently to change these adverse circumstances. For the rest, it is the general condition of gloom that currently prevails.

References

1. The choice that could save South Africa, or wreck it. The Economist. 2017 December 9. Available from: https://www.economist.com/news/leaders/21732114-avoid-dire-two-decade-dynasty-dysfunction-south-africas-ruling-anc-should-ditch
2. Fukuyama F. The origins of political order. Mapungubwe Institute for Strategic Reflection Public Lecture 2013. Available from: http://www.mistra.org.za/Media/Speeches/Pages/The-Origins-of-Political-Order-by-Francis-Fukuyama.aspx
3. Jansen J. As by fire: The end of the South African university. Cape Town: Tafelberg; 2017.

HOW TO CITE: Butler-Adam J. Developing young scientists. Really? S Afr J Sci. 2018;114(1/2), Art. #a0256, 1 page. http://dx.doi.org/10.17159/sajs.2018/a0256

Ancient human DNA: How sequencing the genome of a boy from Ballito Bay changed human history

AUTHORS:
Marlize Lombard[1]
Mattias Jakobsson[1,2,3]
Carina Schlebusch[1,2]

AFFILIATIONS:
[1]Centre for Anthropological Research & Department of Anthropology and Development Studies, University of Johannesburg, Johannesburg, South Africa
[2]Department of Organismal Biology, Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden
[3]SciLife Lab, Uppsala, Sweden

CORRESPONDENCE TO:
Marlize Lombard

EMAIL:
mlombard@uj.ac.za

KEYWORDS:
human genome; hunter–gatherer; *Homo sapiens*; population split-time estimations

HOW TO CITE:
Lombard M, Jakobsson M, Schlebusch C. Ancient human DNA: How sequencing the genome of a boy from Ballito Bay changed human history. S Afr J Sci. 2018;114(1/2), Art. #a0253, 3 pages. http://dx.doi.org/10.17159/sajs.2018/a0253

Being able to extract DNA and then sequence the full genomes of ancient human remains from tropical coasts is often considered precarious because of the warm, humid climate. Yet, we have now demonstrated the successful sequencing of full genomes (i.e. gaining the information of all chromosomes – including autosomes, X-chromosomes, Y-chromosomes and mitochondrial DNA) obtained from Stone Age human remains found along the tropical east coast of southern Africa.[1] With a minimalist sampling strategy, causing the least amount of morphological damage, we sequenced genome-wide data from three sets of approximately 2000-year-old human remains found 60 years ago on the Ballito and Doonside beaches of KwaZulu-Natal, South Africa. One set of remains – those of a young boy (Figure 1) – yielded a remarkably complete genome, where every position was covered by sequenced DNA (on average) 13 times.[1]

Photo: ©Susan Pfeiffer, University of Toronto, Canada; courtesy of the KwaZulu-Natal Museum, Pietermaritzburg.

Figure 1: The approximately 2000-year-old skull and mandible of the boy from Ballito Bay.

In contrast to approaches targeting a limited number of markers found polymorphic in some modern populations,[2,3] whole genome-sequence data from ancient remains include the complete and unbiased genetic information carried by an individual. The data potentially also incorporate genetic variants unique to the individual or population. The approach thus allows for direct population genetic analyses of prehistoric individuals, using information on mutations and frequency spectra[4], such as population split-time estimations[1], genetic diversity estimates[5], and changes in effective population size through time[6]. With increasing numbers of complete, modern-day human genomes becoming available[7], direct comparison of the entire inherited material will become the norm for population genomic analyses[4,8], assuring that every possible position in the genomes of ancient individuals can be used for genetic inferences.

Separating the different types of genetic data might be difficult for non-specialists. For instance, Morris recently noted 'at least two different methodologies that produce different success rates and differing levels of data volume', and highlighted the risks with multiple replicate sampling of ancient human remains.[9] Yet, every individual carries a specific genome, and the only way to access all its information is to sequence the entire genome, which can be accomplished with a single, small sample. Other types of investigations – such as Y-chromosome, mitochondrial DNA or SNP-capture (single nucleotide polymorphism) approaches – harness only a subset of the genetic information in the genome, with various degrees of bias. For example, the SNP-capture approach obtains information on a subset of positions that has been found to be variable in a limited number of individuals living today. As a consequence, variation that is unique to groups that are not currently living, or perhaps were not represented when a SNP-capture array was designed, will be missed. The only way to investigate an unbiased representation of an ancient individual's genome is to sequence it.[1,5,6,10,11]

Three of the seven individuals for whom we generated entire inherited DNA data[1], lived along the KwaZulu-Natal coast during the final Later Stone Age[12]. This period was shortly before the influx of pastoralists from East Africa who exchanged their genetic heritage with local hunter–gatherer groups – forming the historically known Khoekhoe herders of southern Africa – and before farmers of West African descent settled on the landscape from about 1700 years ago, contributing to the local gene pool and giving rise to the local Iron Age.[1,13]

The context of the three Stone Age hunter–gatherers (who displayed no recent admixture with migrating farmers and pastoralists), coupled with the high-quality DNA coverage obtained for the boy from Ballito Bay, provided us with the unique opportunity to recalculate the genetic time depth for our species (*Homo sapiens*) to between 350 000 and 260 000 years ago.[1] Previously, the deepest genetic split was considered to have been between about 160 000 and 100 000 years ago.[14] And, based on fossil material from Ethiopia[15], the oldest modern humans were thought to have lived about 190 000 years ago in East Africa. Our work demonstrates that it is the context of human remains that matters when looking at potential deep splits in our lineage, and not their age. However, full-genome data from older remains may yet reveal more surprising outcomes. For example, any additional gene flow into southern African Stone Age populations, predating 2000 years ago, will increase the time depth of the first *H. sapiens* population split.

The new genetic split-time estimate[1] coincides with the interpretation of fossil material from Morocco in North Africa, dated to about 300 000 years ago[16], which is seen as anatomically transitional between archaic and modern *H. sapiens*. It is also consistent with the age of the Florisbad skull that was found in the Free State, South Africa, dated to 260 000 years ago.[17] The Florisbad remains were discovered with Middle Stone Age artefacts, and have been referred to as archaic *H. sapiens*[18], representing a combination of archaic and modern characteristics[17,19], with a cranial volume similar to that of modern humans of about 1300 mL. Other human remains from South Africa dating to between 300 000 and 200 000 years ago are those from Hoedjiespunt, currently ascribed to *H. heidelbergensis*, because although they are morphologically modern, they seemed larger than modern Africans.[20]

Interestingly, the age range for *H. naledi* fossils from the Rising Star Cave in Gauteng, South Africa, of about 335 000 to 236 000 years ago, suggests that these small-brained (cranial volume of 465–610 mL) hominins co-existed with the large-brained ones.[21] The southern African geo-cultural landscape during this time is diverse, with stone tool assemblages representing both late Earlier Stone Age and early Middle Stone Age expressions as well as transitional technologies.[12] The presence of more than one hominin population, each probably occupying its own bio-cultural niche, is therefore not surprising. However, what is unexpected is the marked difference in cranial volume and upper-limb morphology of *H. naledi* compared to *H. heidelbergensis* and *H. sapiens* (both archaic and modern). These differences would indicate that in southern Africa, next to the encephalising lineage/s of our own species, there was ecological space for a small-brained, rock- or tree-climbing hominin. How these physiological traits were expressed in the archaeological record is potentially one of the most interesting puzzles for behavioural and cognitive archaeologists to explore over the next decade or so. Gene-culture co-evolution studies might also be able to contribute to how we understand this complex time in our evolutionary history.

An increased time depth (now based on both fossil[16] and genetic[1] data) for the origin of our species in Africa, coupled with the simultaneous existence of a clearly different hominin (*H. naledi*) in southern Africa, and similar looking hominins in different geographical regions of the continent (*H. sapiens*, archaic *H. sapiens* and *H. heidelbergensis*), makes for interesting times in human evolution research. It demands that we take a critical new look at the period between about 350 000 and 250 000 years ago from a multidisciplinary, continent-wide perspective.

Acknowledgements

We thank the Human Sciences staff of the KwaZulu-Natal Museum in Pietermaritzburg for access to the human remains, Amafa/Heritage KwaZulu-Natal and SHARA for granting the necessary permits, and Susan Pfeiffer of the University of Toronto for providing us with a photograph of the cranium and mandible of the boy from Ballito Bay. The project was supported by grants from the Knut and Alice Wallenberg Foundation (to M.J.), the Swedish Research Council (no. 642-2013-8019 to M.J. and no. 621-2014-5211 to C.S.), the Göran Gustafsson Foundation (to M.J.) and an African Origins Platform grant from the South African National Research Foundation (to M.L.).

References

1. Schlebusch CM, Malmström H, Günther T, Sjödin P, Coutinho A, Edlund H, et al. Southern African ancient genomes estimate modern human divergence to 350,000 to 260,000 years ago. Science. 2017;358:652–655. https://doi.org/10.1126/science.aao6266
2. Haak W, Lazaridis I, Patterson N, Rohland N, Mallick S, Llamas B, et al. Massive migration from the steppe was a source for Indo-European languages in Europe. Nature. 2015;5222:207–211. https://doi.org/10.1038/nature14317
3. Skoglund P, Thompson JC, Prendergast ME, Mittnik A, Sirak K, Hajdinjak M, et al. Reconstructing prehistoric African population structure. Cell. 2017;171(1):59–71. https://doi.org/10.1016/j.cell.2017.08.049
4. Nielsen R, Slatkin M. An introduction to population genetics: Theory and applications. Sunderland: Sinauer Associates; 2013.
5. Skoglund P, Malmström H, Omrak A, Raghavan M, Valdiosera C, Günther T, et al. Genomic diversity and admixture differs for Stone-Age Scandinavian foragers and farmers. Science. 2014, 344:747-750. https://doi.org/10.1126/science.1253448
6. Prüfer K, Racimo F, Patterson N, Jay F, Sankararaman S, Sawyer S, et al. The complete genome sequence of a Neanderthal from the Altai Mountains. Nature. 2014;505:43–49. https://doi.org/10.1038/nature12886
7. The 1000 Genomes Project Consortium. A global reference for human genetic variation. Nature. 2015;526:68–74. https://doi.org/10.1038/nature15393
8. The International HapMap Consortium. A second generation human haplotype map of over 3.1 million SNPs. Nature. 2007;449:851–861. https://doi.org/10.1038/nature06258

9. Morris AG. Ancient DNA comes of age, but still has some teenage problems. S Afr J Sci. 2017;113(9/10), Art. #a0232, 2 pages. https://doi.org/10.17159/sajs.2017/a0232

10. Allentoft ME, Sikora M, Sjögren KG, Rasmussen S, Rasmussen M, Stenderup J, et al. Population genomics of bronze age Eurasia. Nature. 2015;522:167–172. https://doi.org/10.1038/nature14507

11. Lazaridis I, Patterson N, Mittnik A, Renaud G, Mallick S, Kirsanow K, et al. Ancient human genomes suggest three ancestral populations for present-day Europeans. Nature. 2014;513:409–413. https://doi.org/10.1038/nature13673

12. Lombard M, Wadley L, Deacon J, Wurz S, Parsons I, Mohapi M, et al. South African and Lesotho Stone Age sequence updated. S Afr Archaeol Bull. 2012;67:123–144.

13. Schlebusch CM, Prins F, Lombard M, Jakobsson M, Soodyall H. The disappearing San of southeastern Africa and their genetic affinities. Hum Genet. 2016;135:1365–1373. https://doi.org/10.1007/s00439-016-1729-8

14. Lombard M, Schlebusch C, Soodyall H. Bridging disciplines to better elucidate the evolution of early *Homo sapiens* in southern Africa. S Afr J Sci. 2013;109(11/12):27–34. https://doi.org/10.1590/sajs.2013/20130065

15. White TD, Asfaw B, DeGusta D, Gilbert H, Richards GD, Suwa G, et al. Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. Nature. 2003;423(6941):742–747. https://doi.org/10.1038/nature01669

16. Hublin JJ, Ben-Ncer A, Bailey SE, Freidline SE, Neubauer S, Skinner MM, et al. New fossils from Jebel Irhoud, Morocco and the pan-African origin of *Homo sapiens*. Nature. 2017;546(7657):289–292. https://doi.org/10.1038/nature22336

17. Grün R, Brink JS, Spooner NA, Taylor L, Stringer CB, Franciscus RG, et al. Direct dating of Florisbad hominid. Nature. 1996;382:500–501. https://doi.org/10.1038/382500a0

18. Clarke RJ. Early Acheulean with *Homo habilis* at Sterkfontein. In: Tobias PV, editor. Hominid evolution: Past, present and future. New York: Alan Liss; 1985. p. 287–298.

19. Curnoe D, Brink J. Evidence of pathological conditions in the Florisbad cranium. J Hum Evol. 2010;59:504–513. https://doi.org/10.1016/j.jhevol.2010.06.003

20. Berger LR, Parkington JE. A new Pleistocene hominid-bearing locality at Hoedjiespunt, South Africa. Am J Phys Anthropol. 1995;98:601–609. https://doi.org/10.1002/ajpa.1330980415

21. Berger LR, Hawks J, Dirks P, Elliott M, Roberts EM. *Homo naledi* and Pleistocene hominin evolution in subequatorial Africa. eLife. 2017;6, e24234, 19 pages. https://doi.org/10.7554/eLife.24234

Young South African researchers attend the 2017 Lindau Nobel Laureate Meeting

AUTHORS:
Nolwazi Nombona[1]
Mark Williams-Wynn[2]
Paul Kennedy[3]

AFFILIATIONS:
[1]Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa
[2]Thermodynamics Research Unit, School of Engineering, University of KwaZulu-Natal, Durban, South Africa
[3]Independent Science Communicator, Cape Town, South Africa

CORRESPONDENCE TO:
Mark Williams-Wynn

EMAIL:
Williams-Wynn@ukzn.ac.za

KEYWORDS:
chemistry; researchers; networking; mentorship

HOW TO CITE:
Nombona N, Williams-Wynn M, Kennedy P. Young South African researchers attend the 2017 Lindau Nobel Laureate Meeting. S Afr J Sci. 2018;114(1/2), Art. #a0248, 2 pages. http://dx.doi.org/10.17159/sajs.2018/a0248

What do you get when 420 young scientists and 30 Nobel Laureates from around the world converge on a quaint Bavarian island for almost a week? The prestigious annual Lindau Nobel Laureate Meeting.

The 67th Lindau Nobel Laureate Meeting – dedicated to chemistry – took place in Lindau, Germany, from 25 to 30 June 2017. The annual Lindau Nobel Laureate Meetings bring together over 400 early career scientists from all over the world, along with approximately 30 Nobel Laureates, to promote scientific exchange and engagement. The motto of the Lindau Nobel Laureate Meetings – 'Educate, Inspire, Connect' – typifies what transpires at these events. Started in 1951 to facilitate post-war reconciliation among scientists, the first meeting was a great success and lead to periodic meetings of Nobel Laureates. A few years later, young researchers were invited to join the dialogue, and this format has since been fostered into an annual event which is now attended by participants from over 70 countries.

To attend as a young researcher, most applicants must first be selected and nominated by an academic partner, and then pass the Lindau Nobel Laureate Council's final selection process. The Academy of Science of South Africa (ASSAf) is the academic and nominating partner in South Africa and provides a travel grant through support from the Department of Science and Technology for a young researcher to attend the Meeting. For participants hailing from Africa, funding to attend the Meeting is also provided through the Horst Köhler Fellowship Programme run by the Robert Bosch Stiftung.

For many of the Nobel Laureates, the meeting is the highlight of their year, as they get to meet with enthusiastic young researchers who look to them for advice about their research, advice about their careers, and even advice about non-scientific matters. Some of the Nobel Laureates joke that the young researchers 'keep them young'. Simply having the Nobel Laureates present is a cornerstone of the meetings; their presence inspires the young researchers, and inspires the conversations that transpire, giving an opportunity for the young researchers to converse with peers from different backgrounds without prejudice or discrimination.

The participants of the Meetings are afforded the option to either stay in a hotel or to be hosted by a local Lindau family. Being hosted by a local family allows for greater immersion into German culture, and the host families eagerly await the week that they host their guest.

Two of the participants from South Africa were Dr Nolwazi Nombona and Dr Mark Williams-Wynn. Nolwazi Nombona has a PhD in Chemistry from Rhodes University and currently works at the University of Pretoria where she designs nanomaterial sensors to detect harmful chemicals and organisms in the environment. Mark Williams-Wynn completed his PhD in Chemical Engineering at the University of KwaZulu-Natal, where he developed a process to treat oil sludge using novel solvents. He is currently completing a Post-Doctoral Fellowship at the University of KwaZulu-Natal, where he is developing processes for the recovery of valuable materials from electronic waste. These young researchers share their personal experiences from the 67th Lindau Nobel Laureate Meeting below.

Experience of the 67th Lindau Nobel Laureate Meeting: Nolwazi Nombona

The first that I heard of the Lindau Nobel Laureate Meetings was when a senior professor approached me to ask if they could nominate me to attend. I secretly thought: Why would they select me? But I submitted an application and then promptly forgot about it. Months later, I received an email that turned my world on its head. The African Academy of Sciences had nominated me for consideration to the Council and I was chosen to attend. I couldn't believe it: I was going to Lindau! I was excited for the opportunity to meet and interact with Nobel Laureates – the remarkable people I'd only read about on the Internet. But after the initial elation, the nervousness kicked in. I worried to myself: What on earth would I possibly have to say to them?

In hindsight, my fears were completely groundless. My experience far exceeded any of my expectations. The atmosphere in Lindau was friendly and relaxed; and this made the interaction with the Nobel Laureates far less intimidating than I had expected. At the opening ceremony, the excitement in the auditorium was tangible. As became typical for the duration of the Meeting, we had an opportunity to mingle with and meet the Nobel Laureates as well as fellow researchers who hailed from all corners of the globe. The Meeting was centred on lectures, discussion sessions, and science breakfasts, but outside of these times, there were many opportunities to discuss topics ranging from current research activities to politics and cultural norms.

Over the course of the week, the Nobel Laureates delivered short lectures; some focused on the fundamental challenges in their respective research areas, whilst others shared their experiences as researchers. For me, the highlight was the keynote address that was delivered by Prof. William E. Moerner (2014 Chemistry Nobel Laureate) on behalf of Prof. Steven Chu (1997 Physics Nobel Laureate). Chu mentioned that governments seem to be in doubt about scientific evidence (especially on climate change) and emphasised the need to have political scientists who can work with governments to develop better policy options for a sustainable future. Apart from the scientific aspects that were covered during the lectures, what was of most value to me was the guidance that each Nobel Laureate imparted during their lecture. They motivated us to never doubt our abilities and inspired us to hold on to the passion we have for science. Possibly the most interesting lecture (judging from the applause given) was delivered by Prof. Ben Feringa (2016 Chemistry Nobel Laureate). In his talk, Feringa took us through his discovery of a 'nano-car' which he built from compounds that use light-induced chemical energy to move across a surface, highlighting the positive impact these nano-machines could have, especially in medicine.

The African delegates had a special African breakfast with Prof. Peter Agre (2003 Chemistry Nobel Laureate). This breakfast gave us a chance to meet other African delegates and we had a rare opportunity to pick Agre's brain regarding his work in Africa through his role as the Director of the Johns Hopkins Malaria Research Institute. The discussion touched on various issues, including why we have not been successful in eradicating malaria. The dialogue was so thought-provoking that ASSAf organised a follow-up lunch discussion with Agre and the researchers from South Africa.

The Lindau Nobel Laureate Meeting was a unique experience, and it exposed me to colleagues working on similar research projects around the world. The discussions were enlightening and the networks created will benefit my scientific research career for years to come. I would encourage every young scientist to apply to attend this meeting, as it provides a remarkable opportunity to interact with current and future Nobel Prize winning scientists from across the globe.

Experience of the 67th Lindau Nobel Laureate Meeting: Mark Williams-Wynn

There is a distinct lack of conversation about the Lindau Nobel Laureate Meeting in South Africa – the first that I heard of this opportunity was when I was asked by my supervisor if he could nominate me to attend the 67th Meeting. The selection process is very rigorous, and it was 4 months after submitting my application that I received an email informing me that I had been selected to attend. I was extremely excited to receive this email, to the point that I immediately rushed to my supervisor's office to tell him the news.

A travel grant was provided by ASSAf, and as the selected delegates were from different universities and research organisations throughout South Africa, ASSAf organised a pre-meeting team-building gathering, during which we met the other delegates. Several Lindau alumni were also invited to this gathering, to share their experiences and give us advice on how we should approach the meeting. This advice varied from the sensible, 'Meet as many people as you can', to the less sensible, 'Don't sleep at all'.

For my stay, I was hosted by Lindau residents, and my host family proved to be exceptional. They went so far as to organise transport for me from Munich to Lindau, and to make sure that I got onto the correct train at the end of my stay. We had many discussions, which varied from the nuances of our cultural differences, to discussions about topics raised at the Meeting, to sport, to politics, and everything in between. The experience of being hosted by locals added substantially to the entire 'Lindau experience'.

During the Meeting, numerous programme additions were organised, to which only a small group of researchers was invited. These additions were sponsored by research organisations or multinational corporations. I was fortunate enough to be invited to attend two such events. The first event was the Summer Festival of Science, which was hosted by the German Federal Ministry for Education and Research. During this event, I found myself conversing with CEOs and vice-presidents from large multinational companies such as the Linde Group, Cabot Corporation and Lockheed Martin.

Another opportunity was a flight in a zeppelin, as a part of an introduction to the 'Clockwork Ocean' expedition being undertaken by the 'Helmholtz-Zentrum Geesthacht' of the Helmholtz Association. We were introduced to the methodology and equipment used to study the behaviour and impact of water eddies in the seas and oceans. Thereafter, we were taken on a 45-minute flight in the zeppelin for a magical view of Lindau and the Bodensee from the sky. We were joined for this flight by two Nobel Laureates, who were just as enthralled as we were by the views that unfolded.

The days of the conference flew past at a breathtaking pace, although not without presenting each of us with many opportunities to network and to learn from both the Nobel Laureates and the other researchers present. The advice from the alumni to not sleep made much more sense at this point. There were simply so many interesting people to meet and to discuss science with, that we all ended up sleeping far less than usual.

For me, the lectures that most stood out were those in which the Nobel Laureates chose to share their personal experiences as researchers. These were lectures by Agre, Dan Shechtman (2011 Chemistry Nobel Laureate) and Martin Chalfie (2008 Chemistry Nobel Laureate). After the lectures, each Nobel Laureate held a discussion session with the young researchers. I found Shechtman's discussion session particularly pertinent to me, as we discussed science entrepreneurship and education.

There was a strong emphasis on women in science, technology, engineering and mathematics (STEM) at this year's Meeting, and as such, many of the young scientists involved in discussion panels and sessions were women. In stark contrast, only one of the 29 Nobel Laureates present was a woman (Ada Yonath, 2009 Chemistry Nobel Laureate).

On the final day of the Meeting, we were treated to a boat ride to the garden island of Mainau, where we spent the day. Two occurrences during the events held on the island further highlighted women in STEM. During the closing panel discussion on 'Ethics in Science', a young researcher from the University of Cambridge, Dr Karen Stroobants, was, by far, the stand-out panel member, eclipsing the otherwise male-dominated panel. Secondly, Dr Hlamulo Makelane, from South Africa, gave heartfelt and emotive closing remarks for the Lindau Meeting on behalf of the young researchers, doing South Africa and women in STEM proud.

Everything considered, the Lindau Nobel Laureate Meeting was a once in a lifetime experience that I would recommend to anyone who is eligible to attend. Were it not for the fact that young scientists are only afforded the opportunity to attend once, I would have applied immediately for the next Meeting.

Kromdraai evolved, but poorly packaged

BOOK TITLE:
Kromdraai: A birthplace of *Paranthropus* in the Cradle of Humankind

BOOK COVER:

EDITORS:
José Braga and J. Francis Thackeray

ISBN:
9781928355069 (hardcover)

PUBLISHER:
SUN Press, Stellenbosch; ZAR340

PUBLISHED:
2016

REVIEWER:
Andy I.R. Herries[1,2]

AFFILIATIONS:
[1]Department of Archaeology and History, College of Arts, Social Science and Commerce, La Trobe University, Melbourne, Australia

[2]Centre for Anthropological Research, University of Johannesburg, Johannesburg, South Africa

EMAIL:
A.Herries@latrobe.edu.au

HOW TO CITE:
Herries AIR. Kromdraai evolved, but poorly packaged. S Afr J Sci. 2018;114(1/2), Art. #a0241, 2 pages. http://dx.doi.org/10.17159/sajs.2018/a0241

The Kromdraai Palaeocave System has been of interest to palaeoanthropology since Robert Broom's identification of the type specimen of *Paranthropus robustus* (TM1517) in 1938.[1] It is one of the classic hominin-bearing sites of South Africa and has been excavated by a number of iconic South African scientists including Bob Brain in the 1950s, and Elizabeth Vrba in the 1970s and 1980s. However, so little published work has come from the site. Since 2002, the work at the site has been directed by José Braga and Francis Thackeray (the latter also excavating in the 1990s) as part of a joint French–South African collaboration, and they have brought their recent research together in a new book: *Kromdraai: A birthplace of* Paranthropus *in the Cradle of Humankind*[2]. It is an odd book in the sense that when it arrived it looked like it was going to be a more popular science book, more akin to Ron Clarke and Tim Partridge's *Caves of the Ape-Men*[3]. The cover artwork also does nothing to portray the subject matter within, as it is simply a picture of mossy covered dolomite. However, in opening the book you come to the realisation that it is actually an edited volume of scientific articles packaged in an odd, rectangular, coffee-table format. In part this is probably a reflection of the relatively new (2003), pay-to-publish publisher chosen by the authors, African Sun Media. The nature of this type of publishing bleeds through the book in other ways in that there are both excellently reproduced photos and figures in some instances, but poor-quality, blurry figures in others – most notably one of the most important in the book, Figure 3.1, which shows the new plan of the stratigraphy of the site. It does make you wonder why the authors chose this format of publishing for research that could have been published in higher impact, and critically for the South African market, open access journals.

With regard to the science presented, the book covers the history of research at the site; some very interesting new research using 3D scanning and photogrammetry; an important revised stratigraphy; a paper on the hominin material including valuable work using the enamel-dentine junction for identifying different species; and a preliminary analysis of the fauna excavated from the oldest fossil deposit at the site, Member 2. Chapter 2, which covers the 3D mapping and visualisation of the site is perhaps the one that stands out as a good example of new types of research being undertaken on these old sites, although it is research that is now regularly being undertaken at such sites.[4,5] Here the different scales of this type of analysis do stand as different from what has been published to date, although a journal format with its ability to have online content, such as videos, may have been a better format to showcase these 3D models.

The stratigraphy chapter by Bruxelles et al. on Kromdraai B (as disappointingly the faunal site Kromdraai A is really not dealt with) is also an important piece of research that fundamentally shows the complexity of this site. In many ways, it also suggests that the research at the site needs to simply start from scratch, because the vast majority of fossils excavated from the site have very uncertain to unknown provenience. It is a sentiment that is being increasingly echoed about the early sites that have been excavated or sampled for over 70 years. In another way, it is a rather transformative chapter for the site as well, because it changes the perception from that of Kromdraai as a small site that had been pretty much exhausted, with all the fossils coming from a single deposit, to that of a massive site with great future potential. The new excavations have both expanded the lateral extent of the site as well as its depth, with a hint that much older *Australopithecus*-bearing deposits may be buried below. Here the reader is, in some sense, presented with a vision that is truly different from that presented by Partridge[6,7] on the stratigraphy of the site, but in other senses (in continuing to follow a Member system), the vision is perhaps not revolutionary enough. What it does do, although not an intentional aim of the research, is to lay bare the problems of the numbered Member system used at all these sites. Namely, what do you do when you find a new deposit between Member 2 and 5? Here Bruxelles et al. have opted to create numbered sub-Member units (4.1–4.3). This creates an ultra-confusing renaming convention whereby parts of Member 3 remain Member 3, and other parts of Member 3 become 4.1. Member 4 becomes 4.2, Member 5 becomes 4.3 and Members 1–3 of the previously defined KB West formation become Members 5–7. Thankfully they have a nice table to illustrate these changes.

The next issues that will come with the Member system of the site is when dates are given to these various Members and sub-Members and they are perhaps found to not be in this stratigraphic order, or, as shown for other sites[8], some of the Members are contemporary with each other. The lack of chronometric dates is certainly the most absent piece of research from the volume. The same potential problem exists for this Member system as the original, in that defining sedimentologically distinct Members is not defining a chronostratigraphy, and very different looking sedimentological deposits can form at the same time in different parts of the same cavern and system. Only time will tell how accurate this new stratigraphy is, but the way it is presented with numerous sections through the deposit described and illustrated is a very useful reference for any future work at the site. This is perhaps an example of a paper with great value that might not have been suitable for a journal format. It is the pure descriptive science that is needed to conduct research and provide a legacy record of a site, but work which sadly many journals seem unprepared to publish these days because the information is deemed of 'only local interest' or 'limited impact'. Yet this is exactly the type of primary research that needs to be published, so that we can fully understand what was done at the sites, and how they were interpreted when 2017 is as long ago as 1938 is today. What this chapter also does is lay bare one of the truly fundamental outcomes of this book – that we will likely never know the exact provenience, and thus age, of the type specimen of *Paranthropus robustus*.

In contrast to this geology chapter, the faunal chapter is instead rather devoid of actual data and its formatting has not been homogenised between different taxonomic groups, which I assume is a reflection of different author styles. Very few photos of the material being described are presented and in some cases only a species list is presented with no primary descriptions or metrics. In such situations, which is becoming all too common in palaeontological papers, the reader has to take the authors' word for the existence of a species as no actual data are presented. A species list with no primary descriptions and evidence of what the fossils were compared to, is like stating the answer is 42, without any maths calculations showing how the number was obtained. In terms of the science, the book is thus a mixed bag.

On the cover page, it is stated: 'The publication was subjected to an independent double-blind peer evaluation by the publisher.' Given the various issues in the book with regard to the formatting, language and science, what exactly does this mean? The book would have benefitted from a thorough proofreading, as there are grammatical and spelling errors throughout. These errors give the impression that the contents were not vetted particularly thoroughly by the reviewers. In a time when there is a dramatic rise in anti-science (such as the number of people who actually believe the earth is flat), when the very nature of peer review is under threat from a proliferation of for-profit journals, and when research funding is becoming increasingly difficult to obtain, it is not an unreasonable question to ask where such pay-to-publish books sit within academia and our evaluation of a scientist's work. Is it, as in the model adopted by some open access journals, now a case of scientists publishing their unhindered views of the record, with peer review simply coming from widespread popular analysis of its quality after the fact? Certainly, in a time when there is a push towards publishing data from research to combat the 'reproducibility crisis' in science[9], this book feels, at best, somewhat old school, and, at worst, a result of a method of publishing that allows the authors to present the story they choose without hindrance.

This lack of thorough reviewing comes through in other ways, as the story presented suggests a distinct 'cherry picking' of certain papers and data to present a particular story of the South African record. This is most notable in the poor and biased referencing of current research, especially regional chronology. For example, citing the McKee et al.[10] faunal seriation paper as evidence for the age of Makapansgat, Taung and Sterkfontein in 2016, but none of the chronometric studies undertaken in the last 10 years[8] or so is one such example. The understanding of local chronology is based purely on cosmogenic nuclide burial dating; although citing Granger et al.[11] for the age of *Australopithecus africanus* at Sterkfontein at 3.0–2.6 Ma is odd in that it is a study dating the Member 2 Stw573 deposits and Member 5, not the Member 4 deposit from which *Au. africanus* has primarily been recovered. Chronometric studies actually put this deposit at 2.6–2.0 Ma based on a combination of electron spin resonance, uranium-lead and palaeomagnetic dating.[8]

There is some truly fascinating new research that transforms our idea of what the site may represent and yield, but the sloppy nature of the reviewing, publication, writing and formatting, means that many readers will not come away trusting the information presented, rightly or wrongly, in the same way they do similar books such as Brain's 1993 *Swartkrans: A Cave's Chronicle of Early Man*[12]. Nonetheless, as Bob Brain states in the Foreward to the book, it is a delight to see how the Kromdraai Research Project is changing our understanding of the Kromdraai deposits and its hominins through these mostly very preliminary findings. I personally cannot wait to see what future work at the site will yield.

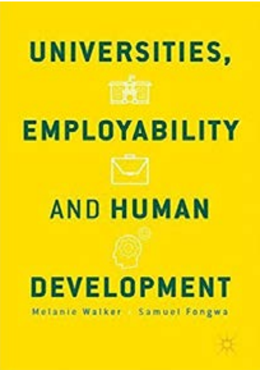
References

1. Broom R. The Pleistocene anthropoid apes of South Africa. Nature. 1938;142:377–379. https://doi.org/10.1038/142377a0
2. Braga J, Thackeray JF. Kromdraai: A birthplace of *Paranthropus* in the Cradle of Humankind. Stellenbosch: SUN Press; 2016. https://doi.org/10.18820/9781928355076
3. Clarke R, Partridge T. Caves of the ape-men: South Africa's Cradle of Humankind World Heritage Site. Johannesburg: Wits University Press; 2010.
4. Kruger A, Randolph-Quinney PS, Elliott M. Multimodal spatial mapping and visualisation of Dinaledi Chamber and Rising Star Cave. S Afr J Sci. 2016;112(5/6), Art. #2016-0032, 11 pages. https://doi.org/10.17159/sajs.2016/20160032
5. Armstrong B, Blackwood A, Penzo-Kajewski P, Menter C, Herries AIR. Terrestrial laser scanning and photogrammetry techniques for documenting fossil bearing palaeokarst with an example from the Drimolen Palaeocave System, South Africa. Archaeol Prospect. In press 2017. https://doi.org/10.1002/arp.1580
6. Partridge TC. Some preliminary observations on the stratigraphy and sedimentology of the Kromdraai B hominid site. In: Coetzee JA, Van Zinderen Bakker EM, editors. Palaeoecology of Africa and the surrounding islands. Vol. 15. New York: CRC Press; 1982. p. 3–12.
7. Partridge TC. Hominid-bearing cave and tufa deposits. In: Partridge TC, Maud RR, editors. The Cenozoic of southern Africa. New York: Oxford University Press; 2000. p. 100–125.
8. Herries AIR, Pickering R, Adams JW, Curnoe D, Warr G, Latham AG, et al. A multi-disciplinary perspective on the age of *Australopithecus* in southern Africa. In: Reed KE, Fleagle JG, Leakey R, editors. Paleobiology of *Australopithecus*. Vertebrate Paleobiology and Paleoanthropology Series. Dordrecht: Springer; 2013. p. 21–40. https://doi.org/10.1007/978-94-007-5919-0_3
9. Marwick B, Jacobs Z. Here's the three-pronged approach we're using in our own research to tackle the reproducibility issue. The Conversation. 2017 July 19; Science and Technology. Available from: https://theconversation.com/heres-the-three-pronged-approach-were-using-in-our-own-research-to-tackle-the-reproducibility-issue-80997
10. McKee J, Thackeray JF, Berger LR. Faunal assemblage seriation of southern African Pliocene and Pleistocene fossil deposits. Am J Phys Anthropol. 1995;96:235–250. https://doi.org/10.1002/ajpa.1330960303
11. Granger DE, Gibbon RJ, Kuman K, Clarke RJ, Bruxelles L, Caffee MW. New cosmogenic burial ages for Sterkfontein Member 2 *Australopithecus* and Member 5 Oldowan. Nature. 2015;522:85–88. https://doi.org/10.1038/nature14268
12. Brain CK. Swartkrans: A cave's chronicle of early man. Pretoria: Transvaal Museum; 1993.

Higher education's contribution to graduate employability and the social good

BOOK TITLE:
Universities, employability and human development

BOOK COVER:



AUTHORS:
Melanie Walker and Samuel Fongwa

ISBN:
9781137584519 (hardcover)

PUBLISHER:
Palgrave MacMillan, London; USD79.99

PUBLISHED:
2017

REVIEWER:
Delia Marshall

AFFILIATION:
Physics Department, University of the Western Cape, Cape Town, South Africa

EMAIL:
dmarshall@uwc.ac.za

HOW TO CITE:
Marshall D. Higher education's contribution to graduate employability and the social good. S Afr J Sci. 2018;114(1/2), Art. #a0250, 2 pages. http://dx.doi.org/10.17159/sajs.2018/a0250

In contemporary times of globalisation, massification of higher education and economic, social and environmental challenges, there has been renewed debate internationally on the purposes of higher education. In South Africa too, higher education's role in society has been thrown into sharp focus by the student protests of 2015–2016. Walker and Fongwa's well-timed book tackles this pressing question of higher education's role in society.

The book has its origin in an international project on higher education and employability, and presents the South African part of the study, based on case studies of four universities that represent a range of institutional types. Drawing on interviews and surveys with students, lecturers, support officers and employers, the study uses qualitative and quantitative data to build a picture of how employability is perceived, and what universities are doing to develop graduates – not merely for the workplace but also for broader critical citizenship.

The book's first key contribution is a critique of dominant economic conceptualisations of employability. Of course, in a context like South Africa, with high levels of unemployment and a sluggish economy, one cannot completely dismiss the economic purposes of higher education, both for individuals' lives and for economic growth. However, Walker and Fongwa argue that employability needs to involve more than individuals' entry into the workplace, or contributions to human capital and economic growth. Such conceptualisations are limited, they argue, and need to be enlarged by a conceptualisation of employability that encompasses public good values, such as concerns of social justice, inequality and poverty reduction. This enlarged view of employability, encompassing students' preparation for both work and society, is especially important in a context, like South Africa, of huge inequality and poverty.

In considering the significant ways in which individuals can be shaped by their experiences of higher education, the authors draw on the work of Dreze and Sen[1], providing a perspective on how education can be instrumentally, intrinsically and socially significant for individuals. This perspective is valuable for thinking about the 'public good' purposes of higher education because it foregrounds the important role that education plays in developing individuals' capacity to deliberate critically about social concerns, to engage with diversity, and to actively engage around social inequalities. All these are crucial capacities for building critical citizens and for strengthening a young democracy such as that in South Africa.

The power of Walker and Fongwa's approach is that they extend the conceptualisation of the 'public good' from its philosophical origins to questions of what this might mean practically for higher education. They do this by linking public good with the capabilities approach, drawing on the work of economist Amartya Sen[2] and related work on human development. For Sen, 'capabilities' relate to the opportunities that individuals have for being able to realise outcomes that they value. These opportunities are shaped and mediated by what are termed 'conversion factors' – the structural arrangements which differentially shape the opportunities for individuals based on their social backgrounds. These theoretical ideas, as well as concepts drawn from Martha Nussbaum's work[3], form the theoretical basis of the study.

The research findings are reported in several chapters which present quantitative data alongside rich interview data. The first part examines final-year student and academic staff conceptions of employability. Perhaps not surprisingly, the predominant focus is on knowledge and practical skills. Walker and Fongwa argue that, while obviously knowledge and skills are crucial, 'without wider commitments to the public good and the good lives of others both may become individualistic and socially hollowed out' (p.102). The study also looks at conversion factors shaping graduate employability; these include race, social class, university reputation and field of study.

From perceptions of employability, the focus then returns to students' experiences of higher education itself. With the current trend towards snappily worded university mission statements and Charters of Graduate Attributes, I found this section particularly interesting. Here, they draw on Nussbaum's notion of 'freedom education' premised on the development of three core capabilities: critical examination, global citizenship and narrative imagination. They examine institutional documents and policies, and interview academic staff and students to get a sense of how educational arrangements in the institutions are set up to develop these capabilities. Not surprisingly they find that, while most universities claim in their mission statements to focus on broader social good and citizenship graduate attributes, in fact these attributes are seldom embedded in the curriculum and pedagogy itself, but are relegated to the co-curricular programme, if addressed at all. About their findings they caution:

> *For a society with so much inequality and social injustice, any university curriculum and pedagogy that focuses on skills and employability without an active focus on issues of exclusion, social responsiveness and democratic citizenship limits the potential of universities in contributing to human development.* (p.130)

The last empirical section in the book draws on the fascinating narratives of 25 students, interviewed in their final year at university and then again about 1 year after graduation. These careful narratives, which follow students as they make their way into the world after graduation, bring to life the theoretical ideas explored in the book and point to ways in which institutions might do more 'to enable the best possible conditions for all their students to aspire and achieve' (p.213). They also present a more nuanced picture of graduate entry to the workplace than the large-scale graduate destination studies – which currently dominate this field – are able to provide. The final chapter then engagingly draws together the earlier theoretical and empirical sections to offer a practical way forward for institutions in developing graduates not only for work but for participation in society.

This is a theoretically and empirically significant book. For researchers in higher education studies or sociology of education, it will serve as a valuable handbook providing comprehensive overviews of philosophy of education, the capabilities approach, the higher education policy landscape, and graduate employability trends. The empirical aspects will also be of great interest to researchers and practitioners.

Walker and Fongwa argue for curricula and pedagogical practices that more explicitly prepare graduates to engage productively in the South African context of inequality and poverty. Student voices in this study, too, express that more could be done to promote social engagement and citizenship values. This has obvious resonances with the #FeesMustFall student calls for curricula transformation and Africanisation. However, it was interesting that the students in this study were not suggesting an entire overhaul of curricula or contesting discipline knowledge itself. Although the empirical stage of this research project predated the student protests, I could not help feeling that I wanted to read more about how these authors would engage with these developments. No doubt this is something they will be exploring down the line.

This book is a must-read for higher education lecturers, policymakers and university managers. It articulates a powerful framework for enlarging how we commonly think about employability. It provides tangible ways forward for institutions that wish to take seriously the public good purposes of higher education and it offers a more expansion vision of higher education for tackling social justice concerns globally.

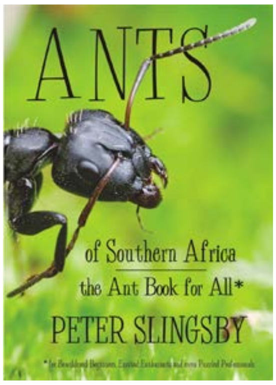
References

1. Dreze J, Sen A. India: Development and participation. Oxford: Oxford University Press; 2002. https://doi.org/10.1093/acprof:oso/9780199257492.001.0001
2. Sen A. Development as freedom. Oxford: Oxford University Press; 1999.
3. Nussbaum M. Creating capabilities: The human development approach. Cambridge, MA: Belknap Press; 2011. https://doi.org/10.4159/harvard.9780674061200

The world of southern African ants made accessible

BOOK TITLE:
Ants of southern Africa: The Ant book for all

BOOK COVER:



AUTHOR:
Peter Slingsby

ISBN:
9781920377045 (softcover)

PUBLISHER:
Slingsby Maps, Muizenberg; ZAR295

PUBLISHED:
2017

REVIEWER:
Brigitte Braschler

AFFILIATION:
Section of Conservation Biology, Department of Environmental Sciences, University of Basel, Basel, Switzerland

EMAIL:
Brigitte.braschler@unibas.ch

HOW TO CITE:
Braschler B. The world of southern African ants made accessible. S Afr J Sci. 2018;114(1/2), Art. #a0251, 1 page. http://dx.doi.org/10.17159/sajs.2018/a0251

Ants fulfil central roles in southern African ecosystems: changing soil structure and chemistry, dispersing seeds and hunting arthropods. Ants occur in all habitats, even inside buildings. Most people encounter them frequently. Hearing that I work with ants, people often tell me of the ants in their kitchen and garden. Indeed, ants are not only known to be occasionally irritating, but have also long piqued people's curiosity as numerous fables and children's movies attest. The ants' fascinating range of behaviours makes them rewarding objects of study for professionals and amateurs alike.

Yet many people remain unaware of the astonishing diversity of this group. One reason is the small size of these animals; another is the large number of morphologically similar species. Whereas field guides to plants or birds enable laypersons to identify many species in the outdoors, identification keys for small invertebrates, if available, typically require equipment like microscopes only available to few, mostly professional, researchers. This limitation applies to printed and online identification keys for African ants. Existing insect field guides, which are also suitable for non-experts, often cover a broad spectrum of taxonomic groups. They are thus limited to a few common or conspicuous ant species. Given the frequent use of ants in ecological research or conservation projects, a modern species-level field guide, dedicated to southern African ants, has been lacking.

Peter Slingsby subtitled his field guide 'The Ant Book for All', and his aim is indeed met. The book includes much of interest even to those with years of experience working with South African ants, but is easy to use for beginners. The short introductory chapters provide information on ant biology and ecology, and the history of the study of ants in southern Africa. At the end of the book, information on collecting ants, ant diversity in the region, a glossary, and indices for both scientific and common names are provided. Maps show habitat types and collection sites.

A section on ant anatomy and a 'How to use this book' section commence the main part of the book. The keys are simple enough for the layperson to identify many species to genus level; especially if they are observing a whole nest with brood. The keys fill only two pages. The focus is on behaviour and appearance in the field, which are visible to the naked eye or using a hand lens. A list with short descriptions of common genera and information on where to encounter them is provided. Genera are thereafter presented in alphabetical order within subfamilies. Larger genera are preceded by an introduction, sometimes with sketches showing identifying characteristics. However, the focus is on field photographs of more than 225 common species and descriptions of their distributions, behaviour and anatomy. The guide is unusual in also providing common names and drawings showing actual size. There are shorter notes on a further 400 species. The guide thus covers the majority of the described ant species so far recorded for southern Africa. Keys to distinguish species within genera are not provided. Instead, after identifying possible genera using the key, the user will need to search for matches among the species descriptions and photos. I tested the guide using field photographs of South African ants with the help of two undergraduate biology students. After a short introduction using the illustrations and legends in the guide, they correctly identified all photos to genus and most to species level.

The photographs by Philip Herbst and many other contributors to the iSpot website (www.ispotnature.org) are of the highest quality. The numerous field photographs show live ants in their natural habitats. Where such were not available, the author provides excellent illustrations. Symbols show under which light conditions species are active and how common they are. Where specialist terms are required, these are explained with illustrations or in the glossary. With this much information provided, the pages might feel crowded. The legends explaining some frequently used symbols are not necessary on each page with species descriptions and species photographs, although they may help occasional users.

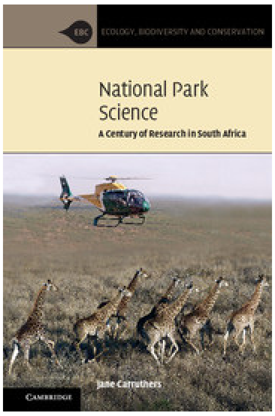
In this wealth of information, it is perhaps unavoidable that some errors slipped in. They are few. In the legend to the otherwise excellent maps, the Nama Karoo and Succulent Karoo are mixed up. Furthermore, in a table with illustrations distinguishing six genera based on six characters, *Solenopsis* is erroneously shown to have spines on the propodeum.

The enthusiasm the author feels for his subject penetrates the whole book. His highly personal style is unusual for an entomological book but highly engaging. The humorous asides and anecdotes and the many details on the ants' lives make the book enjoyable to browse, even with no ants at hand. Slingsby's book is a helpful tool for conservation managers or researchers interested in using ants as indicators for biodiversity or environmental change. It is an excellent reference for information on ant species. The book is unparalleled in usefulness in the field or for people without access to specialist equipment. However, for professional use, identifications of ants should be confirmed using taxonomic literature – keeping in mind that many ant species in southern Africa are yet to be described. The book will be very valuable for citizen scientists, professional biologists or conservationists working with ants in the field, and all those who observe and photograph ants and want to know more about them.

Research, politics and conservation in South Africa's national parks

BOOK TITLE:
National park science: A century of research in South Africa

BOOK COVER:



AUTHOR:
Jane Carruthers

ISBN:
9781107191440 (hardcover)

PUBLISHER:
Cambridge University Press, Cambridge; GBP67.99

PUBLISHED:
2017

REVIEWER:
Brian W. van Wilgen

AFFILIATION:
Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa

EMAIL:
bvanwilgen@sun.ac.za

HOW TO CITE:
Van Wilgen BW. Research, politics and conservation in South Africa's national parks. S Afr J Sci. 2018;114(1/2), Art. #a0254, 1 page. http://dx.doi.org/10.17159/sajs.2018/a0254

National parks in South Africa have provided opportunities for scientific research in relatively pristine protected areas for over 100 years. The diversity of the parks themselves influenced the direction of the research, but the research agenda was also strongly influenced by the socio-economic and political context in which it took place. In this book, Jane Carruthers traces the development of scientific endeavours within South Africa's 19 national parks, and introduces the personalities involved. What differentiates this book from several others written by scientific practitioners – for example, Salomon Joubert's three-volume history of the Kruger National Park (KNP)[1] – is that the development of research agendas and practices are examined critically in the context of the historical and political milieu within which they took place.

The earliest scientific paper to emanate from what was to become South Africa's first national park was by James Stevenson-Hamilton in 1905. At that time, there was no science of biology or ecology, and no professional training in ecosystem management. Managers were drawn from the military, but Stevenson-Hamilton, in marked contrast to his contemporaries, took a keen interest in the animals, people and environment of the vast area for which he was responsible. His books, which include accounts of the wildlife[2], people[3], and conservation history[4] of the KNP, laid a foundation for future work in protected areas. In fact, for the first half of the 20th century, the history of research in national parks revolved almost exclusively around Stevenson-Hamilton.

Following World War II, pressure from scientists saw the creation of a Scientific Advisory Council, but it was not very influential. What was more influential was the report of a commission chaired by Prof. P.W. Hoek, which identified widespread and concerning practices. These included the appointment of unqualified people who neglected their duties, displayed no interest in conservation, and used the protected areas to run their livestock. This led to a restructuring of the organisation, and was followed by the appointment in 1950 of three scientists at the KNP, including T.G. Nel, the first trained biologist to be employed. Nel in turn appointed Dr U. de V. (Tol) Pienaar, another trained biologist, in 1955. Pienaar became very influential, rising to warden of the KNP in 1978, and to Chief Director of the National Parks Board from 1987 to 1991. The period from 1960 until the early 1990s was characterised by the National Parks Board's own brand of research that sought to 'measure, monitor and manipulate'. The period saw the development of an inward-looking research philosophy in which the national parks scientists regarded their understanding as adequate, and they saw no need for outside opinions.

The 1970s and early 1980s saw profound changes to the practise of ecological science in South Africa. Brian Huntley established co-operative research programmes at the Council for Scientific and Industrial Research, headed by academics as well as government scientists. Several 'biome projects' (savanna, fynbos, karoo, forest and grassland) led to deeper understanding of ecology and predictive models, and the training of a new breed of young ecologists. However, the national parks scientists did not participate in these programmes, and remained 'supremely self-confident and regarded outside interest as unwarranted interference'. This is not to say that national parks were not productive; a large number of checklists and descriptive studies were conducted, making a contribution to understanding by providing important foundational building blocks for ecological science.

Further and inevitable changes to research agendas came about in the 1990s. Robbie Robinson, the new CEO of national parks, adopted English as the language of formal communication, suspended elephant culling (much to the dismay of the KNP's scientists), established new national parks with new collaborative management models, and gave greater powers to the regions. He also oversaw the creation of a new 'Scientific Services' division, with regional offices, and created a social ecology unit. In 1994, he invited Richard Bell (a highly regarded wildlife researcher) to review the past work of researchers – a bold move by Robinson, as the organisation had never been peer reviewed. Bell's report found that the KNP master plan was 'deeply flawed – woolly in language, conceptually vague, and containing nothing about how scientific research should be conducted'. It was another wake-up call.

In South Africa, a democratically elected government was installed in 1994, which opened the doors to international research funding, and led to more changes to South African National Park's Scientific Services. Research shifted from a paradigm of 'command and control' to one of strategic adaptive management; curiosity-driven research was introduced alongside the descriptive research; the research team was significantly diversified; and new research centres were established. Led by the dynamic and energetic Harry Biggs (with able support from Kevin Rogers and Charles Breen, both external academics), the new paradigm of strategic adaptive management was developed and tested.

Reading through this book, I was struck by two things. Firstly, this is mainly about the KNP, with research in other national parks playing a minor role, at least until recently. Nonetheless, research in 'other national parks' is more than adequately covered. Secondly, a small number of strong leaders played a fundamental role in shaping the research agenda over the past century: James Stevenson-Hamilton, Tol Pienaar, Robbie Robinson and Harry Biggs. This book is a fascinating account of the journey that they took, the socio-political context within which they operated, and the legacy that they left – both in the published literature and in the establishment and development of a suite of national parks. I would recommend this book highly to researchers and students active in protected areas in South Africa and beyond, as well as to anyone with an interest in the history and management of our national parks.

References

1. Joubert SCJ. The Kruger National Park: A history. Johannesburg: High Branching; 2012.
2. Stevenson-Hamilton J. Animal life in Africa. London: Heinemann; 1912.
3. Stevenson-Hamilton J. The Lowveld: Its wildlife and its people. London: Cassell; 1929.
4. Stevenson-Hamilton J. South African Eden. London: Cassell & Co.; 1937.

The cranium of Sts 5 ('Mrs Ples') in relation to sexual dimorphism of *Australopithecus africanus*

AUTHORS:
Gaokgatlhe M. Tawane[1]
J. Francis Thackeray[2]

AFFILIATIONS:
[1]Ditsong National Museum of Natural History, Pretoria, South Africa
[2]Evolutionary Studies Institute, School of Geosciences, University of the Witwatersrand, Johannesburg, South Africa

CORRESPONDENCE TO:
Francis Thackeray

EMAIL:
francis.thackeray@wits.ac.za

KEYWORDS:
Hominini; human evolution; Pleistocene; Sterkfontein; South Africa

HOW TO CITE:
Tawane GM, Thackeray JF. The cranium of Sts 5 ('Mrs Ples') in relation to sexual dimorphism of *Australopithecus africanus*. S Afr J Sci. 2018;114(1/2), Art. #a0249, 4 pages. http://dx.doi.org/10.17159/sajs.2018/a0249

Fossil Sts 5 ('Mrs Ples') is a Plio-Pleistocene cranium assigned to *Australopithecus africanus.* It was discovered in April 1947 by Robert Broom and John Robinson at Sterkfontein in the Gauteng Province, situated in the Cradle of Humankind in South Africa.[1] It is thought to date to at least 2.1 mya[2-4], probably closer to 2.5 mya. Broom had initially referred to such specimens from Sterkfontein as *Plesianthropus* (where 'plesi' refers to 'almost', and 'anthropus' to 'human').

Broom[1,5] suggested that the edentulous specimen represented a female individual on the basis of small canine sockets, but in 1947 he did not have a substantial comparative sample for *A. africanus*. He considered Sts 5 to be an adult based on his claim that cranial sutures appeared to be closed, assuming that suture closure could be used to estimate developmental age. The identification of Sts 5 as the cranium of a female adult is still the subject of ongoing debate. Resolution of this issue is important for an understanding of sexual dimorphism and ontogeny in *A. africanus*.

The debate concerning the developmental age and sex of Sts 5 can be summarised in terms of a diversity of views held in recent decades. Rak[6] used the presence of facial anterior pillars to suggest that Sts 5 represented a male individual. Lockwood[7] examined variability in facial anatomy in more than 12 specimens of *A. africanus* to try to distinguish between female and male individuals, but was not in a position to be certain as to whether 'Mrs Ples' was the cranium of a female individual, as suggested initially by Broom, or that of a male individual, as contended by Rak.

With regard to the developmental age of Sts 5, Thackeray et al.[8] used CT scans of the roots of dentition to suggest that the individual was adolescent. By contrast, Bonmati et al.[9] concluded that the individual was adult at the time of death, while Villmoare et al.[10] suggested that 'Mrs Ples' was senescent. Grine et al.[11] stated: 'There is no evidence to contradict the assertion that "Mrs Ples" is an adult female'.

Here, we do not attempt to resolve the issue as to whether Sts 5 represents an adult or an adolescent individual. Instead, we address the question as to whether Sts 5 is the cranium of a small male individual distinct from that of a large female individual, using alveolar canine dimensions and a re-examination of Lockwood's [7] craniofacial data as an expression of sexual dimorphism in *A. africanus*.

Canine sockets and alveolar bone loss

Broom's[1,5] suggestion that Sts 5 represents a female individual, based on a small canine socket, needs to be examined in the context of post-mortem damage. After mechanical preparation of the cranium, using hammer and chisel, Broom et al.[12] measured the buccolingual (BL) and mesiodistal (MD) canine socket diameters as 9.0 mm and 7.6 mm, respectively.

Unfortunately, acetic acid was used at some stage of preparation, as is evident from acid damage to the petrosal bones within the cranium. If acid caused such damage to substantially thick petrosal bones, it is likely that (at some time since 1950) acetic acid preparation also caused damage to alveolar bone associated with the canine sockets. Such acid damage would have led to a reduction of canine socket diameters because the roots of the canines (and the associated sockets) are conical.

In 2012, the BL and MD diameters for the right canine alveolar socket were given by Grine et al.[11] as 7.2 mm and 6.9 mm, respectively. These values correspond closely to a BL value of 7.0 mm given by Thackeray[13] and a MD dimension of 6.9 mm obtained in this study. The reduction in the reported BL diameter, from 9 mm to 7.2 mm, could relate to post-mortem damage to the conical sockets, of the kind associated with acid preparation of the fossil. Villmoare et al.[10] confirmed that some degree of alveolar bone loss had occurred in the case of Sts 5.

It is not known to what extent Broom's mechanical preparation of the maxilla contributed to the damage of original alveolar bone adjacent to the canine socket. It is also not certain to what extent some degree of predepositional bone loss may have occurred after the canine teeth had broken, prior to the sockets being filled with sediment which became calcified. However, assuming that original measurements by Broom et al.[12] were accurate, it is apparent that in 1950 the conical canine alveolar sockets were larger than they are currently. We suggest that this difference is a result of acid preparation sometime after 1950. These observations are relevant to the identification of the sex of Sts 5, compared to other cranial specimens of *A. africanus* that have been identified as belonging to either male or female individuals.

The measurement of 9 mm by Broom et al.[12] for the BL diameter of Sts 5 is larger than the BL diameter of 8 mm for a definite male specimen of *A. africanus* (Stw 505), and almost as large as the BL diameters for another male adult, TM 1511, estimated as 10.2 mm for the left canine[12] and 10.5 mm for the right canine[11]. Discovered in 1936, TM 1511 was not prepared in acetic acid.

Relationships between BL and MD canine diameters for presumed male and female specimens of *A. africanus* are shown in Figure 1, based partly on data presented by Grine et al.[11] but (for the first time, in this study) including the position of Sts 5 based on BL and MD diameter measurements published by Broom et al.[12] in 1950 and recorded before the damage associated with acetic acid preparation. According to these data, the canine diameter measurements of Sts 5 are consistent with the hypothesis that 'Mrs Ples' indeed represents a male individual. The data for BL and MD diameters shown in Figure 1 counter the statement by Grine et al.[11] that 'there is no evidence to contradict the assertion' that Sts 5 represents a female individual.

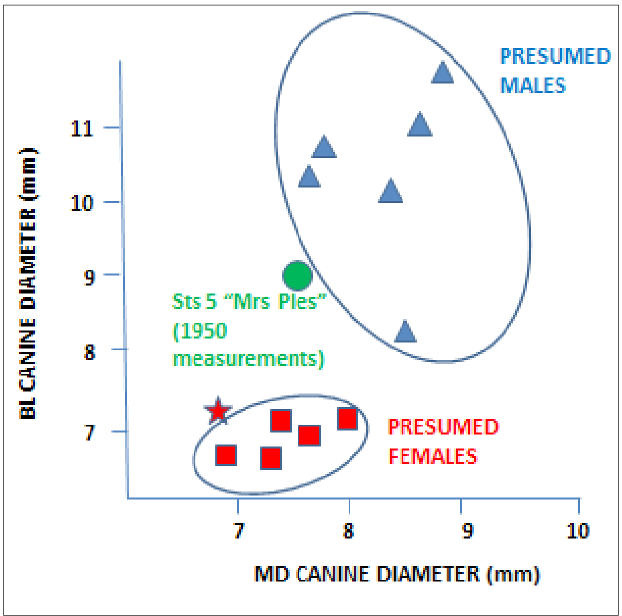


Figure 1: Relationship between buccolingual (BL) and mesiodistal (MD) diameters for conical canine sockets, based in part on data for presumed male individuals (blue triangles) and presumed female individuals (red squares) of *Australopithecus africanus*, published by Grine et al.[11] The green circle represents MD and BL measurements for Sts 5 as published by Broom et al.[12], most probably taken before damage and alveolar bone loss occurred. According to these data, Sts 5 is more likely to belong to a small male individual than a female individual, as proposed by Grine et al.[11] The red star represents measurements of Sts 5 given by Grine et al.[11], probably obtained after damage caused by digestion of cranial bone in acetic acid. Presumed male individuals are Stw 505, TM 1511, Sts 52, Stw 183, Stw 252, Stw 369 and presumed female individuals are Sts 71, Sts 17, Sts 53, Stw 13, Stw 73.[11]

Sexual dimorphism in *A. africanus*

Sexual dimorphism of the facial anatomy of *A. africanus* was investigated by Lockwood who recognised Sts 71 as a female adult and Stw 505 as a large male adult; and, on the basis of many facial variables taken together, Lockwood[7] concluded that the sex of the relatively small Sts 5 individual was 'indeterminate'. This problem relates at least in part to the challenge of distinguishing a relatively large female from a small male individual.[13]

Certain features can help to address this problem. Among the most remarkable facial features of Sts 5 is its prominent glabella which Lockwood[7] described as 'marked' (as in the case of the male Stw 505), distinct from the slight glabellar prominence in Sts 71 (identified as female). In fact, Lockwood[7] stated that the glabellar as well as the supraorbital morphology of Sts 5 indicated that this specimen was one of the 'best candidates' *for being male* (our emphasis).

Lockwood[7] calculated mean values and standard deviations for 21 craniofacial dimensions for a sample of 13 specimens of *A. africanus* housed at the University of the Witwatersrand and the Ditsong National Museum of Natural History (formerly the Transvaal Museum), including Sts 5 (Table 1). We have calculated standardised z-scores for the facial dimensions of Sts 5 using the means and standard deviations for these dimensions in Sts 5 and the other *A. africanus* specimens measured by Lockwood[7]. The z-scores are calculated by:

z = [x - mean for *A. africanus* dimensions]/standard deviation for *A. africanus* dimensions, where x is the dimension for Sts 5, for each of the 21 variables listed in Table 1.

Table 1: Measurements of 21 craniometric distances of Sts 5 in relation to the means and standard deviations for corresponding variables for specimens of *Australopithecus africanus* measured by Lockwood[7]. The *z*-values for Sts 5 in bold are relatively large in relation to the *z*-values for Sts 5 for other cranial dimensions.

Cranio-facial measurement		Sts 5 (mm)	Mean *A. africanus* (mm)	Standard deviation (mm)	*z* for Sts 5
Orbital height	ORBH	30.5	32.2	2.8	-0.607
Glabellar height	GLAH	75.3	82.1	10.7	-0.635
Upper facial height	UPFH	70	77.8	10	-0.789
Nasal height	NASH	47.6	54.1	7.1	-0.915
Orbito-alveolar height	OALH	49	49.1	5.3	-0.019
Orbito-jugal height	OJUH	57.8	53.8	6.6	**0.606**
Foraminal height	FORH	38	35.9	3	**0.700**
Malar depth	MALH	25.1	26.4	3.8	-0.342
Alveolar height	ALVH	30	25.7	3.2	**1.343**
Superior facial breadth	SUFB	95.1	95.5	8.2	-0.048
Anterior interorbital breadth	ITOB	15.5	16	1.5	-0.333
Bimaxillary breadth	BMAB	105	99.7	8.1	**0.654**
Interforaminal breadth	IFOB	43.6	44.8	6.4	-0.187
Nasal aperture breadth	NASB	27	24.9	2.5	**0.840**
Snout breadth	SNOB	45.6	47	5	-0.280
Anterior maxillo-alveolar breadth	ANMB	45.4	46.3	3.3	-0.272
Maxillo-alveolar breadth	MAXB	65.4	64.9	4.7	0.106
Anterior palatal breadth	APAB	33	32.5	2.6	0.192
Palatal breadth	PALB	36.4	35.1	3.8	0.342
Maxillo-alveolar length	MAXL	50.4	51.4	2.2	-0.454
Post-canine maxillo-alveolar length	PMXL	42	41.2	2.1	0.380

Five craniofacial dimensions are relatively large in Sts 5: alveolar height (ALVH), foraminal height, nasal breadth, bi-maxillary breadth and orbito-jugal height. Results are presented in Figure 2 for ALVH and bimaxillary breadth, as two examples.

ALVH in Sts 5 has a value of 30 mm compared with a mean value of 25.7±3.2 mm (n=11) for specimens of the species examined by Lockwood[7]. ALVH in *A. africanus* ranges between 21.1 mm and 30.0 mm. Thus Sts 5 has the largest ALVH dimension in this sample of the species. ALVH in Sts 5 (30 mm) is not only larger than the ALVH value of 23 mm in Sts 71 (identified as a female adult), but also larger than the ALVH value of 29 mm in Stw 505 identified as a large male adult. This is also reflected by standardised z-scores (Figure 2). Similarly, in terms of bimaxillary breadth, Sts 5 appears to be closer to that of a male individual (Stw 505), as shown in Figure 2.

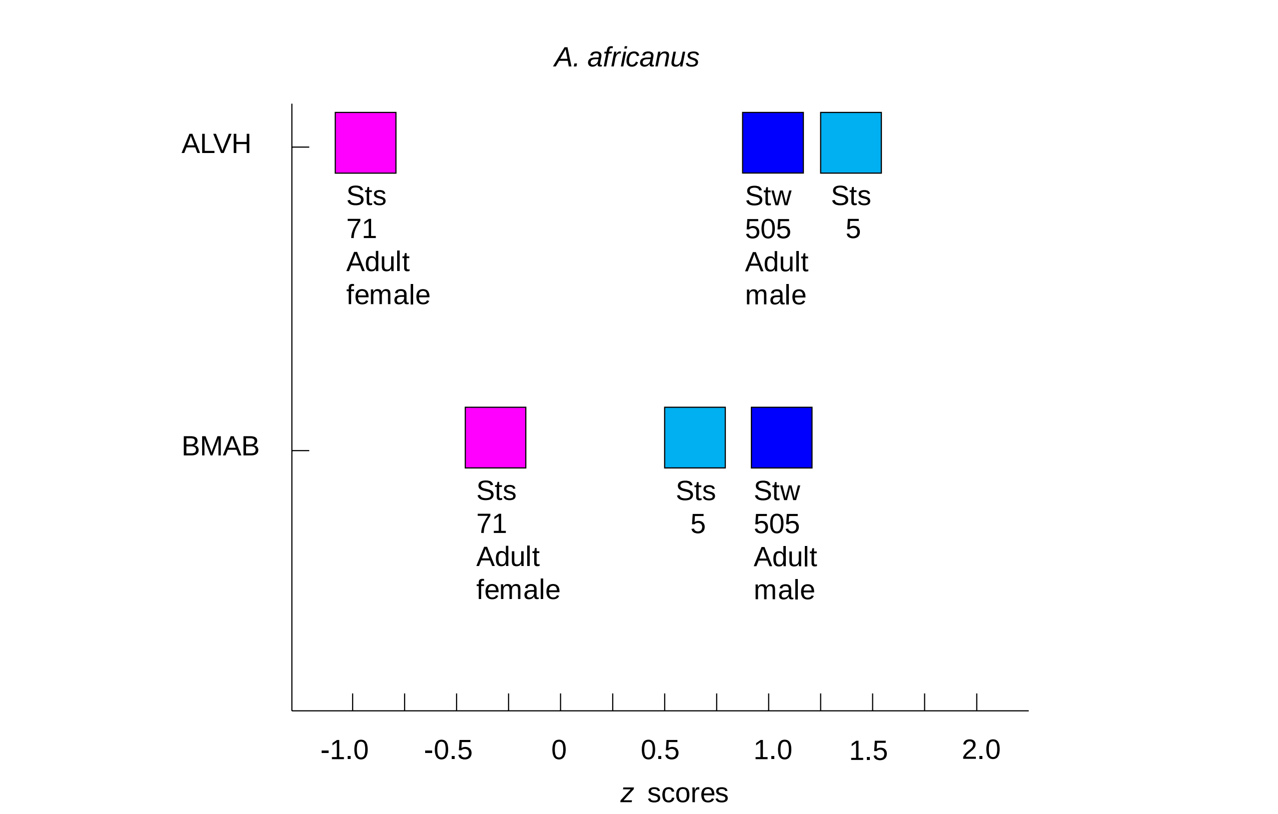


Figure 2: Standardised *z*-values for Sts 5, compared to other specimens of *Australopithecus africanus,* based on means and standard deviations of alveolar height (ALVH) and bi-maxillary breadth (BMAB).

Conclusion

Both age and sex are factors that would have contributed to variation in growth and development of crania of australopithecines.[13-16] If Sts 5 was adolescent, as suggested by Thackeray et al.[8], this would partially account for the relatively small dimensions of some of the facial variables of this specimen, for example nasion height and upper posterior facial height. However, the relatively large values of certain facial variables of 'Mrs Ples' (Figure 2, Table 1) – for example, ALVH as well as other dimensions such as foraminal height, nasal breadth, bi-maxillary breadth and orbito-jugal height – can partially be accounted for in terms of Sts 5 belonging to a male individual. The fact that some variables of Sts 5 are relatively large for Sts 5, whereas others are relatively small (as compared to the mean values for *A. africanus*) could be because of a combination of factors associated with both ontogeny and sexual dimorphism.

Despite observations by Villmoare et al.[10] regarding remodelling of anterior maxillary bone, the prominent glabella of Sts 5 and its supra-orbital morphology are not inconsistent with it being male, as noted by Lockwood[7]. Furthermore, the indisputable evidence for open cranial sutures[17] is not inconsistent with the hypothesis that Sts 5 was adolescent at the time of death. These observations, together with the relatively large BL measurement for the canine alveolar diameter (as published originally by Broom et al.[12]), refute the statement that 'there is no evidence to contradict the assertion that 'Mrs Ples' is an adult female'[11].

On the basis of the data presented here, we conclude that Sts 5 is a small male rather than a large female individual. This conclusion is relevant to an understanding of Sts 5 in the context of sexual dimorphism in *A. africanus*.

Acknowledgements

J.F.T. thanks the Andrew W. Mellon Foundation, the National Research Foundation (South Africa) and the DST/NRF Centre of Excellence in Palaeosciences for their support. We thank J. Braga, C. Dean, A.L. Dinat and A.D. Botham for helpful comments.

References

1. Broom R. Discovery of a new skull of the South African ape-man, *Plesianthropus*. Nature. 1947;159:672.

2. Partridge TC. Dating of the Sterkfontein hominids: Progress and possibilities. Trans R Soc S Afr. 2005;60(2):107–109. https://dx.doi.org/10.1080/00359190509520486

3. Pickering R, Kramers JD. Re-appraisal of the stratigraphy and dating of new U-Pb dates for the Sterkfontein hominin site, South Africa. J Hum Evol. 2010;59(1):70–86. http://dx.doi.org/10.1016/j.jhevol.2010.03.014

4. Thackeray JF, Dupont LM. Last recorded occurrence of *Australopithecus africanus* and climatic change in southern Africa. S Afr J Sci. 2006;102:50.

5. Broom R. The most perfect pre-human skull ever found. The discovery of a nearly perfect 'missing link' skull. Illustrated London News. 1947;210:508–509.

6. Rak R. The australopithecine face. New York: Academic Press; 1983.

7. Lockwood CA. Sexual dimorphism in the face of *Australopithecus africanus*. Am J Phys Anthropol. 1999;108(9):97–127. http://dx.doi.org/10.1002/(SICI)1096-8644(199901)108:1<97::AID-AJPA6>3.0.CO;2-O

8. Thackeray JF, Braga J, Treil J, Niksch N, Labuschagnge JH. 'Mrs Ples' (Sts 5) from Sterkfontein: An adolescent male? S Afr J Sci. 2002;98(1):21–22.

9. Bonmati A, Arsuaga J-L, Lorenzo C. Revisiting the developmental age-at-death of the "Mrs Ples" (Sts 5) and Sts 14 specimens from Sterkfontein (South Africa): Do they belong to the same individual? Anat Rec. 2008;291(12):1707–1722. http://dx.doi.org/10.1002/ar.20795

10. Villmoare B, Kujkendall K, Rae TC, Brimacombe CS. Continuous dental eruption identifies Sts 5 as the developmentally oldest fossil hominin and informs the taxonomy of *Australopithecus africanus*. J Hum Evol. 2013;65:798–805. http://dx.doi.org/10.1016/j.jhevol.2013.09.007

11. Grine FE, Weber GW, Plavcan JM, Benazzi S. Sex at Sterkfontein: 'Mrs Ples' is still an adult female. J Hum Evol. 2012;62(5):593–604. http://dx.doi.org/10.1016/j.jhevol.2012.01.010

12. Broom R, Robinson JT, Schepers GWH. Further evidence of the structure of the Sterkfontein ape-man *Plesianthropus*. Transv Mus Mem. 1950;4(4):11–13.

13. Thackeray JF. 'Mrs Ples' from Sterkfontein: Small male or large female? S Afr Archaeol Bull. 2000;55:155–158. http://dx.doi.org/10.10.2307/3888964

14. Ackermann RR, Krowitz GE. Morphological and craniofacial shape and growth patterns in *Australopithecus africanus*. Am J Phys Anthropol. 2000;30:91.

15. Lockwood CA, Mentor CG, Moggi-Ceechi J, Keyser A. Extended male growth in a fossil hominin species. Science. 2007;318(5855):1443–1446. http://dx.doi.org/10.10.1126/science.1149211

16. Prat S, Thackeray JF. Position des lignes temporales sur le cranium de "Mrs" Ples (*A. africanus*): une attribution sexuelle est-elle possible? [Possible position of the temporal lines on the cranium of 'Mrs' Ples (*A. africanus*): Is sexual determination possible?] C R Acad Sci II. 2001;332:403–409. French. http://dx.doi.org/10.1016/S1251-8050(01)01548-8

17. Potze S, Thackeray JF. Temporal lines and open sutures revealed on cranial bone adhering to matrix associated with Sts 5 ("Mrs Ples"), Sterkfontein, South Africa. J Hum Evol. 2010;58(6):533–535. http://dx.doi.org/10.1016/j.jhevol.2009.11.005

Restoration of wetlands on the Agulhas Plain is unlikely to generate peat

AUTHORS:
Anthony Mills[1]
Roland Hunter[2]

AFFILIATIONS:
[1]Department of Soil Science, Stellenbosch University, Stellenbosch, South Africa
[2]C4 EcoSolutions, Cape Town, South Africa

CORRESPONDENCE TO:
Anthony Mills

EMAIL:
mills@sun.ac.za

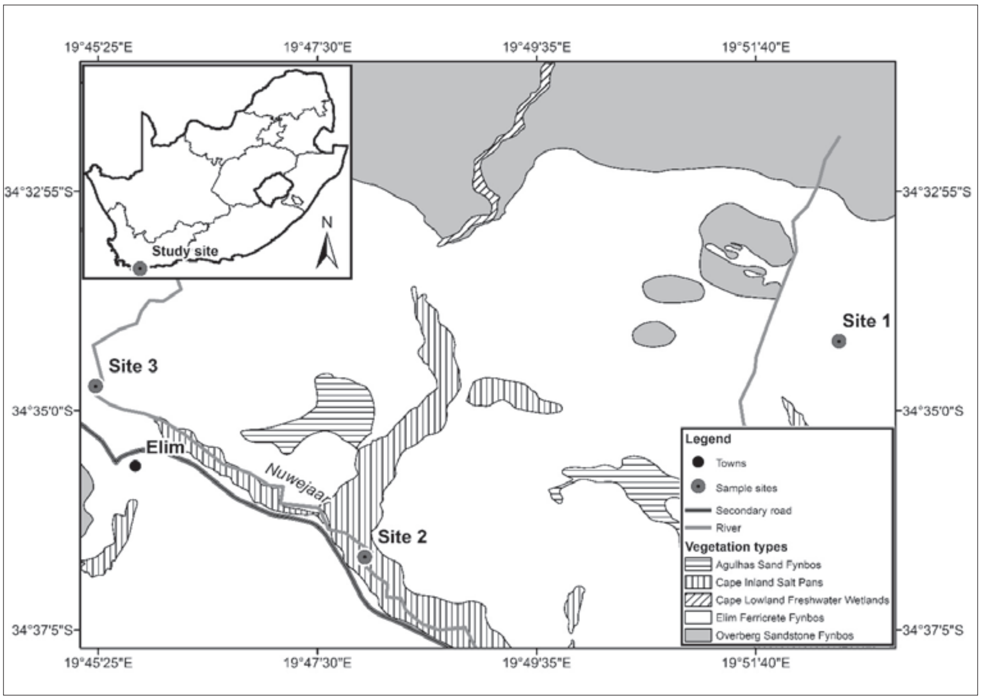
KEYWORDS:
carbon; organic soil; South Africa

HOW TO CITE:
Mills A, Hunter R. Restoration of wetlands on the Agulhas Plain is unlikely to generate peat. S Afr J Sci. 2018;114(1/2), Art. #a0252, 3 pages. http://dx.doi.org/10.17159/sajs.2018/a0252

Wetlands in the Nuwejaars Special Management Area (NSMA) on the Agulhas Plain of South Africa are classified as Western Cape Floodplain Wetlands[1] and are characterised by dense stands of palmiet (*Prionium serratum* L.f.)[2-5]. Invasions of alien plants and construction of infrastructure are resulting in considerable degradation of ecosystem services emanating from the wetlands.[3] Large-scale restoration – by removing alien plants and rehydrating soils – is constrained by funding, and consequently new income streams from restored wetland landscapes need to be investigated. One option is to sequester carbon and generate carbon credits during the wetland restoration process.[6] The economic viability of this option largely depends on the amount of carbon that could be sequestered. Previous studies of Western Cape Floodplain Wetlands[1] have found that the carbon content of soils in wetlands with palmiet is surprisingly variable (e.g. ~1.3% in the Kromme River[7] versus ~24% in the Goukou River[8]). In general, however, wetlands in the Western Cape do not usually have a carbon content of more than 10%, possibly because of the rapid decomposition of organic matter during the hot, dry summer months.[9]

In certain parts of the wetlands of the NSMA there are thick (>0.5 m) layers of dark soil. The full geographical extent of these layers is not known, partly because they tend to be buried beneath pale sandy sediments (probably deposited by floodwaters) and are only visible at sites where they have been exposed by erosion. Local landowners refer to the dark soil layers as peat. In the South African context, the term peat is generally used in a colloquial manner, with the term organic soils being favoured in the scientific literature. Organic soil layers in South Africa are defined as those with a mean carbon content of at least 10% throughout a vertical distance of 20 cm.[9,10] To our knowledge, the organic carbon content of the dark soil layers in the NSMA, prior to this study, had not been determined; it was consequently unclear whether they could be classified as organic, which would make the term 'peat' colloquially appropriate.

As a first step towards determining the carbon sequestration potential of the NSMA wetlands and resolving whether the dark soil layers were organic, we determined the organic carbon content of distinct soil layers at three sites with different land use histories: (1) D'Alton Farm (34.57233 S, 19.87432 E); (2) Elim Bridge 1 (34.60651 S, 19.79916 E); and (3) Elim Bridge 2 (34.57946 S, 19.75651 E) (see Figure 1). Site 1 (D'Alton Farm) is located on the bank of the Kastaaings River and has been grazed by domestic livestock for more than 50 years. A dense stand of the alien tree *Acacia longifolia* was present on the site until 2005, when a severe flood caused extensive damage, removing the trees and exposing the dark soil layers. Given this land use history, we categorised this site as extremely degraded. Site 2 (Elim Bridge 1) is situated in the floodplain of the Nuwejaars River, is relatively undisturbed, and has not been eroded. We categorised this site as non-degraded. Site 3 (Elim Bridge 2) has historically been used as a rangeland for cattle and was cleared of invasive species in 2010, with a small amount of erosion occurring thereafter. We categorised this site as moderately degraded.



Sources: The map is based on data sets from the Municipal Demarcation Board[14] and SANBI[15].

Figure 1: Location of study sites in the Nuwejaars Special Management Area (NSMA), Western Cape, South Africa: Site 1: D'Alton Farm, Site 2: Elim Bridge 1, Site 3: Elim Bridge 2.

In June 2011, 32 soil profiles were cored with an 8.26-cm auger to a depth of 2.4 m: 16 soil profiles at Site 1, 8 at Site 2 and 8 at Site 3. Soil samples were taken from each profile at the following approximate depths: 0.1, 0.25, 0.4, 0.8, 1.2, 1.6, 2.0 and 2.4 m. The samples were subsequently air dried and sieved (<2 mm). Layers encountered during sampling included: (1) a pale surface layer of quartzitic sand above 0.5 m; (2) dark layers of quartzitic sand with distinct, fine pieces of organic matter; (3) pale layers of quartzitic sandstone gravel below 1 m; and (4) a layer of gleyed clay below 2 m.

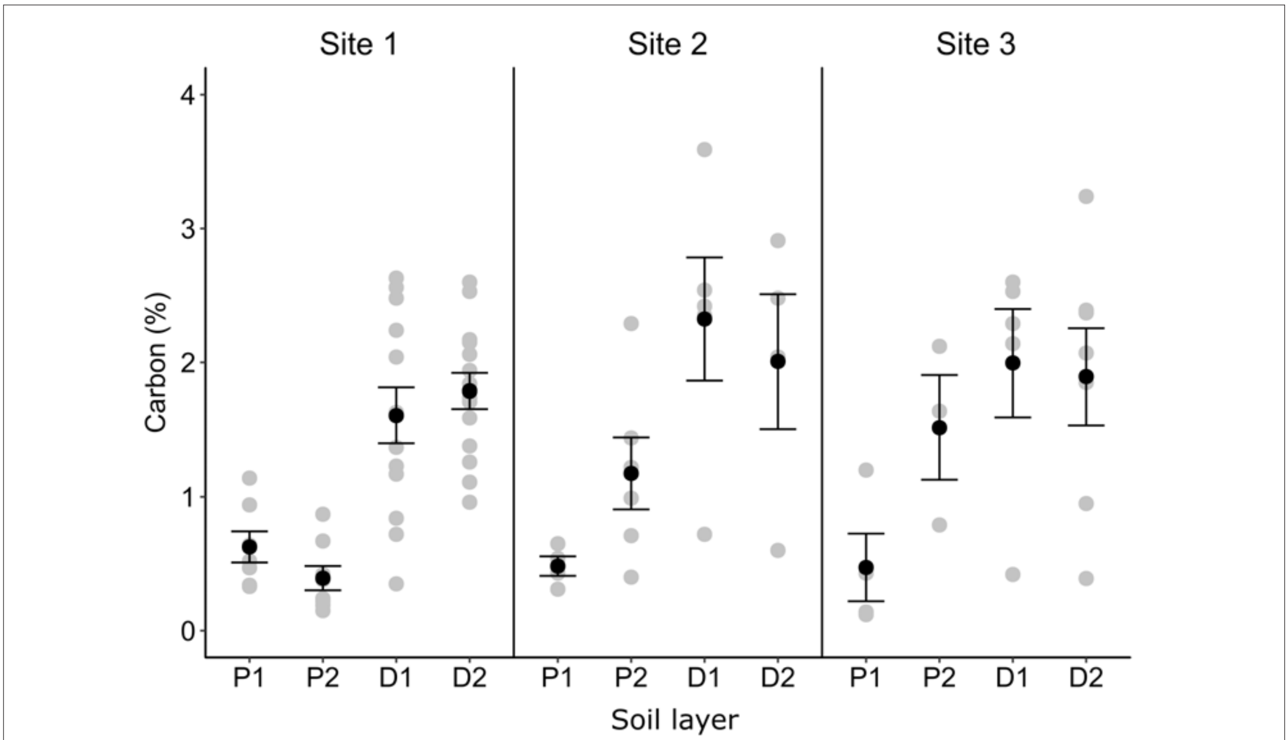
To determine whether dark soil layers were relatively enriched in carbon, samples from dark as well as pale layers (except the gleyed clay layer) were analysed for organic carbon using the Walkley–Black method.[11] Samples of dark soil layers from D'Alton Farm ($n=12$) and the Elim Bridge ($n=8$) sites were also analysed for clay, silt, fine sand, medium sand and coarse sand content.

All statistical analyses were conducted in R.[12] Soil carbon data were analysed for significant differences between site, depth and layer type using mixed-effects models (function lmer; lme4 package). Layers and depth were separately considered as fixed effects, whereas site and replicate were considered random effects. Data were transformed using BoxCox transformation to reach or improve normality prior to analysis. Post-hoc pairwise comparisons were performed using Tukey's test.

Dark soil layers comprised mainly fine and medium sand, with contents of 57.7±2.5% and 21.3±2.4% (mean±SE), respectively. The contents of other size fractions, namely coarse sand, silt and clay contents were 6.4±1.0%, 6.1±0.9% and 8.6±1.4%, respectively. Site-specific percentages are presented in Table 1. Results of the carbon analyses are presented in Figure 2. No significant differences in carbon content of pale or dark layers between the sites were recorded. The mean carbon content of dark layers (1.85±0.1%) across all sites was significantly greater than that of pale layers (0.72±0.1%; $p<0.001$). Shallow (above 0.5 m) layers across all sites had a minor but statistically significant greater amount of carbon than deep (below 0.5 m) layers (1.9±0.1% versus 1.7±0.2% for dark layers; 0.9±0.2% versus 0.6±0.1% for pale layers; $p<0.001$).

Table 1: Clay, silt, fine sand, medium sand and coarse sand content (%) of dark soil layers at three study sites in the Nuwejaars Special Management Area, South Africa. Sample size (n), means (%), standard deviation (SD), standard error (SE) and confidence intervals (CI) are presented.

Site	Factor	*n*	Mean (%)	SD	SE	CI
D'Alton Farm	Clay	12	4.0	0.5	0.1	0.3
	Silt	12	3.7	3.0	0.9	1.9
	Fine sand	12	53.4	14.1	4.1	9.0
	Medium sand	12	29.1	12.2	3.5	7.7
	Coarse sand	12	9.8	6.4	1.9	4.1
Elim Bridge 1	Clay	8	15.3	8.0	2.8	6.7
	Silt	8	11.0	3.4	1.2	2.9
	Fine sand	8	56.1	12.2	4.3	10.2
	Medium sand	8	12.9	5.7	2.0	4.8
	Coarse sand	8	4.7	2.0	0.7	1.7
Elim Bridge 2	Clay	8	8.8	7.8	2.7	6.5
	Silt	8	4.8	3.8	1.4	3.2
	Fine sand	8	65.8	11.1	3.9	9.3
	Medium sand	8	17.8	11.9	4.2	10.0
	Coarse sand	8	2.8	2.9	1.0	2.4



P1, deep pale layers (n=15); P2, shallow pale layers (n=17); D1, deep dark layers (n=23); D2, shallow dark layers (n=25).

Individual values are depicted as light grey circles; means and standard errors are depicted as black circles and bars, respectively.

Figure 2: Organic carbon content of shallow (<0.5 m) and deep (>0.5 m) pale and dark soil layers at the three study sites in the Nuwejaars Special Management Area, South Africa.

Methodologies for generating carbon credits in wetlands focus predominantly on peatlands[13] because restoration of degraded peatlands can be expected to sequester large amounts of carbon per unit area. Our preliminary study at three separate sites in the NSMA did not find any evidence of the presence of degraded peatlands. We expected to find differences in carbon content of the dark soil layers between our study sites because of their different physical conditions in terms of degree of erosion and extent of alien plant invasion. However, no such differences were found, which leads to two preliminary conclusions. Firstly, dark soil layers in undegraded sites in the NSMA are not carbon-rich, given that mean carbon content of these layers was less than 2.5% across all sites. And secondly, carbon in the dark layers is relatively resilient to decay, given that organic carbon content was similar in sites with markedly different land use histories. Based on our results, opportunities for generating carbon credits through wetland restoration at our three study sites in the NSMA are likely to be limited. A caveat to this conclusion is that our study only investigated a small part of the NSMA. Further research is warranted to determine whether there are organic soils in other parts of the NSMA and to what extent carbon is lost from them after degradation. Until results of such future studies are available, it is probably prudent to avoid the use of the term peat when describing the dark soil layers in these wetlands.

Acknowledgements

We thank the landowners and management of the Nuwejaars Special Management Area for allowing access to their land, assistance with field sampling, and site-specific information. We gratefully acknowledge the Nuwejaars Wetland Special Management Area, the South African Department of Environmental Affairs, Natural Resources Management Programme and the National Research Foundation (grant number FA2005040700027) for funding this research. Our thanks go in particular to R. Allardice, M. D'Alton and E. Brink. The field work of T. Thabisisani as well as technical support from J. Baum, J. Allen, S. Mochrie and S. Foden are also gratefully acknowledged.

References

1. Marneweck GC, Grundling PL, Muller JL. Defining and classification of peat wetland eco-regions in South Africa. Pretoria: Department of Agriculture; 2001.
2. Herdien EL, Petersen C, Reed C, Impson D, Belcher A, Ndiitwani T, et al. Ecological state of rivers of the Overberg region 2004/2005. Pretoria: River Eco-status Monitoring Programme; Department of Water Affairs; 2006. Available from: http://www.dwa.gov.za/iwqs/rhp/technical_reports.aspx.
3. South African National Biodiversity Institute. Duiwenhoks and Goukou wetlands prove their worth. The Gumboot. 2007.
4. South African National Biodiversity Institute. Duiwenhoks Goukou. The Gumboot. 2009.
5. Bekker D. The geomorphic origin, evolution and collapse of a peatland dominated by *Prionium serratum*: A case study of the Tierkloof Wetland, Western Cape [MSc thesis]. Grahamstown: Rhodes University; 2009.
6. Bonn A, Reed M, Evans C, Joosten H, Bain C, Farmer J. Investing in nature: Developing ecosystem service markets for peatland restoration. Ecosyst Serv. 2014;9:54–65. http://dx.doi.org/10.1016/j.ecoser.2014.06.011
7. Ayine N. Plant community distribution and diversity, and threats to vegetation of the Kromme River peat basins [MSc thesis]. Grahamstown: Rhodes University; 2007.
8. Sieben EJJ. Plant functional composition and ecosystem properties: The case of peatlands in South Africa. Plant Ecol. 2012;213:809–820. http://dx.doi.org/10.1007/s11258-012-0043-3
9. Fey M. Soils of South Africa. Their distribution, properties, classification, genesis, use and environmental significance. Cambridge: Cambridge University Press; 2010.
10. Soil Classification Working Group. Soil classification – A taxonomic system for South Africa. Memoirs on the Agricultural Natural Resources of South Africa no. 15. Pretoria: Department of Agricultural Development; 1991.
11. Walkley A. A critical examination of a rapid method for determination of organic carbon in soils – Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 1947;63:251–257.
12. R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2016. Available from: http://www.R-project.org.
13. Verified Carbon Standard (VCS). Baseline and monitoring methodology for the rewetting of drained peatlands used for peat extraction, forestry or agriculture based on GESTs. Washington DC: VCS; 2011. Available from: https://goo.gl/GZFc1u
14. Municipal Demarcation Board. 2016 Boundaries, district municipalities. Pretoria: Municipal Demarcation Board; 2016. Available from: http://www.demarcation.org.za/site/shapefiles/
15. South African National Biodiversity Institute. Vegetation map of South Africa, Lesotho and Swaziland [online].c2009 [updated 2012; cited 2017 Dec 07]. Available from: http://bgis.sanbi.org/

Soil algae and cyanobacteria on gold mine tailings material: Comments on Seiderer et al. (2017)

AUTHOR:
Philip Lloyd[1]

AFFILIATION:
[1]Energy Institute, Cape Peninsula University of Technology, Cape Town, South Africa

CORRESPONDENCE TO:
Philip Lloyd

EMAIL:
lloydp@cput.ac.za

KEYWORDS:
oxidation; pyrites; acidity; revegetation; *Thiobacillus*

HOW TO CITE:
Lloyd P. Soil algae and cyanobacteria on gold mine tailings material: Comments on Seiderer et al. (2017). S Afr J Sci. 2018;114(1/2), Art. #a0255, 1 page. http://dx.doi.org/10.17159/sajs.2018/a0255

Seiderer et al. recently described[1] efforts to grow algae and cyanobacteria on gold mine tailings. They noted:

> *The presence of acids and the high salt content of gold tailings material are likely synergistic in causing biotoxicity as low pH generally increases the bioavailability of metals. As a result, most gold mine* [tailings] *are devoid of vegetation and have a stressed heterotrophic microbial community.*

They reported the pyrites content as <5%.

It is known that, under the conditions on tailings dams, pyrites oxidise and generate acid. This process is dynamic; it starts when the soil pH is less than about 5 and continues until most of the pyrite in the upper few metres has oxidised. Thus their suggested process is most unlikely to prove sustainable. The ongoing production of acidity would have destroyed the colonies first established.

In the early years of the Vegetation Unit established by the Chamber of Mines, attempts were made to vegetate slimes dams soon after placement. In spite of intensive liming, soil acidity would increase. Experiments showed a direct correlation between the amount of residual pyrite in the tailings and the quantity of lime required to ensure sustained vegetative cover. As long as there was more than about 0.2% m/m pyrites in the material, acid was generated and the growth of vegetation negatively affected.

An additional phenomenon was a rise in acidity during the dry season. This rise was traced to evaporation and concentration of the acidity in the near surface moisture. There were strikingly different depth profiles of acidity at the end of summer and the end of winter.

The root cause was the arrival of *Thiobacillus*. For about a year after placement, the tailings were essentially sterile, and slightly alkaline. As things like the residual cyanide were oxidised, the pH started to drop, and at a soil pH of about 5 the thiobacilli became very active. Then the pH dropped rapidly, and remained low. Few other microbial species were present while the thiobacilli were active.

Thiobacillus required oxygen. In sand dumps, diffusional processes and permeability to oxygen-saturated rain meant that oxidation took place throughout the depth of the tailings. But in the slimes, which comprise the majority of the tailings, the fine size (<75 μm) slowed both diffusion and penetration by rain, and oxidation proceeded very slowly more than about 50 cm below surface. The mechanism by which oxygen found its way into the depth of the slimes was finally identified as the expansion and contraction of the gas trapped inside the tailings as the barometric pressure varied. Gas emerging from the slimes when a low-pressure system passed over the tailings could be as low as 3% oxygen.

The arrival of the thiobacilli was associated with an increase in the fixed nitrogen content of the soil. At that stage, it was not known that the thiobacilli were nitrogen-fixers. The Porton microbiological unit in the UK proved that nitrogen fixation was indeed taking place.[2]

These findings enabled procedures to be developed to ensure sustainable growth on tailings. The Vegetation Unit would not attempt to grass tailings until most of the pyrite had been oxidised by the bacteria. A small amount of lime would be added, and the site would then be sprayed continually with water for several weeks to drive the residual acid deep into the slimes. Only then would planting begin – and the young plants had to be shielded against wind-blown slime. Hundreds of hectares were grassed in this way. There were a few patches of failure, which were traced to wind-blown damage of plants; the rest were sustained for 20 or more years, as other species took over.

This work was unfortunately never published in South Africa. It transpired that the same bacterial processes were solubilising uranium, which could be recovered cheaply by mining the tailings. At the time, uranium was a strategic resource, and the information was considered confidential. Some years later, the results were presented at a Canadian conference[3]. It is likely that Seiderer et al. would not have had access to this information.

References

1. Seiderer T, Venter A, Van Wyk F, Levanets A, Jordaan A. Growth of soil algae and cyanobacteria on gold mine tailings material. S Afr J Sci. 2017;113 (11/12), Art. #2016-0384, 6 pages. http://dx.doi.org/10.17159/sajs.2017/20160384
2. Mackintosh ME. Nitrogen fixation by *Thiobacillus ferrooxidans*. Microbiology. 1978;105:215–218. https://doi.org/10.1099/00221287-105-2-215
3. Lloyd PJD. Ninety years' experience in the preservation of uranium ore dumps. In: Brawner CO, editor. Proceedings of the First International Conference on Uranium Mine Waste Disposal; 1980 May 19–21; Vancouver, Canada. New York: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers; 1980. p. 33–42.

Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo Province, South Africa

AUTHORS:
Shandukani R. Netshifhefhe[1,2]
Ednah C. Kunjeku[3]
Frances D. Duncan[1]

AFFILIATIONS:
[1]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa
[2]Gauteng Department of Agriculture and Rural Development, Johannesburg, South Africa
[3]Department of Plant Production, University of Venda, Thohoyandou, South Africa

CORRESPONDENCE TO:
Shandukani Netshifhefhe

EMAIL:
shandukani.netshifhefhe@gauteng.gov.za

DATES:
Received: 01 May 2017
Revised: 24 July 2017
Accepted: 10 Aug. 2017

KEYWORDS:
insects; entomophagy; harvesters; marketers; *Macrotermes* spp.

HOW TO CITE:
Netshifhefhe SR, Kunjeku EC, Duncan FD. Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo Province, South Africa. S Afr J Sci. 2018;114(1/2), Art. #2017-0145, 10 pages. http://dx.doi.org/10.17159/sajs.2018/20170145

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
National Research Foundation (South Africa)

Termites are a good food source, being rich in proteins, fats, vitamins and many essential mineral nutrients, and thus provide food security for poor households. We report on a survey conducted in the Vhembe District Municipality of Limpopo Province, South Africa, to identify edible termite species and find out how they are harvested, prepared, graded, packaged and marketed. We also looked at the socio-economic factors of the harvesters, marketers and consumers. Using a structured questionnaire, 104 individuals were interviewed from 48 villages. Most of the harvesters were over the age of 60 years but termites are consumed by the whole family. The results of the survey revealed that only three termite species are consumed: soldiers of *Macrotermes falciger* (89.90%), *M. natalensis* (8.08%) and *M. michaelseni* (2.02%). The preferred method of preparation was frying (77.55% of the respondents). At least 80.77% of the respondents indicated that some religions have restrictions on termite consumption but no ethnic restrictions were reported. The income derived from selling termites was estimated to range from ZAR2040 to ZAR17 680 per annum between April 2015 and April 2016. The results of this study showed that edible termites contribute significantly to the livelihoods of many rural families and this indigenous knowledge should be passed on to younger generations. Research on the sustainability of termite harvesting is recommended.

Significance:

- Termites are sources of food with high economic and social importance, and are easily accessible by the poor.
- Studies have been conducted on edible termites in many African countries, yet comparatively little is known about edible termites in South Africa.
- Preservation of indigenous knowledge used during harvesting and processing needs to be prioritised.

Introduction

The consumption of insects by humans is commonly known as entomophagy.[1] Early hominids have been reported to have eaten insects, with termite soldiers and alates of the genus *Macrotermes* being part of their diet.[2,3]

Termites are rich in proteins, vitamins and mineral nutrients.[4] The crude protein content of termites ranges from 20.4% in *Macrotermes bellicosus* (Smeathman) to 35.88% in *Macrotermes nigeriensis* (Sjostedt).[4,5] *Macrotermes bellicosus* alates have been found to be rich in vitamins, with contents of 2.89 μg/100 g for vitamin A; 1.98 mg/100 g for vitamin B2 and 3.41 mg/100 g for vitamin C.[4] Mbah and Elekima[5] found alates to be high in minerals, namely calcium 21 mg/100 g; phosphorus 1.36 mg/100 g; iron 27 mg/100 g and magnesium 0.15 mg/100 g. In addition to these nutrients, a study conducted by Banjo et al.[4] found that *M. bellicosus* has a carbohydrate content of 43.3%, while Mbah and Elekima[5] found that the oil content of the same termite species is 28.37%. The studies conducted by Phelps et al.[6] in Zimbabwe found that *Macrotermes falciger* (Gerstacker) are very high in energy with 761 kcal/100 g. Termites can therefore provide food security in many poor African countries as they contain essential nutrients, which are often lacking in the diets of people in those countries.[7]

Macrotermes nigeriensis alates have been reported by Igwe et al.[8] and Ajayi and Adedire[9] to be consumed as a delicacy in certain parts of Nigeria. People living in Nkoya in the northeastern part of the Western Province of Zambia use termites as an important part of their diets.[10] Chavunduka[11] reported the consumption of termite soldiers of *Macrotermes* species in Zimbabwe. About 14 species of the family Macrotermitidae have been reported to be consumed in sub-Saharan Africa alone, including in some parts of South Africa.[12] The majority of these termite species belong to the genus *Macrotermes*. Of the 12 recognised species of *Macrotermes* that occur in the sub-Saharan Africa region, 9 are commonly eaten and have been recorded from southern Africa.[13,14] These species are all naturally open-woodland or savanna dwellers and all termite castes – queen, soldiers, alates and workers – are eaten.[15,16] In South Africa, Bodenheimer[17] documented the alates of *Macrotermes swaziae* (Full) and *Microhodotermes viator* (Latreille) as edible termite species, while Quin[18] also reported *Odontotermes badius* (Haviland) and *O. capensis* (DeGeer) to be edible.

Harvesting of soldier termites in Uganda was reported to have been done by using wet grass blades or parts of tree pods or bark, by inserting them into the holes of termite mounds that had been opened with a knife.[19] Alates emerge from holes at the mound after the first rains and are caught using light traps suspended over water buckets and basins to collect them as they drop. Bergier[20] indicated that baskets placed upside down over the holes were used in Democratic Republic of Congo to collect the emerging alates.

Termites are killed by drowning, boiling or roasting for a few minutes and are then sun-dried.[10] A study conducted by Niaba et al.[21] in Cote d'Ivoire found that termites prepared for human consumption were either dried or fresh and prepared through grilling, baking, frying, seasoning or roasting. Botswanan women of San origin prepared the alates of *Hodotermes mossambicus* (Hagen) by roasting.[22]

Comparatively little is known about the use of termites as food in South Africa. The current study was consequently undertaken to document the edible termite species found in the Vhembe District Municipality of South Africa. The study also looked at consumption, harvesting and biomass harvested; processing and marketing of edible termites as an income-generating activity; and, lastly, assessed the contribution of termites to food security.

Material and methods

Study area

The study was carried out over a period of 12 months (April 2015 to April 2016) in major termite consumption areas in 48 villages in the three local municipalities of the Vhembe District in the Limpopo Province: Thulamela, Makhado and Mutale. These areas were selected because termites are an important food supplement for people living in the district (personal observation).

The Vhembe District Municipality is one of the five districts of the Limpopo Province in South Africa. The district is located at 22°56'S and 30°28'E in the far north and shares borders with Zimbabwe in the north, Mozambique in the east and Botswana in the northwest.[23] According to Mpandeli[24], the average annual precipitation in the Vhembe District is 820 mm, with the rainfall season starting in October and peaking in January–February. Winter starts in May and ends in August. The district has been reported to have extreme temperatures, with maximum temperatures of more than 35 °C during summer months in most parts of the district.[25]

Agriculture is the largest contributor to the district's economy, with small numbers of commercial farmers and predominantly medium- to smallholder farmers cultivating field, tropical and subtropical crops and livestock.[26] Figure 1 depicts the location of the Vhembe District with termite-harvesting mounds and markets where the studies were conducted. A significant portion of the land is arable. The district falls under communal tenure systems, where most of the land legally belongs to the state and is administered by traditional authorities.[27] Most of the villages within the district are rural with a high unemployment rate and the majority of residents, mainly women, are living in poverty and/or depend on government social grants.[28]

Data collection methods

Questionnaires and interviews

Three sets of structured questionnaires were developed to source the information from the selected harvesters, marketers and consumers. Marketers and consumers were randomly selected. The marketers were interviewed at the markets. The consumers – the buyers of termites – were interviewed at their homes and workplaces. The consumers were randomly selected by approaching people door-to-door at homes and workplaces and by approaching those seen purchasing termites at the markets. Consumers are a separate group and are people who eat termites. Marketers and harvesters also consume termites but were not interviewed as part of the consumer group in Table 1.

A chain referral sampling technique as explained by Biernacki and Waldorf[29] was applied to locate the harvesters through the assistance of the termite marketers at the vendor markets around the study areas. The harvesters were randomly selected from the list provided by the marketers, community members and referrals from other harvesters. Harvesters were interviewed at harvest sites and at their homes. The questionnaire took between 1 h and 1.5 h to complete, depending on how quickly the respondents answered the questions. All the interviews were conducted individually in local languages, i.e. Tshivenda and Xitsonga, with assistance from a Xitsonga fieldworker who is competent in the language.

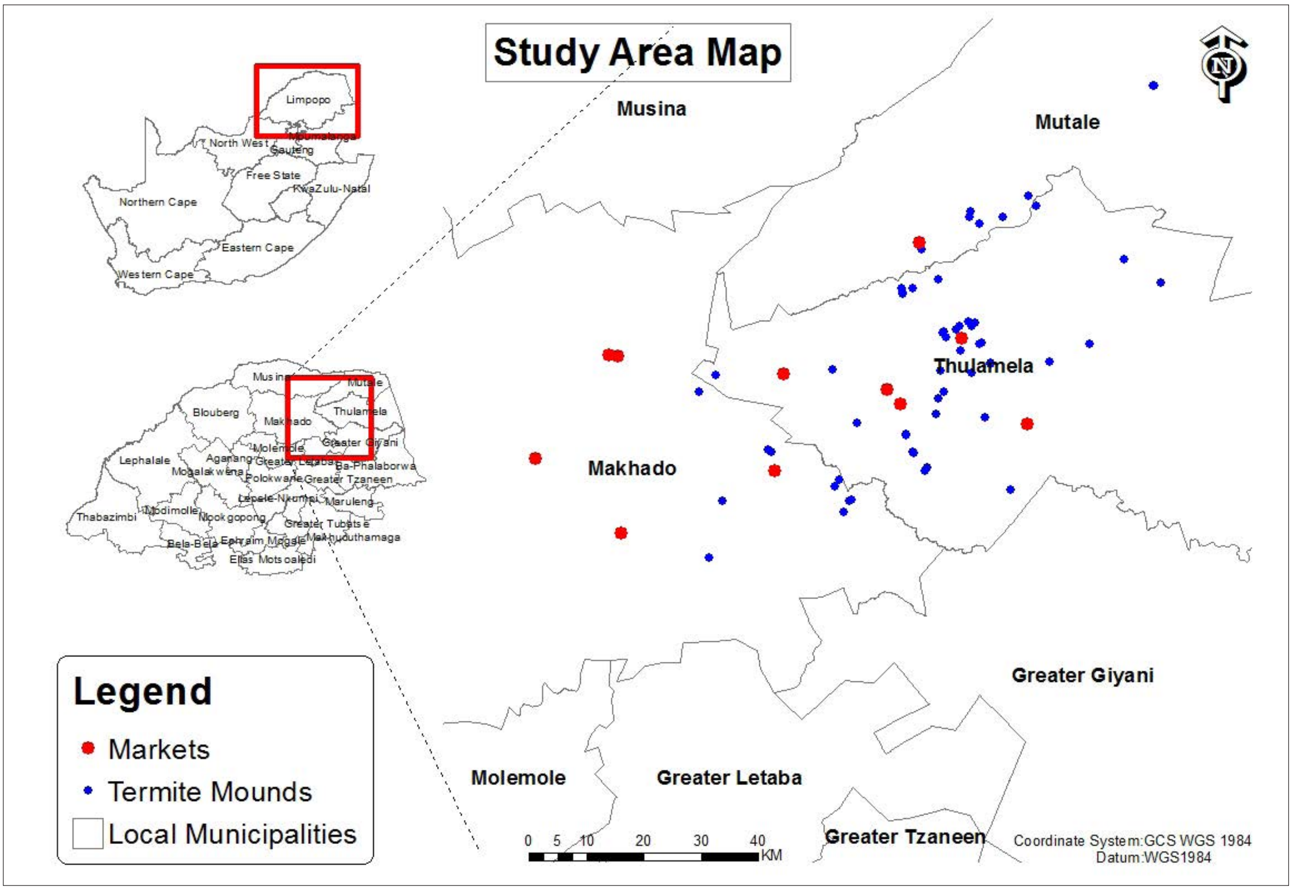


Figure 1: Location of the Vhembe District in the Limpopo Province, South Africa (inset) with specific study sites (termite harvesting sites/mounds and markets) indicated. (Enlarged area: 22°49'S to 23°41'S and 29°77'E to 31°02'E).

The consumers', marketers' and harvesters' questionnaires covered the socio-economic characteristics of the respondents, including culture and religion, importance of termites as food, ethnic preferences and prohibitions, uses of termites, frequency and means of termite consumption, species preference, knowledge of termite taxonomy, knowledge of termite abundance and distribution, and knowledge of the role of termites in human nutrition and health. In addition to the above aspects, the marketers' questionnaire also covered marketing, selling prices, marketer's estimated income, what consumers look for before buying, quantity of termites transported per batch, the type and volume of the packaging unit, grading and quality standards (including size, aroma and colour), variability of prices between seasons and volumes sold. Harvesters' questionnaires also covered seasonal availability, distance travelled to harvesting sites, how they know a particular species is edible, how termites are harvested or captured, preparation, preservation, which species are easy or difficult to harvest, how often harvesting occurs, and the quantity of termites harvested or captured in a single harvest.

The study was approved by the Human Research Ethics Committee of the University of the Witwatersrand (protocol number H15/0314).

Edible termite surveys

A total of 62 mounds were randomly selected and sampled with assistance of harvesters in the area. Harvesters were asked to identify mounds in the area from which they were harvesting. The positions of edible termite mounds were recorded using a Garmin GPS 60. At least 10 minor and 10 major soldier castes were collected from each mound and preserved in vials containing 80% ethyl alcohol. These samples were identified to species by the Biosystematics Division of the ARC–Plant Protection Research Institute in Pretoria, South Africa.

Statistical procedures and data analysis

Statistical Analysis System (SAS), version 9.3 of 2012 was used for the analysis of the descriptive statistics.[30] Data from the questionnaire surveys were analysed separately per municipality for the three local municipalities and also combined (Vhembe District) as the total for the study area. The termite soldiers and alates harvested or captured were determined by recording the number of litres harvested per week, adding this over a period of 12 months. The daily intake of termites was determined by recording the number of cups consumed per household per day and dividing this by the number of household members, and multiplying this by 64.8 grams (a steel cup is equivalent to 64.8 g of termites). The volumes of termites sold annually were determined by recording the number of cups sold per week per month and adding this over a period of 12 months. The rand value of termites was determined using a price of ZAR20 per cup (one steel cup was equivalent to 0.3 L) of termites. Dry weight of termites was determined after sun drying (ready for market). Mapping of the villages and mounds was done using ArcGIS 6.3 software. A chi-square test was used to test for associations between species and local municipalities and between termite types and local municipalities and the proportions of education between harvesters and marketers.[31] Analysis of variance (ANOVA) was used to test the differences between harvesters, marketers and consumers for daily intake.[32]

Results and discussion

Socio-economic characteristics

The results of the socio-economic data of the termite harvester, marketer and consumer respondents are shown in Table 1. The majority of all respondents to the three questionnaires were female and over the age of 50. However, in Mutale, the age of respondents ranged from 25 to 39 years (47.37%), unlike for the other two municipalities. Most (67.6%) harvesters were over 60 years of age and most (64.5%) marketers were over 50 years of age. The interviews were conducted during normal school hours, which may have affected the availability of the younger age group who would have been in attendance at their educational institutes. In light of that, the results demonstrate that individuals within the district across all ages participate in edible termite activities, be it as a consumer, marketer or harvester. The school-attending children participated only in a limited way, mainly during harvesting. About one third (35%) of the respondents had never attended school, while a large proportion of those that had attended school, had secondary education. A 2x2 chi-square test on the proportions of no versus some education between harvesters and marketers (who eat termites) was significant ($X^2 = 5.25$; d.f. $= 1$; $p = 0.022$) (Table 1). At least 65.5% of the marketers had some form of formal education compared with 26.4% of the harvesters. Tshivenda and Christianity were the most dominant language and religion, respectively, in the district.

A 2x2 chi-square test on the proportions of marketers' education (no versus some) between municipalities was highly significant ($X^2 = 10.83$; d.f. $= 2$; $p = 0.001$) (Table 1). Thus, there was strong association between education status and municipality, as the marketers from Makhado were less educated than those from the Thulamela municipality.

Termite species diversity and preferences

In all municipalities, we found that most of the respondents were able to identify the major edible termite genera, species and the castes using vernacular names. A 3x2 chi-square test on the proportions of knowledge between the three groups was significant ($p < 0.05$) and the harvester group had 100% knowledge of the termite species, while the consumer group had only 83.3% knowledge and the marketers had 90.3% knowledge. Harvesters and marketers were mainly consistent in providing the vernacular names of termite species as compared to the consumers.

The edible termite species collected from the district belonged to one family of the higher termite species of Termitidae: Macrotermitinae. All of the collected species belonged to the genus *Macrotermes* Holmgren. The fungus-growing termite genus *Macrotermes* has been reported by Roonwal[32] as the most important and widely distributed genus in Africa. The three consumed species collected in the study areas in order of preference were *M. falciger*, *M. natalensis* and *M. michaelseni*. Consumers' most preferred termite option was the soldiers of *M. falciger* (89.90%), *M. natalensis* (8.08%) and *M. michaelseni* (2.02%). *Macrotermes natalensis* and *M. michaelseni* were mainly preferred in Nzhelele (Makhado) and some parts of Mutale where *M. falciger* either is not available or is rarely available. The collection of soldier termites all year round seems to be widespread. The level of consumption of *M. natalensis* and *M. michaelseni* was not large enough for a reliable test and was combined for the chi-square test. A 2x3 chi-square test on the proportions of species consumed per local municipality was not significant ($X^2 = 4.27$; d.f. $= 2$; $p = 0.118$). *Macrotermes falciger* was the most common species collected in Thulamela (51.7%) followed by Makhado (28.1%) then Mutale (20.2%) (Table 2).

Macrotermes falciger has larger soldiers than *M. natalensis* and *M. michaelseni*, and was the only species sold at all six surveyed local markets. Harvesters preferred harvesting the major soldiers of *M. falciger* because of their higher demand and harvesters would be able to fill the harvesting buckets more quickly. It was observed that soldier termites were available all year round even though they are scarce in winter months (May to July). The alates were collected during the beginning of the rainy season in October/November in the Vhembe District. Studies conducted by van Huis[12] found that alates are mainly collected during the night and emerge from the holes of the mounds after the first summer rainfall. Meyer[33] found that the alates release of *M. natalensis* in the Kruger National Park occurs mainly during December and February.

Contrary to the findings by Nonaka[22] in studies conducted in Botswana, all the harvesters in the Vhembe District collected more soldiers than the winged reproductives (alates) because they are available all year round, are easy to harvest and are more in demand than alates. This finding substantiates those of Chavunduka[11] who found that major soldiers and alates of *M. falciger* are eaten as food in many parts of Zimbabwe. During the surveys conducted in the Vhembe District, it was reported by consumers that alates can cause stomach disorders.

Macrotermes natalensis are smaller than *M. falciger* and the species was not found in any of the markets surveyed. The *M. natalensis* major soldiers are about the size of the ignored minor soldiers of *M. falciger*.

Table 1: Socio-economic characteristics of respondents in the Vhembe District, Limpopo Province, South Africa. Data are given as percentages of respondents with the number of respondents in brackets. Not all respondents consumed termites.

Characteristics		Local municipality							
		Makhado			Mutale		Thulamela		
		Harvesters	Marketers	Consumers	Harvesters	Consumers	Harvesters	Marketers	Consumers
Number of respondents		12	10	10	9	10	16	21	16
Age (years)	18 – 24								6.25 (1)
	25 – 39			50.00 (5)	22.22 (2)	70.00 (7)		19.05 (4)	25.00 (4)
	40 – 49		30.00 (3)	20.00 (2)		10.00 (1)	6.25 (1)	19.05 (4)	37.50 (6)
	50 – 59	16.67 (2)	20.00 (2)	30.00 (3)	22.22 (2)	20.00 (2)	31.25 (5)	28.57 (6)	18.75 (3)
	>60	83.33 (10)	50.00 (5)		55.56 (5)		62.50 (10)	33.33 (7)	12.50 (2)
Gender	Male		10.00 (1)	30.00 (3)		20.00 (2)			43.75 (7)
	Female	100.00 (12)	90.00 (9)	70.00 (7)	100.00 (9)	80.00 (8)	100.00 (16)	100.00 (21)	56.25 (9)
Language	Shona							4.76 (1)	
	Tshivenda	91.67 (11)	50.00 (5)	90.00 (9)	100.00 (9)	100.00 (10)	93.75 (15)	85.71 (18)	93.75 (15)
	Xitsonga	8.33 (1)	50.00 (5)	10.00 (1)			6.25 (1)	9.52 (2)	6.25 (1)
Religion	African tradition	50.00 (6)	20.00 (2)	20.00 (2)	66.67 (6)	10.00 (1)	25.00 (4)	19.05 (4)	18.75 (3)
	Christianity	50.00 (6)	80.00 (8)	70.00 (7)	33.33 (3)	90.00 (9)	75.00 (12)	80.95 (17)	81.25 (13)
	Rastafarian			10.00 (1)					
Educational status	No schooling	83.33 (10)	80.00 (8)		55.56 (5)		56.25 (9)	19.05 (4)	
	Primary schooling	8.33 (1)	10.00 (1)	10.00 (1)	22.22 (2)	20.00 (2)	25.00 (4)	19.05 (4)	25.00 (4)
	Secondary schooling	8.33 (1)	10.00 (1)	70.00 (7)	22.22 (2)	80.00 (8)	18.75 (3)	57.14 (12)	31.25 (5)
	Tertiary education			20.00 (2)				4.76 (1)	43.75 (7)

Table 2: Termite species, list of castes, corresponding vernacular names and level of consumption of each type in the Vhembe District, Limpopo Province, South Africa. Data are given as percentages of respondents in the district with the number of respondents in brackets.

Scientific name	Vernacular name		Level of consumption of each type / species			
			Local municipality			District
	Tshivenda	Xitsonga	Makhado	Mutale	Thulamela	Vhembe
Termite species						
Macrotermes falciger	*Madzhulu a nthwa*	*Tintshwa*	25.25 (25)	18.18 (18)	46.47 (46)	89.90 (89)
Macrotermes natalensis	*Madzhulu a nemeneme*	*Timenemene*	5.05 (5)	1.01 (1)	2.02 (2)	8.08 (8)
Macrotermes michaelseni	*Madzhulu a nemeneme*	*Timenemene*	1.01 (1)	0 (0)	1.01 (1)	2.02 (2)
Termite caste						
Alates	*Nthwa*	*Tintshwa*	11.11 (11)	5.05 (5)	21.21 (21)	37.38 (37)
	Nemeneme	*Tintshwa*				
Major soldiers	*Magena*	*Majenje*	20.20 (20)	14.14 (14)	28.28 (28)	62.62 (62)
	Magege	*Jendze*				
Minor soldiers	*Vhutshembelane*	*Swijenjana*				
	Vhutshemela	*Jendze*				

The minor soldiers of *M. natalensis* in Vhembe are quite small, but both major and minor soldiers are harvested and consumed together. These termites are thought to be not as palatable as the *M. falciger* species. *Macrotermes michaelseni* is the least preferred species, was also not available in the market and was detected only twice after direction received from the harvesters. This might be because there were very few mounds of this species in the study area. Although *Odontotermes* spp. and *H. mossambicus* occur in Vhembe and are known to be eaten by humans,[18,22,34] these species were not sold at any of the markets surveyed.

Termite consumption

The overwhelming majority of the respondents (94.23%) of all ages and genders from three local municipalities consumed termites. The findings by Nyeko and Olubayo[35] on the studies conducted in Uganda found that both male and female respondents of all ages consumed soldiers, alates and workers. A majority (97.96%) of the respondents grew up eating termites. Soldiers of mainly *M. falciger* were the most preferred and regularly consumed in the district followed by alates. A 2x3 chi-square test on the proportions of termite type consumption per local municipality was not significant ($X^2 = 1.67$; d.f. $= 2$; $p = 0.434$). In all three municipalities, more soldiers (62.62%) than alates (37.38%) were consumed (Table 2). No workers were consumed. Table 3 shows the state in which edible termites are consumed in the district. It was observed that most of the respondents in the district consumed termites as frequently as possible.

The results of this survey show that the termites were eaten fresh (raw straight out of the mound) or were dried or refrigerated. Termites were prepared in a variety of ways: boiled, fried, grilled, roasted and sundried. They were normally eaten with maize meal porridge. At least 77.55% of consumers preferred fried termites mixed with tomato and onions followed by boiled (11.22%), sundried (5.01%), fresh (3.06) and grilled (1.02%). The results of this study also affirm those of Niaba et al.[21] who found that the majority of Ivorians preferred fried termites seasoned with spices. It was observed from this study that fresh termites were consumed by the harvesters while harvesting. The average daily intake of soldier termites per person was 22.27 g (dry weight), with a maximum of 38 g and a minimum of 7.70 g. Termite consumers in the study area indicated that one steel cup (0.30 L) of soldier termites (dry weight) can feed an average of three members of a household daily. A one-way ANOVA was done to test for differences in daily intake between the three groups involved with termites. No significant differences were found at the 5% level. Consumers ate more (23.17 g) than harvesters (21.09 g), but the differences among the three groups were not significant (Table 4).

Most of the respondents rated health benefits or nutrition as the main reason for consumption, as termites were reported to enhance health and ease digestion (Table 3). Of interest, one of the marketers, a qualified retired nurse, stated that termites are high in proteins compared to beef, fish and poultry and that termites are good for breastfeeding mothers as they contain iron. She also stated that termites were used by many households to combat malnutrition in the district. A study conducted in Owerri, Nigeria, by Igwe et al.[8] revealed that *M. nigeriensis* is a good source of proteins, minerals and nutrients and played a significant role in fighting protein energy malnutrition.

Table 3: Results of consumption survey from three groups of harvesters, marketers and consumers combined. Data are given as percentages of respondents with the number of respondents in brackets.

Characteristics	Local municipality			District
	Makhado	Mutale	Thulamela	Vhembe
Number of respondents	31	18	49	98
Frequency of termite consumption				
As often as possible	32.26 (10)	22.22 (4)	34.69 (17)	31.63 (31)
Occasionally	25.81 (8)	11.11 (2)	12.24 (6)	16.33 (16)
Once a week	22.58 (7)	27.78 (5)	30.61 (15)	27.55 (27)
Twice a week	19.35 (6)	38.89 (7)	22.45 (11)	24.49 (24)
Why termites are eaten				
Curiosity	3.23 (1)	5.56 (1)	2.04 (1)	3.06 (3)
Custom	19.35 (6)	5.56 (1)	4.08 (2)	9.18 (9)
Desire			4.08 (2)	2.04 (2)
Enjoyment	9.68 (3)			3.06 (3)
Flavour	9.68 (3)	5.56 (1)	6.12 (3)	7.14 (7)
Nutrition	38.71 (12)	61.11 (11)	63.27 (31)	55.10 (54)
Poverty	19.35 (6)	22.22 (4)	20.41 (10)	20.41 (20)
Most preferred termite caste				
Alates	35.48 (11)	22.22 (4)	42.86 (21)	33.73 (36)
Soldiers	64.52 (20)	77.78 (14)	57.14 (28)	63.27 (62)

Table 4: Daily termite intake of three groups associated with termites in the Vhembe District, Limpopo Province, South Africa

Group	Sample size	Mean intake (g)	Standard error of the mean
Harvesters	37	21.09	1.325
Marketers	31	22.55	1.435
Consumers	36	23.17	1.288

In addition to the health benefits derived from consuming termites, it was also observed that some pregnant and lactating women consumed soil from termitaria of the three identified *Macrotermes* species for nutrients and good health. This phenomenon of eating soil is termed geophagy and has health benefits of enhanced maternal calcium status and improved foetal skeletal formation.[36] This corroborates the findings by Saatoff et al.[37] who stated that women in South Africa consumed soil from termitaria. It was also discovered that some babies within the study area were fed soft porridge mixed with ground powder of termite soldiers and alates by their parents who were either termite consumers or marketers. Other anecdotal reports in the study area were that traditional healers used powdered termites in their traditional medicines to cure diseases and injuries. Figueirêdo et al.[38] documented the use of *M. nigeriensis* in Nigeria for the treatment of wounds and illness in pregnant women.

Termite type preferences and prohibitions

With reference to religion, of the 37 harvesters interviewed, most (63.6%) were Christian – 4 of whom did not consume termites – and the rest were of the African tradition. Similarly, most (86.2%) of the 29 marketers interviewed were Christian – 1 of whom did not consume termites – and the rest were of the African tradition. Most (80.6%) of the consumers interviewed were Christian, one was a Rastafarian, and the rest were of the African tradition. The majority (80.77%) of respondents indicated that some religions have restrictions on termite consumption; they stated that some of the old traditional churches prohibit the eating of termites while the charismatic churches do not. The results of this study support the findings made by Silow[10] that some missionaries condemned the eating of winged termites as a heathen custom and Christians were advised to not eat termites as the practice was non-Christian. A study conducted by Egan[39] in the Blouberg Municipality in the Limpopo Province found that members of the Zion Christian Church were prohibited to eat any insect other than locusts. Vhavenda or Vatsonga clans in the district were reported to not have restrictions on termite consumption.

Harvesting of edible termites

Harvesting of termites was mostly done by women and in some cases they were assisted by their children. Harvesting of soldier termites occurred all year round in all three municipalities. During harvesting, both the major and minor soldiers were collected. Harvesting of termite soldiers took place most often (29.73%) 3 days a week, followed by 2 days (21.62%) then 4 days and 6 days (13.51%), 7 days (10.81%) and, least often, 1 and 5 days (5.41%) a week. We have shown that harvesters are actively involved in feeding the population and also contributing to the economy of the district. The winged termites were collected after the first rains of the rainy season, mainly in October/November periods. In some of the villages, mainly in the Thulamela Municipality, the alates were also collected until January. The harvesting of the alates was done 2 days (66.67%) and 3 days (33.33%) a week. Reasons given for harvesting termites included: poverty, to get money, high demand of termites in the study area, part of tradition, following parent's tradition, interest and to be kept busy.

The harvesters indicated that the knowledge about which termite species to harvest was indigenous knowledge passed onto them by their parents or grandparents at a very young age or from other harvesters. The harvesters used size, taste and colour of termites as well as the mound type and size to identify the species. According to the harvesters, *M. falciger* is identified by its dark brown/red colour, dark abdomen, big head, large size and good taste, whereas *M. natalensis* are differentiated by a light brown/red colour, thinness, small head, shiny colour and sour taste. *Macrotermes michaelseni* was reported to be similar to *M. natalensis* except that the head of *M. michaelseni* is slightly darker than *M. natalensis*. Low and wide mounds characterise *M. falciger* whereas taller and narrower mounds are those of *M. natalensis* and *M. michaelseni*.

Distance travelled by harvesters to the harvest sites varied between 100 m and 8 km. Most (81.1%) harvesters travelled up to 4 km to harvest sites and many (37.8%) had to travel only up to 2 km. Harvesting took place in the yard, next to roads and in open fields, orchards and mountains. Harvesters raised the issue of safety as a major concern and they often resorted to harvesting in groups for safety reasons.

Harvesting of soldier termites was carried out at any time during the day but more termites were collected in the morning and late afternoon. Soldier termites were collected by inserting grasses or fibres made from trees into the opening of the 'eyes' of the nest and after a short period withdrawing the grass. Eyes are the small openings of the termites' nests. Both the soldier termites and workers who had bitten the grass or fibre were then stripped into the harvesting container. The grass or fibres were either moistened with water or saliva when becoming dry to facilitate grasping. Harvesters usually wrapped grasses or fibres in plastics, put them in empty mealie meal bags and stored them in the shade during harvesting to prevent desiccation. Table 6 gives the names of the various plants used for harvesting soldier termites. Studies conducted in Uganda by Roulon-Doko[40] also described that the women in Uganda lower saliva-moistened grass blades of *Imperata cylindrica* to collect soldier termites. Harvesters used plant leaves in attracting termite soldiers to the mouth of the mound by closing the mouth with leaves (Table 5). All of these plants have putrid and strongly scented leaves which is believed to attract termite soldiers. The most used plant species to harvest termites were the stems of *Cyperus* spp.; ground or pulverised *Nicotiana tabacum* leaves and *Clerodendrum glabrum* leaves were the most widely used plants to attract termites during harvesting (Table 5).

Most of the harvesters indicated that soldiers were easy to harvest because they were available any time, were quick to harvest and many could be harvested from one hole. Alates were reported to be the most difficult to harvest because of the high labour intensity involved, and because they do not emerge on windy days, are sensitive to noise, emerge in the evening (with evening harvesting being a safety concern), are available only after rains and because it takes at least 3 days to harvest them after placing traps. Mounds of *M. natalensis* were also reported to be more difficult to harvest from because the soil is harder than that of *M. falciger* mounds.

Alates were collected after rains using a bucket or pot by digging a hole in the soil at the bottom end of the mound on a steep slope and then placing an empty bucket (without the lid) in the cavity. The hole was covered with sticks and leaves of either banana (*Musa paradisiaca* Linnaeus and *M. sapientum* Linnaeus) or *Peltophorum africanum* (Sond). It was claimed that the leaves of these two plants provide good shade. As alates leave the nest, they roll or fly to the bottom of the hole where they are trapped and collected. A similar harvesting method was reported in Zimbabwe by Chavunduka[11]. The only difference was that in Zimbabwe, the roof was covered with grass and a pot containing water was used. To limit the number of alates flying in an evening, harvesters used pestles to close the openings at the onset of a rainy season. This method is traditionally known as '*u tsivha*' in Tshivenda. Households collected termites for home consumption but the alates were also sold at the market.

Table 6 shows summary statistics of edible termites harvested, marketed and consumed in the Vhembe District. The results show that a minimum of 1 L of soldier termites and 20 L of alates were harvested in a single harvest compared to the highest harvests of 10 L and 40 L, respectively. The soldier termite biomass of *M. falciger* varied from 641.3 g to 642.8 g (fresh weight/litre). These soldiers weigh on average 0.15 g each and these values therefore correspond to approximately 4280 individuals/litre. Harvesting season of the alates lasted a maximum of 4 months depending on rainfall.

Table 5: Plants used for harvesting and attracting termites and their extent of use. The values in the table are percentages with actual counts in brackets.

Botanical name	Common name	Vernacular name (Tshivenda)	Family	Part of the plant used	Extent of use by municipality (actual counts)			
					Thulamela	Makhado	Mutale	Total (Vhembe)
Plants for harvesting								
Cyperus latifolius Poir	Smooth flat sedge	*Dzhesi*	Cyperaceae	Stems	7.14 (4)	8.92 (5)	5.36 (3)	21.42 (12)
Cyperus sexangularis Nees	Bushveld sedge	*Mutate*	Cyperaceae	Stems	1.79 (1)	1.79 (1)	8.92 (5)	12.50 (7)
Cyperus rotundus Linnaeus	Nut sedge grass, purple sedge grass	*Mutate*	Cyperaceae	Stems	19.64 (11)	12.50 (7)	3.57 (2)	35.71 (20)
Plectranthus laxiflorus Benth	Citronella spur-flower, white spur flower	*Bunganyunyu Sindambudzi*	Lamiaceae	Stems	0 (0)	3.57 (2)	0 (0)	3.57 (2)
Annona senegalensis Pers.	African/ wild custard apple	*Muembe*	Annonaceae	Fibres	7.14 (4)	1.79 (1)	1.79 (1)	10.72 (6)
Musa spp. Linnaeus	Banana	*Muomva*	Musaceae	Leaves, fibres	3.57 (2)	0 (0)	0 (0)	3.57 (2)
Agave sisalana Perrine	Sisal plant	*Tshikwenga Savha*	Asparagaceae	Leaves, fibres	3.57 (2)	0 (0)	0 (0)	3.57 (2)
Balanites maughamii Sprague	Torchwood	*Mudulu*	Zygophyllaceae	Fibres	0 (0)	1.79 (1)	0 (0)	1.79 (1)
Grewia flava DC	Velvet raisin / wild currant	*Muhwana Murabva*	Malvaceae	Fibres	0 (0)	1.79 (1)	0 (0)	1.79 (1)
Cocculus hirsutus (L.) Diels	Broom creeper	*Muzwingwe*	Menispermaceae	Stems	1.79 (1)	0 (0)	3.57 (2)	5.36 (3)
Total					44.64 (25)	32.14 (18)	23.21 (13)	100 (56)
Attractants								
Clerodendrum glabrum E. Mey	Tinder wood	*Munukhatshilongwe*	Lamiaceae	Leaves	11.11 (2)	22.22 (4)	0 (0)	33.33 (6)
Lippia javanica (Burm. f.) Spreng	Lemon bush	*Musudzungwane Mukundamboho*	Verbenaceae	Leaves	0 (0)	16.66 (3)	0 (0)	16.66 (3)
Nicotiana tabacum Linnaeus	Tobacco plant	*Fola*	Solanaceae	Ground or pulverised tobacco leaves	16.66 (3)	11.11 (2)	5.56 (1)	33.33 (6)
Cannabis sativa Linnaeus	Marijuana plant	*Mbanzhe*	Cannabaceae	Leaves	5.56 (1)	0 (0)	0 (0)	5.56 (1)
Plectranthus laxiflorus Benth	Citronella spur-flower, white spur flower	*Bunganyunyu Sindambudzi*	Lamiaceae	Leaves	0 (0)	11.11 (2)	0 (0)	11.11 (2)
Total					**33.33 (6)**	**61.11 (11)**	**5.56 (1)**	**100 (18)**

Table 6: Summary statistics of edible termites harvested, marketed and consumed in the Vhembe District, Limpopo Province, South Africa (as estimated by the respondents)

Characteristics	Municipality and district			
	Makhado	Mutale[†]	Thulamela	Vhembe
Termite soldiers captured in a single harvest (litres)				
Average	3.25	4.44	4.25	3.97
Minimum	1.00	2.00	2.00	1.00
Maximum	5.00	6.00	10.00	10.00
Alates captured in a single harvest (litres)				
Average	40.00	20.00	35.00	33.33
Minimum	40.00	20.00	20.00	20.00
Maximum	40.00	20.00	40.00	40.00
Termite soldiers harvested during peak times per week (litres)				
Average	13.33	15.00	23.81	18.27
Minimum	3.00	5.00	2.00	2.00
Maximum	35.00	24.00	60.00	60.00
Alates captured during peak times per week (litres)				
Average	120.00	80.00	65.00	76.66
Minimum	120.00	80.00	40.00	40.00
Maximum	120.00	80.00	80.00	120.00
Volume delivered to the market per consignment (litres)				
Average	14.00	–	22.00	19.70
Minimum	10.00	–	5.00	5.00
Maximum	20.00	–	80.00	80.00
Volume of soldiers and alates sold daily by marketers (litres)				
Average	2.40	–	4.95	4.13
Minimum	1.00	–	1.00	1.00
Maximum	4.00	–	20.00	20.00
Volume of soldiers and alates sold annually by marketers (litres)				
Average	101.00	–	111.43	108.06
Minimum	80.00	–	30.00	30.00
Maximum	120.00	–	260.00	260.00
Daily intake per person (dry weight in grams)				
Average	25.23	22.00	20.54	22.27
Minimum	9.00	11.00	8.00	8.00
Maximum	32.00	38.00	32.00	38.00

[†]*Termites were not sold in Mutale informal markets.*

With the growing population and the mass collection of termites, questions are being raised as to the sustainability of harvesting termites. Indications from the harvesters, based on the yields received per mound, were that they have not noticed any decline in termite availability over the years, even though harvesting has been increasing. Termite harvesters promoted responsible harvesting through mound rotations and protected mounds from destruction. They were concerned about the destruction of mounds in new areas zoned for housing developments.

Farmers and the local community also played their part in protecting the termite mounds. Most of the termite mounds located within the crop fields were not destroyed during ploughing and farmers planted around the mounds. Mounds are considered the property of the family if found near their homes or fields. The permission of that family has to be requested before harvesting can take place. Research into the sustainability of termite harvesting is recommended.

Preparation and preservation of edible termites

Harvested termite soldiers were killed using boiled or cold water or by roasting and then either sun dried or refrigerated to reduce spoilage. *Macrotermes natalensis* and *M. michaelseni* soldiers were prepared differently because these two species are not as palatable as *M. falciger*. Their preparation for cooking included vigorously whisking them with a natural whisk (a forked, fresh tree branch) in water and then rinsing. The whisking process created foam in the water, which suggests some chemical or toxin was being released and removed. The harvesters believed that whisking was to eliminate the bitter taste of the soldiers of these two species.

Marketing and economic benefits of edible termites

A total of 13 informal street markets were surveyed in the district: Makhado (8), Thulamela (4) and Mutale (1) (Figure 1). Of these informal markets, 46% sold termites, of which 66.67% were in Thulamela and 33.33% in Makhado. No termites were sold in Mutale informal markets. The vendors in both Thulamela and Makhado municipalities rented space from the municipalities on the side of the road or pavement and no one was registered as a business entity. Sellers also rented space for storage of the termites, other edible insects and dried vegetables. The majority (96.77%) of vendors selling termites were women between the ages of 50 and 60 years. The marketers were not actively involved in any harvesting but only bought termites from harvesters. There were large numbers of sellers in Thohoyandou (Thulamela Municipality) sitting close to one another, resulting in competition for buyers and this led to sellers giving extras to attract more customers. It was observed that customers checked for freshness, presence of legs, cleanliness, species type and oil on alates before they bought. Sellers allowed buyers to taste before buying. Some buyers preferred termites fresh from the mounds.

Termites were graded using a traditional way of sieving according to morphospecies, size and type by harvesters before selling to marketers or consumers. Major soldiers were separated from minor soldiers and workers. Minor soldiers were fed to chickens. The average marketer in the district sold 14, 120 and 367 steel beakers (0.30 L) of termites daily, monthly and annually, respectively. Table 7 shows the number of sellers, volumes sold, and unit weights and prices in South African rands (ZAR) with the standard deviation. The price of termites per steel beaker (0.30 L) was ZAR20. The dry weight of termites per the packaging unit (steel beaker) was 64.8 g. The lowest volume of termites sold daily was 1 L (3.5 steel beakers), which is equivalent to ZAR70, while the highest volume sold daily during peak times was 20 L (70 steel beakers), which equates to ZAR1400. Peak season when termites are most visible and available is normally between October and February. The majority of sellers reported no price fluctuations during the year or between seasons. The quality of the termites did not affect the price. Buyers can purchase soldiers or alates separately in a beaker or combined in a mix. All of the termite sellers sold throughout the year, 6 days a week, working half day on Saturdays. The average income derived from termites was estimated at ZAR292 daily, ZAR2395 monthly and ZAR7348 annually. The lowest annual income from the sale of termites was estimated at ZAR2040 compared with highest annual income of ZAR17 680.

Table 7: The number of sellers, volumes sold plus unit weights and prices in ZAR recorded in Vhembe District, Limpopo District, South Africa

Variable	Quantity	Standard deviation
Number of sellers selling termites	31	
Average litres sold per day (estimate by seller)	4.13	4.61
Average litres sold per month (estimate by seller)	35.23	20.52
Average litres sold per year (estimate by seller)	108.06	44.90
Average dry weight of termites in 1 beaker (kg)	0.0648	
Price per steel mug (ZAR)	20	

According to Statistics South Africa[41], the retail prices of various fresh meats as at the end of January 2017 were: beef chuck (ZAR73.67/kg), beef rump steak (ZAR117.18/kg), pork chops (ZAR78.59/kg), whole chicken (ZAR43.69/kg) and lamb leg (ZAR123.84/kg). The price per kilogram of termites was estimated at ZAR100.00/kg. The retail prices obtained from two local butcheries for dried beef meat, sausages and pork were ZAR329/kg, ZAR320/kg and ZAR430/kg, respectively. Dried lamb and dried chicken were not sold. This comparison indicates that the price per kilogram for termites was more than the price of fresh chicken, beef and pork, but less than that of lamb chops and dried meats. However, 1 kg of termites can feed at least 15 people – far more than 1 kg of fresh chicken, beef or pork and dried meats. In addition, termites can be harvested in the district by anyone at no cost.

Alternative sources of income for sellers of termites were the sales of other edible insects (mopane worms and edible stinkbugs) and vegetables (dried/fresh pumpkin leaves and flowers, *Amaranthus hybridus*, *Cleome gynandra*, dried/fresh *Corchorus tridens*, *Solanum nigrum* and dried *Biden pilosa*). The results of this study indicate that termites are contributing to the socio-economic well-being and food security of the people living in the district. Most of the termite trading took place in Thulamela, with the Thohoyandou Complex the largest provider of termite markets, followed by the Sibasa Complex.

Conclusion

Macrotermes termites play a significant role in food security in many communities in the Vhembe District, thus the indigenous knowledge of harvesting and preparation should be retained. As termites are a protein source and can generate income, promotion of sustainable termite harvesting for food security should be adopted. Further research into the sustainability is required as well as the nutritional value of various termite species. In conclusion, the approach of entomophagy can play a big role in combating the global food crisis. Promoting indigenous knowledge of diets and sustainable harvesting of insects should be taught at schools at an early stage.

Acknowledgements

The efforts, support and technical advice of Dr Khathutshelo Tshikolomo and Dr Mervyn Mansell are most appreciated. The study was supported financially by the National Research Foundation (South Africa) funding to F.D.D. We thank Ms Nunu Baloyi from the University of Venda, School of Agriculture and Rural Development, and Ms Ndamulelo Netshifhefhe for administering the questionnaires in Xitsonga and Tshivenda, respectively. We also thank Ms Vivienne Uys from ARC–PPRI, Biosystematics for the identification of termite specimens.

Authors' contributions

S.R.N. and F.D.D. worked on the original concept of the manuscript. E.C.K. gave valuable scientific inputs during conceptualisation and also provided significant contributions during the editing of the manuscript.

References

1. DeFoliart GR. Insects as food: Why the Western attitude is important. Annu Rev Entomol. 1999;44:21–50. http://dx.doi.org/10.1146/annurev.ento.44.1.21
2. Meyer-Rochow VB, Kenichi N, Somkhit B. More feared than revered: Insects and their impact on human societies (with some specific data on the importance of entomophagy in a Lotian setting). Entomol Heute. 2007;7:19–23.
3. Lesnik JJ. Termites in the hominin diet: A meta-analysis of termite genera, species and castes as a dietary supplement for South African robust australopithecines. J Hum Evol. 2014;71:94–104. http://dx.doi.org/10.1016/j.jhevol.2013.07.015
4. Banjo AD, Lawal OA, Songonuga EA. The nutritional value of fourteen species of edible insects in Southwestern Nigeria. Afr J Biotechnol. 2006;5(3):298–301.
5. Mbah CE, Elekima GOV. Nutrient composition of some terrestrial insects in Ahmadu Bello University, Samaru, Zaria Nigeria. Sci World J. 2007;2(2):17–20. http://dx.doi.org/10.4314/swj.v2i2.51728
6. Phelps RJ, Struthers JK, Moyo SJL. Investigations into the nutritive value of *Macrotermes falciger* (Isoptera: Termitidae). Afr Zool. 1975;10:123–132. http://dx.doi.org/10.1080/00445096.1975.11447501
7. Ayieko MA. Nutritional value of selected species of reproductive Isoptera and Ephemeroptera within the ASAL of Lake Victoria basin. Discov Innov. 2007;19(2):126–130.
8. Igwe CU, Ujonwundu CO, Nwaogu LA, Okwu CN. Chemical analysis of an edible termite, *Macrotermes nigeriensis*: A potential antidote to food security problem. Biochem Anal Biochem. 2011;1, Art. #105, 4 pages. http://dx.doi.org/10.4172/2161-1009.1000105
9. Ajayi OE, Adedire CO. Nutrient characteristics of the subterranean termite, *Macrotermes subhyalinus* (Rambur) (Isoptera: Termitidae). Nig J Entomol. 2007;24:42–47.
10. Silow CA. Notes on Ngangela and Nkoya ethnozoology. Ants and termites. Etnol Stud. 1983;36:177.
11. Chavunduka DM. Insects as a source of protein to the African. The Rhodesia Science News. 1975;9:217–220.
12. Van Huis A. Insects as food in sub-Saharan Africa. Insect Sci Appl. 2003;23(3):163–185. http://dx.doi.org/10.1017/S1742758400023572
13. Ruelle JE. A revision of the termites of the genus *Macrotermes* from the Ethiopian region (Isoptera: Termitidae). Bull Brit Mus (Nat Hist) Entomol. 1970;24(9):365–450.
14. Ruelle JE, Coaton WGH, Sheasby JL. National survey of the Isoptera of Southern Africa. The genus *Macrotermes* (Holmgren) (Termitidae: Macrotermitinae). Cimbebasia (Series A). 1975;3(8):73–94.
15. Ruelle JE. Isoptera. In: Werger MJA, Van Bruggen AC, editors. Biogeography and ecology of southern Africa. The Hague: W. Junk; 1978. p. 747–762.
16. Ajayi OE. Biochemical analysis and nutritional content of four castes of subterranean termites, *Macrotermes sybhyalinus* (Rambur) (Isoptera: Termitidae): Differences in digestibility and anti-nutrient contents among castes. Int J Biology. 2012;4(4):54–59. http://dx.doi.org/10.5539/ijb.v4n4p54
17. Bodenheimer FS. Insects as human food: A chapter of the ecology of man. The Hague: W. Junk; 1951.
18. Quin PJ. Food and feeding habits of the Pedi with special reference to identification, classification, preparation and nutritive value of the respective foods. Johannesburg: Wits University Press; 1959.
19. Takeda J. The dietary repertory of the Ngandu people of the tropical rain forest: An ecological and anthropological study of the subsistence activities and food procurement technology of a slash and burn agriculturist in the Zaire River Basin. Afr Study Monogr Suppl. 1990;11:1–75. http://dx.doi.org/10.14989/68351
20. Bergier E. Peuples entomophages et insectes comestibles: étude sur les moeurs de l'homme et de l'insecte [Entomophagous peoples and edible insects: Study on man's and insect's habits]. Avignon: Imprimerie Rulliere Freres; 1941. French.

21. Niaba KPV, Ocho-Anin AL, Gbassi KG, Beugre AG, Adou M, Anon AB, et al. Consumption survey of edible winged termites in Cote d'Ivoire. Int J Agr Food Sci. 2012;2(4):149–152.

22. Nonaka K. Ethnoentomology of the central Kalahari San. Afr Study Monogr Suppl. 1996;22:29–46.

23. Van Averbeke W. Improving plot holder livelihood and scheme productivity on smallholder canal irrigation schemes in the Vhembe District of Limpopo Province. Report no. TT566/13. Pretoria: Water Research Commission; 2013.

24. Mpandeli NS. Managing climate risks using seasonal climate forecast information in Vhembe District in Limpopo Province, South Africa. J Sustain Dev. 2014;7(5):68–81. http://dx.doi.org/10.5539/jsd.v7n5p68

25. Mpandeli NS. Coping with climate variability in Limpopo Province [PhD thesis]. Johannesburg: University of the Witwatersrand; 2006.

26. Gaffney's Local Government in SA 2009 – 2011. Official yearbook. Johannesburg: Gaffney Group; 2009. p. 948–950.

27. Isaacs M, Mohamed N. Co-managing the commons in the new South Africa: Room for manoeuvre? In: 8th Biennial Conference of the International Association for the Study of Common Property; 2000 31 May – 04 June; Indiana, USA. : Biol Conserv. 2000;143:2468–2476.

28. Statistics South Africa. Community survey. Revised version: Statistical release. Pretoria: Statistics South Africa; 2007

29. Biernacki P, Waldorf D. Snowball sampling: Problem and techniques of chain referral sampling. Sociol Methods Res. 1981;10:141–163.

30. Statistical Analysis System (SAS). SAS® statistics user's guide version 9.3. Cary, NC: SAS Institute Inc.; 2012.

31. Snedecor GW, Cochran WG. Statistical methods. 7th ed. Ames, IA: Iowa State University Press; 1980. p. 234.

32. Roonwal ML. Termites of the Oriental region. In: Krishna K, Weesner FM, editors. Biology of termites. New York: Academic Press; 1969. p. 315–391.

33. Meyer VW. Intracolonial demography, biomass and food consumption of *Macrotermes natalensis* (Haviland) (Isoptera: Termitidae) colonies in the northern Kruger National Park, South Africa [dissertation]. Pretoria: University of Pretoria; 2001.

34. Uys V. A guide to the termite genera of southern Africa. Plant Protection Research Institute Handbook no. 15. Pretoria: Agricultural Research Council; 2002.

35. Nyeko P, Olubayo FM. Participatory assesssment of farmers'experiences of termite problems in agroforestry in Tororo District, Uganda. Agricultural Research and Extension Network Paper. 2005;January, Art. #143, 20 pages. Available from: https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/5172.pdf

36. Wiley SS, Katz SH. Geophagy in pregnancy: A test of a hypothesis. Curr Anthropol. 1998;39:532–545.

37. Saathoff E, Olsen A, Kvalsvig JD, Geissler PW. Geophagy and its association with geohelminth infection in rural schoolchildren from KwaZulu-Natal, South Africa. Trans R Soc Trop Med Hyg. 2002;96:485–490.

38. Figueirêdo RECR de, Alexandre V, Iamara SP, Alves RRN. Edible and medicinal termites: A global overview. J Ethnobiol Ethnomed. 2015;11:29, 7 pages. http://dx.doi.org/10.1186/s13002-015-0016-4

39. Egan BA. Culturally and economically significant insects in the Blouberg Region, Limpopo Province, South Africa [PhD thesis]. Polokwane: University of Limpopo; 2013.

40. Roulon-Doko P. Les activités de cueillète [Harvesting activities]. In: Van Huis A, editor. Insects as food in sub-Saharan Africa. Insect Sci Appl. 1998;23(3):163–185. French.

41. Statistics South Africa. Livestock prices. Pretoria: Statistics South Africa; 2017.

Composition of the Kirsten Skeletal Collection at Stellenbosch University

AUTHORS:
Amanda Alblas[1]
Linda M. Greyling[1]
Elsje-Marie Geldenhuys[1]

AFFILIATION:
[1]Division of Anatomy and Histology, Department of Biomedical Sciences, Stellenbosch University, Cape Town, South Africa

CORRESPONDENCE TO:
Amanda Alblas

EMAIL:
aa2@sun.ac.za

DATES:
Received: 08 June 2017
Revised: 11 Aug. 2017
Accepted: 15 Aug. 2017

KEYWORDS:
physical anthropology; South African coloured population; skeletal reference collection; regional and ancestral specific skeletal standards

HOW TO CITE:
Alblas A, Greyling LM, Geldenhuys E. Composition of the Kirsten Skeletal Collection at Stellenbosch University. S Afr J Sci. 2018;114(1/2), Art. #2017-0198, 6 pages. http://dx.doi.org/10.17159/sajs.2018/20170198

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
None

The Kirsten Skeletal Collection is curated in the Division of Anatomy and Histology, Faculty of Medicine and Health Sciences, Stellenbosch University, South Africa. It comprises the largest documented cadaver-derived South African coloured skeletal collection in the world. Our aim in this paper is to present an inventory and characterise the identified skeletons in the Kirsten Skeletal Collection as well as provide a descriptive indication of what researchers can expect to encounter at the anthropology unit at Stellenbosch University. The skeletal material was derived mainly from the cadaver donation programme of the Division of Anatomy and Histology over a 58-year period (1957–2015). All pertinent information for each individual skeleton is entered into a database and a full skeletal inventory is established. The skeletal database registry was analysed to demonstrate the distribution of age, sex and population affinity of individuals in the collection. Currently, this collection consists of 1161 skeletons with known records. Despite differences in the age and sex composition, the skeletal profile in general reflects mainly the profile of the Western Cape population. Most individuals were born between 1920 and 1950, placing the Kirsten Skeletal Collection in the early to mid-20th century. The age at death for the greatest proportion (41.8%) of individuals was between 40 and 60 years. Current biological profile techniques in age, ancestry and sex estimation can be improved and, among others, new regional and ancestral specific standards for the biologically unique and diverse South African coloured population can be developed.

Significance:

- We present the largest documented skeletal collection of the South African coloured population in the world.
- This work contributes to the skeletal reference database for use by physical anthropologists and others.

Introduction

Human skeletal collections with known records are valuable for both teaching and research. Current research using human skeletal collections includes developing new techniques to test and standardise regional-specific data regarding osteometric measurements and physical observations.[1-5] These reference points provide practical information for the estimation of biological profiles of unknown skeletons[6] in both forensic anthropology and bioarchaeology, including estimation of age, sex and stature. Detailed descriptions of skeletal remains of known populations are used to confirm or contradict archaeological and social theories for past and present communities.[2] Studies on skeletal collections include the physiological stresses and diseases experienced by the community that may have influenced their health status and physical attributes.

Nationally, the South African population was estimated to be almost 52 million people during the 2011 physical census. South African blacks constitute the largest population group in the country at 79.2%.[7] However, the regional population demographic of the Western Cape Province consists of 32.9% South African black, 15.7% South African white and 48.8% South African coloured. Unlike other provinces in South Africa, the Western Cape Province is composed of primarily the self-identified social group called 'South African coloureds'.[6] The Kirsten Skeletal Collection is reasonably representative of the Western Cape with mainly South African coloured individuals, providing a standard database of this area in South Africa. Although the Kirsten Skeletal Collection was established in the late 20th century, it is only in recent years that skeletons were intentionally added to the Collection for the purposes of research.

Our aim in this paper was to present an inventory of the osteological material in the Kirsten Skeletal Collection at Stellenbosch University and provide descriptive information to both national and international researchers interested in anthropological studies of the biologically heterogeneous South African coloured population.

Population demographic origin

South Africa is a multicultural nation with a rich biological history. For centuries, the southwestern corner of Africa was home to the oldest known lineage of modern humans[8,9] – descendants of the original Khoikhoi (pastoralists) and the San (hunter–gatherers) populations[10]. These two historical groups are collectively referred to as the Khoisan or the Khoe-San, and speak a distinctive click language.[11] Although the Khoisan maintained an isolated ancient lifestyle for centuries and remained genetically distinct with unique physical characteristics from Europeans, Asian and other Africans[8], the genetic profiles of some tribes (such as the Khwe groups) show high proportions of Bantu-speaking admixture[10,11].

Linguistic and archaeological evidence indicates that the South African black population originated from the Niger–Congo linguistic phylum in the Cameroon–Nigeria grasslands. They migrated as part of the greater Bantu group to occupy much of the east and southern parts of Africa.[12,13] Variants from this Bantu family in the south included the Nguni group (Xhosa, Zulu, Swati and Ndebele tribes) and the Southern (also called the Sotho-Tswana) groups (Southern Sotho, Northern Sotho, Tswana, Venda and Tsonga tribes).[12,14,15]

The Nguni populations migrated southwards over many centuries with large herds of Nguni cattle. These migration patterns started around 2000 years ago followed by larger migration impressions around 1400 CE.[14,16] When entering southern Africa, settlement patterns among the different tribes formed as a result of the settling of some groups along the way, while others kept moving; for example the Ndebele stayed in the north, the Swazi in the northeast, the Zulu towards the east and the Xhosa in the south.[12]

Historical documents indicate that Portuguese sailors in the 1400s were the first Europeans to have contact with these tribes. The European community settled at the Dutch-controlled Cape Colony between 1652 and the 19th century. Other immigrant groups were mainly descended from the French, Germans, Greeks and Italians. The British settlers colonised the Cape in the mid-1800s.[17,18] The Indian/Asian population originated from Indian and Chinese immigrants, as well as slaves imported to relieve the labour burden in the fast-growing Cape settlement. These slaves were shipped to the Cape colony from Indonesia, southern China and Madagascar, among others.[18,19]

Marriages amongst white European men and women from either the free black populations or Khoisan were common during the early Dutch settlement era.[17,20] Colonisation and migration from many parts of the world became the foundation to modern variation in South African groups, and produced a heterogeneous new population with distinctive physical and biological traits and genetic variations.[6] As a result of the eradication of slavery in 1834–1938, the newly formed self-identified population was named the Cape Coloureds,[17,18] and is today known as the South African coloured population. During the early 1800s, the number of cross-cultural relationships declined[21], and later during the 1900s, racism established by apartheid laws further reduced cross-population gene flow[6,22].

Apartheid in South Africa was a system of racial separation that was enforced by the minority governing party (the white population) that ruled between 1948 and 1994.[22,23] Under this ruling, African people that were a product of the Bantu expansion, were grouped as black people, while people with an admixture of mixed origin, including Khoisan, were classified as coloureds.[20] The *Population Registration Act of 1950* was used to categorise all South Africans as black, white, Indian or coloured during the apartheid reign.[20] Census in the apartheid era was underreported, particularly concerning the black population because of legislation such as the *Native Areas Amendment Bill* and the *Group Areas Act*. Such legislation resulted in the number of people in South Africa being grossly underestimated.[24] The apartheid laws were introduced to force population segregation by assigning certain areas for each population group. This forced segregation with geographical parting of these groups directly limited admixture of different population groups.[6,22] Although apartheid was abolished in 1994, the different populations in South Africa have tended to persist within their socially defined population groups, keeping the different populations largely segregated from one another.[6,25] As a result of limited interracial relationships still today, genetic variation within groups is decreasing and variation between groups is increasing.[6,25]

Materials and methods

Acquisition and processing of skeletal material for the Collection

The Department of Anatomy (later changed to the Division of Anatomy and Histology) at Stellenbosch University was established in 1957. Initially, medical students were trained under the guidance of Professor J.F. van E. Kirsten in the Mike de Vries building (formerly known as D.F. Malan building) on the main campus located in Stellenbosch, South Africa. Kirsten, a qualified general surgeon, was one of the first five professors appointed at the newly established medical faculty, and the first to perform the task of collecting skeletal material for study. The anatomy department relocated over time – initially to Karl Bremer Hospital in Bellville and then, during the 1970s, to the Tygerberg Medical Campus adjacent to the then newly built Tygerberg Hospital. It was during this time that the J.F. van E. Kirsten Museum of Morphology and the Kirsten Skeletal Collection was established, in Kirsten's honour. The initial cadavers used for anatomy training of medical students at Stellenbosch University were received from the University of Pretoria and the University of the Witwatersrand from 1957 to 1960. The first cadavers embalmed at Stellenbosch University's Department of Anatomy were received from Karl Bremer Hospital in 1960. From 1957 onwards, a number of the dissected cadavers were skeletonised, except during a brief period in the 1990s when the Department did not have the capacity or staff to skeletonise cadavers. Between 30 and 40 skeletons are currently added to the collection on an annual basis.

Under the *Human Tissue Act*, *Act 65 of 1983*[26], the more recent *National Health Act*[27] (*Act 61 of 2003*), and the protection of the regional Inspector of Anatomy, the Division of Anatomy and Histology is allowed to receive cadavers for both teaching and research purposes. The cadavers received are either consented donations or unclaimed bodies of persons who died from natural causes in the Western Cape region, specifically the Northern suburbs of Cape Town and surrounding rural towns. Consented donations are individuals (or their family members) who bequeathed their bodies to the University. So-called 'unclaimed' bodies are those for whom no next-of-kin could be traced, either by the institution at which the person died or by any other means. Unclaimed does not necessarily imply that the person is unknown. If, however, family or friends are traced at a later stage when the cadaver is already prepared at the Division, whoever lays legal claim to the body is allowed to remove it for burial. The majority of unclaimed bodies received are from communities with a low socio-economic status. The cadaver intake does not include any unnatural or traumatic deaths as South African legislation requires that all bodies resulting from unnatural deaths be autopsied by the Forensic Pathology Services.[28] Autopsied bodies cannot be embalmed, therefore these bodies cannot be entered into the cadaver programme. Although the skeletal collection consists largely of individuals obtained through this cadaver intake programme, a small number of unidentified fragmented individuals with archaeological or forensic (cases received for biological profile assessment from the police) origins are present in the collection. Past curators accessioned these remains into the collection. Material accessioned in the collection cannot be removed from the database; however, these materials are not used for purposes of research.

Cadavers are used for dissection in the anatomy training of undergraduate and postgraduate medical and allied healthcare students. Upon intake at the Division of Anatomy and Histology, all personal information available on the cadaver, as well as the intake number given to the cadaver, is recorded in the cadaver register of the Division. This information includes age, sex, date of birth, date of death, last known residential address, hospital/funeral home from which the body was acquired and previously self-identified ancestry. Medical records of the individuals are not made available; only cause of death is provided. Since 2011, intake information has included the person's weight at reception and full-face and profile photographs. The cadavers are subsequently embalmed and stored. Before the cadavers are used, a full-body X-ray is taken using Lodox® Statscan® digital imaging system (Figure 1a). After dissection, excess soft tissue is manually removed from the cadavers and the bones are immersed in water. The remains are carefully boiled at relatively low temperature (60–80 °C). Following the boiling process, the remaining tissue on the bones is removed with a scalpel and forceps, whereafter the bones are washed with warm soapy water, and a scrubbing brush is used to lightly scour the surfaces of the bones until smooth. The bones are then air dried at room temperature and bleached with a bleaching agent. The Kirsten Collection intake number is then recorded on each dried bone with a permanent marker.

The processed skeletal material is registered and curated at the Kirsten Skeletal Collection Ossuary at the Division of Anatomy and Histology. All pertinent information for each individual skeleton is entered into a database and a full skeletal inventory is established. At least 350 complete skeletons in anatomical order have been scanned with the Lodox® Statscan® since 2014 (Figure 1b). The practice of correlating these scans with the cadaver scans taken prior to maceration will continue. Projects have been initiated in collaboration with radiologists to use these scans to compare disease lesions on bone, and in collaboration with forensic anthropologists to use these scans to set science-based X-ray standards for identifying human remains.

This study on the skeletal material was ethically cleared by the Health Research and Ethics Committee of Stellenbosch University and conforms to the principles stipulated by the Declaration of Helsinki (1964). The allocated ethics number is S13/05/100.

Figure 1: Cadaver K96/13 received in 2013: (a) Lodox® scan of cadaver prior to dissection by medical students and (b) Lodox® scan of skeleton in anatomical order (anthropology number An1352).

Results

The Kirsten Skeletal Collection currently consists of 1161 skeletons, which, according to the known cadaver records, represent mostly individuals from the Western Cape Province, South Africa. Although the overall preservation of the skeletal elements is good, loans to students, other departments and institutions in the past, have resulted in total or partial loss of some of the material, which has reduced the number of full skeletons available for study. As a result, the collection currently has 674 (58%) complete and 342 (29.5%) incomplete individuals from the cadaver programme. However, 103 (8.9%) cadaver-derived individuals are on loan or at an unknown location. Moreover, this collection hosts a small number (3.6%) of fragmented individuals with archaeological or forensic origins (Table 1).

The greatest proportion (42%) of individuals in the collection were born between 1920 and 1949, with the oldest born in 1855 and the most recent in 1991. Most (54.1%) individuals in the collection died between 1970 and 1989 (Figure 2).

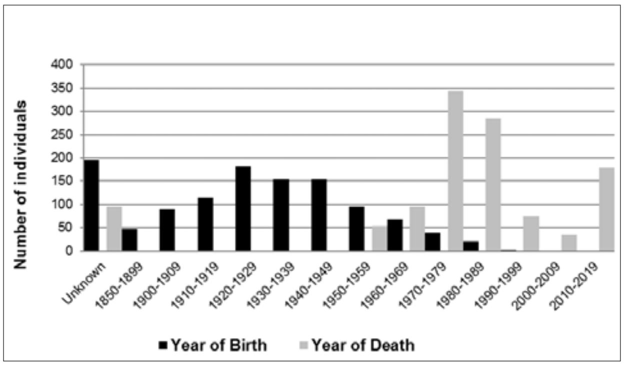


Figure 2: Frequency distributions for year of birth and year of death for the skeletons in the Kirsten Skeletal Collection.

The collection comprises individuals from three main socially defined population groups, namely South African coloured (59.7%), South African black (16.5%) and South African white (12.2%). The regional population composition of the Western Cape Province differs considerably from that of other provinces in South Africa. According to the census of 2011[7], the black population group has the highest proportion (of over 79%) in all provinces with the exception of the Western Cape (32.9%). The South African coloured population is the highest proportion in the Western Cape (48.8%). Therefore, it is expected that a larger South African coloured population is apparent in the Kirsten Skeletal Collection, which is derived mainly from Western Cape individuals. However, the South African coloured population in the Western Cape declined from 58.3% in 1991[24] to 48.8% in 2011[7].

Cadavers were mostly acquired from the large teaching hospitals in the region, namely Tygerberg Hospital (32%), followed by Karl Bremer Hospital (10.1%), both in the Bellville area, and Groote Schuur Hospital (6.8%) in Cape Town. A total of 15.6% of individuals were received directly from undertakers as paupers and 14.6% were from unknown sources or sources that had not been documented (Table 2). Available records for the last residence of individuals in the Kirsten Skeletal Collection indicate that the greatest proportion were from the Cape Town metropole (42.3%) and surrounding towns (19.1%) (Table 3).

Table 1: The state of the skeletal remains in the Kirsten Skeletal Collection

State	Description	*n* (%)
Complete	A complete individual that may be either articulated or unarticulated	674 (58.0)
Incomplete (cranial only)	A complete skull (calvarium, cranium and mandible) without associated post-cranial remains	60 (5.2)
Incomplete (fragmented)	Remains that have only a few bones present because specific bones are on loan to institutions, departments or students on a semi-permanent basis or have been lost through loan to students	197 (16.9)
Incomplete (post-cranial only)	Post-cranial remains which are not associated with a skull	85 (7.3)
On loan (complete)	Complete remains that are on loan to institutions, departments or students on a semi-permanent basis, either articulated or unarticulated	58 (5.0)
Missing/unknown	Remains for which the current location is unknown	45 (3.9)
Archaeological/forensic origin	Skeletons received from sources other than the cadaver programme	42 (3.6)

Table 2: Locations or institutions from which bodies were received

Location/institution	*n* (%)
Tygerberg Hospital	379 (32.6)
Karl Bremer Hospital	117 (10.1)
Groote Schuur Hospital	79 (6.8)
Paarl Hospital	51 (4.4)
Tuberculosis institutes	23 (2.0)
Conradie Hospital	22 (1.9)
Stellenbosch Hospital	19 (1.6)
Victoria Hospital	16 (1.4)
Stikland Hospital	15 (1.3)
Hottentots Holland Hospital	14 (1.2)
Somerset Hospital	13 (1.1)
Brooklyn Chest Hospital	12 (1.0)
Eerste River Hospital	12 (1.0)
Valkenberg Hospital	9 (0.8)
Western Cape mortuaries	5 (0.4)
Undertakers	181 (15.6)
Other	25 (21.1)
Unknown	169 (14.6)

Table 3: Last available residence (region) of individuals in the Kirsten Skeletal Collection

Last residence	*n* (%)
South Africa	
Cape Town Metropole: Cape Flats	175 (15.1)
Cape Town Metropole: Northern suburbs	155 (13.4)
Stellenbosch/Paarl Districts	114 (9.8)
Kuils River/Kraaifontein	93 (8.0)
Cape Town Metropole: Southern suburbs	92 (7.9)
Other Western Cape towns	65 (5.6)
Somerset West District	51 (4.4)
Wellington/Worcester Districts	21 (1.8)
Southern Cape	11 (0.9)
Eastern Cape	10 (0.9)
Northern Cape	6 (0.5)
Free State	2 (0.2)
Namibia	11 (0.9)
Unknown	355 (30.6)

Table 4: Population and age composition of the individuals in the Kirsten Skeletal Collection

	n (%)	BM	BF	WM	WF	CM	CF	KM	KF	KU	UM	UF	US & UA
Unknown	172 (14.8)	9	4	3	2	24	6	0	0	10	4	2	109
Infant (birth – 5 years)	0 (0)	0	0	0	0	0	0	0	0	0	0	0	0
Juvenile (5.1–15 years)	6 (0.5)	1	1	0	0	1	3	0	0	0	0	0	0
Sub-adult (15.1–20 years)	11 (1.0)	3	0	0	0	5	3	0	0	0	0	0	0
Young adult (20.1–40 years)	232 (20.0)	39	11	4	0	93	81	0	1	2	1	0	0
Adult (40.1–60 years)	485 (41.8)	76	17	35	14	240	98	0	0	0	1	1	2
Old adult (60.1–80 years)	222 (19.1)	25	3	40	28	94	31	1	0	0	0	0	0
Very old (80.1–105 years)	33 (2.8)	3	0	5	11	7	7	0	0	0	0	0	0
Total	**1161**	**156**	**36**	**87**	**55**	**464**	**229**	**1**	**1**	**12**	**6**	**3**	**109**

BM, black male; BF, black female; WM, white male; WF, white female; CM, coloured male; CF, coloured female; KM, Khoisan male; KF, Khoisan female; KU, Khoisan unknown sex; UM, unknown ancestry male; UF, unknown ancestry female; US, unknown sex; UA, unknown ancestry

The mean age at death for the entire collection is 51.0 years and ranges from 10 to 103 years. The greatest proportion (41.8%) of individuals died between the ages of 40 and 60. The mean age at death for female individuals from all population groups is 49.7 years (10 to 103 years) and for male individuals, 51.7 years (15 to 100 years) (Table 4). When comparing the age composition of the three populations (black, white and coloured), both male and female groups for the black and coloured populations show the highest proportion of individuals died in the adult (40–60 years) age category, whereas more male and female individuals in the white population were in the old adult (61–80 years) age category at death (Table 4). The average age at death for the black population was 51.0 years for males and 41.5 years for females; for the coloured population was 50.6 years for males and 45.5 years for females; and for the white population was 62.4 years for males and 66.9 years for females.

The sex ratio of the collection demographics is not representative of the South African population. Sex distribution determined by censuses[7] indicate that the South African population is predominantly female. However, the female individuals in this collection are under-represented in all three population groups (coloured, black and white), with the majority (61.6%) of skeletons being male (Table 5).

Table 5: Population and sex composition of the individuals in the Kirsten Skeletal Collection

Population group	*n* (%)	Male	Female	Unknown sex
Coloured	693 (59.7)	464	229	–
Black	192 (16.5)	156	36	–
White	142 (12.2)	87	55	–
Khoisan	14 (1.2)	1	1	12
Asian	1 (0.1)	1	0	–
Unknown	119 (10.3)	6	3	110
Total	**1161 (100)**	**715**	**324**	**122**

Table 6: Cause of death as stated on the death certificate

Cause of death	*n* (%)
Cardiovascular disease	175 (15.1)
Cancer	166 (14.3)
Respiratory disease without PTB	120 (10.3)
Respiratory disease with PTB	111 (9.6)
Brain disease/haemorrhage	36 (3.1)
Cardiopulmonary failure/disease	31 (2.7)
Liver cirrhosis/disease	26 (2.2)
Gastrointestinal disease	19 (1.6)
Renal failure	18 (1.6)
Malnutrition, neglect, hypothermia	16 (1.4)
Cardiovascular disease and tuberculosis	11 (0.9)
Liver disease and cancer	11 (0.9)
Cardiopulmonary failure and liver disease	4 (0.3)
Respiratory disease and brain disease	3 (0.3)
Cardiovascular disease and renal failure	3 (0.3)
Cardiovascular and gastrointestinal diseases	3 (0.3)
Other	64 (5.5)
Unknown/natural causes	344 (29.6)

PTB, pulmonary tuberculosis

According to the death certificates on record, cause of death was mainly cardiovascular disease (15.1%) and cancer of various origins (14.3%), although respiratory diseases such as pulmonary tuberculosis, bronchiectasis, pneumonia and asthma accounted for a large number of intakes (24.1%). In 344 cases (29.6%), the cause of death was indicated as either unknown or natural causes (Table 6), as there is no obligation for clinicians to indicate true cause of death on the death notification form as legislation dictates that the HIV/Aids status of a patient should be kept confidential.[28] Clinicians therefore indicate any HIV/Aids related death as natural and in this context it has the same meaning as unknown. When comparing the main cause of death across ancestral groups, heart disease was the main cause of death among the white group, while cancer was the most common cause amongst the coloured and black groups.[24]

Discussion

The Western Cape Province of South Africa has a rich genetic history, arising from many parts of the world including the local ancient Khoisan population[8-11], the greater Bantu groups from the Niger–Congo phylum[12,14-16], European settlers[17,18] and slaves from the East[18,19]. Marriages amongst the different population groups were once common[17,20], and produced a heterogeneous new and genetically unique population in the Western Cape, until apartheid was introduced and resulted in a drastic decrease in cross-population gene flow[6,20,25].

The origin of the osteological material in the Kirsten Skeletal Collection has been mainly cadavers used during anatomy training of medical students since the anatomy department's origin in the late 1950s. Research projects on this material were initiated only in recent years.[6,22,29-32] These cadavers derive from consented donations or unclaimed bodies of persons who died from natural causes in the Western Cape region.

Date of birth and date of death from cadaver records indicate that the Kirsten Skeletal Collection represents an adult population from the mid- to late 20th century. In comparison, the Raymond A. Dart collection at the University of the Witwatersrand in Johannesburg (Gauteng Province) represents mostly a population from the early to mid-20th century[1] and the Pretoria Bone Collection at the University of Pretoria[5], also a mid- to late 20th century population.

While percentages from both black and coloured population groups show that the greatest proportion of male and female individuals died between 40 and 60 years of age, both male and female individuals from the white population were older than 60 years at death. This difference may be explained by socio-economic circumstances, religious beliefs and unclaimed body donation regulations.[5,27] The reason for the differences in the number of male and female donations and unclaimed bodies may be cultural, as there is a tendency in the coloured group for men to leave family units, either temporarily or permanently, and not keep in communication with relatives[25], and thereby end up as unclaimed bodies in the cadaver register.

Although it was expected that the Kirsten Skeletal Collection would house a larger South African coloured population group, as it is derived from primarily Western Cape individuals, some cultural groups in South Africa are less willing to donate their bodies to science than others. Although organ donation is allowed, violation of the human body, living or dead, is forbidden in, for instance, Islam[33] and therefore bodies are not donated for use in medical training by this group. The black population group is hesitant to donate bodies because of traditional African beliefs that the body is not separate from the soul and they need to be buried as an integrated whole. This means that, in general, black individuals are against body donation, as reflected in the relatively low percentage of skeletal material in the collection (16.5%) as opposed to the high percentage of black individuals (32.9%) residing in the Western Cape, according to the most recent[7] population census. Socio-economic circumstances may be the reason for older white people to donate their bodies while black people are more likely to be migrating labourers with no known family in the region. In many instances, the South African coloured communities, as a result of low socio-economic circumstances, lack the means to host a funeral for the deceased and opt to donate the bodies for medical use.[34]

Conclusion

Data were presented on 1161 individuals in the Kirsten Skeletal Collection, derived mainly from the cadaver donation programme over a 58-year period (1957–2015). The skeletal profile in general, despite differences in the age and sex composition of three population groups, reflects predominantly the profile of the Western Cape population. The Kirsten Skeletal Collection is unique compared to other known skeletal collections in South Africa[1,3-5] in that the majority of the individuals are from the heterogeneous South African coloured population.

Current biological profile techniques in age, ancestry and sex estimation should be improved and new regional and ethnic specific standards can be developed. Researchers may contact the corresponding author for information regarding access to the collection for research. The Kirsten Skeletal Collection retains great potential to contribute to a wealth of future research projects in skeletal biology and related fields, and may be utilised as long as the origin of the remains is acknowledged and accounted for by the use of appropriate methods.

Acknowledgements

We thank Dolf van Rensburg, Ben Jooste and Basil Veenendal for their assistance with the development of the Kirsten Collection and Danni Perreira for editing. We also thank the anonymous reviewers for their input. A special thank you goes to the people who donated their bodies to science.

Authors' contributions

A.A. was the lead author, and collected and analysed the data and wrote the first draft. L.M.G. supervised the study and assisted with data analysis and editing. E.G. assisted with data collection. All authors contributed to critical reviewing and revision of the article and approved the final version.

References

1. Dayal MR, Kegley ADT, Strkalj G, Bidmos MA, Kuykendall KL. The history and composition of the Raymond A. Dart Collection of human skeletons at the University of the Witwatersrand, Johannesburg, South Africa. Am J Phys Anthropol. 2009;140:324–335. https://doi.org/10.1002/ajpa.21072
2. DiGangi EA, Moore MK. Research methods in humans skeletal biology. Waltham, MA: Academic Press; 2013.
3. Hunt D, Albanese J. History and demographic composition of the Robert J. Terry Anatomical Collection. Am J Phys Anthropol. 2005;127:406–417.
4. Komar D, Grivas C. Manufactured populations: What do contemporary reference skeletal collections represent? A comparative study using the Maxwell Museum Documented Collection. Am J Phys Anthropol. 2008;137:224–233. https://doi.org/10.1002/ajpa.20858
5. L'Abbé EN, Loots M, Meiring JH. The Pretoria Bone Collection: A modern South African skeletal sample. HOMO. 2005;56:197–205. https://doi.org/10.1016/j.jchb.2004.10.004
6. Stull KE, Kenyhercz MW, L'Abbé EN. Ancestry estimation in South Africa using craniometrics and geometric morphometrics. Forensic Sci Int. 2014;245,206.e1–206.e7. https://doi.org/10.1016/j.forsciint.2014.10.021
7. Statistics South Africa. Census 2011: Statistical release. Pretoria: Statistics South Africa; 2012.
8. Schuster SC, Miller W, Ratan A, Tomsho LP, Giardine B, Kasson LR. Complete Khoisan and Bantu genomes from southern Africa. Nature. 2010;463:943–947. https://doi.org/10.1038/nature08795
9. Chen YS, Olckers A, Schurr TG, Kogelnik AM, Huoponen K, Wallace, DC. mtDNA variation in the South African Kung and Khwe-and their genetic relationships to other African populations. Am J Hum Genet. 2000;66:1362–1383. https://doi.org/10.1086/302848
10. De Wit E, Delport W, Rugamika CE, Meintjes A, Möller M, Van Helden PD, et al. Genome-wide analysis of the structure of the South African coloured population in the Western Cape. Hum Genet. 2010;128:145–153. https://doi.org/10.1007/s00439-010-0836-1
11. Schlebusch CM, Skoglund P, Sjödin P, Gattepaille LM, Hernandez D, Jay F, et al. Genomic variation in seven Khoe-San groups reveals adaptation and complex African history. Science. 2012;338:374–379. https://doi.org/10.1126/science.1227721
12. Thompson LA. History of South Africa. New Haven, CT: Yale University Press; 2013. https://doi.org/10.1163/18757421-90000065
13. Tishkoff SA, Reed FA, Friedlaender FR, Ehret C, Ranciaro A, Froment A, et al. The genetic structure and history of Africans and African Americans. Science. 2009;324(5930):1035–1044. https://doi.org/10.1126/science.1172257
14. De Filippo C, Barbieri C, Whitten M, Mpoloka MS, Gunnarsdottir ED, Bostoen K, et al. Y-chromosomal variation in sub-Saharan Africa: Insights into the history of Niger–Congo groups. Mol Biol Evol. 2011;28(3):1255–1269. https://doi.org/10.1093/molbev/msq312
15. Plaza S, Salas A, Calafell F, Corte-Real F, Bertranpetit J, Carracedo A, et al. Insights into the western Bantu dispersal: mtDNA lineage analysis in Angola. Hum Genet. 2004;115(5):439–47. https://doi.org/10.1007/s00439-004-1164-0
16. Coelho M, Sequeira F, Luiselli D. Beleza S, Rocha J. On the edge of Bantu expansions: mtDNA, Y chromosome and lactase persistence genetic variation in southwestern Angola. BMC Evol Biol. 2009;9:80. https://doi.org/10.1186/1471-2148-9-80
17. Patterson N, Petersen DC, Van der Ross RE, Sudoyo H, Glashoff RH, Marzuki S, et al. Genetic structure of a unique admixed population: Implications for medical research. Hum Mol Genet. 2010;19:411–419. https://doi.org/10.1093/hmg/ddp505
18. Van der Ross RE. Up from slavery: Slaves at the Cape: Their origins, treatment and contribution. Cape Town: Ampersand Press in association with the University of the Western Cape; 2005.
19. Petersen DC, Libiger O, Tindall EA, Harie RE, Hannick LI, Glashoff RH, et al. Complex patterns of genomic admixture within southern Africa. PLoS Genet. 2013;9, e1003309, 17 pages. https://doi.org/10.1371/journal.pgen.1003309
20. Jacobson CK, Amoateng AY, Heaton TB. Inter-racial marriages in South Africa. J Comp Fam Stud. 2004;35:443.
21. Sherman R, Steyn M. E-race-ing the line: South African interracial relationships yesterday and today. In: The prize and the price: Shaping sexualities in South Africa. Cape Town: HSRC Press; 2009.
22. McDowell J, Kenyhercz M, L'Abbé E. An evaluation of nasal bone and aperture shape among three South African populations. Forensic Sci Int. 2015;189:e1–e7. https://doi.org/10.1016/j.forsciint.2015.04.016
23. Erasmus Z. Apartheid race categories: Daring to question their continued use. Transform Crit Perspect South Afr. 2012:79, 11 pages. https://doi.org/10.1353/trn.2012.0008
24. Labuschagne BCJ, Mathey B. Cadaver profile at University of Stellenbosch Medical School, South Africa, 1956-1996. Clin Anat. 2000;13:88–93. https://doi.org/10.1002/(sici)1098-2353(2000)13:2<88::aid-ca3>3.0.co;2-q
25. Kalmijn M. Intermarriage and homogamy: Causes, patterns. Annu Rev Sociol. 1998:395–421.
26. South African National Department of Health. Human Tissues Act. Government Gazette. 1983;216:1–34.
27. South African National Department of Health. National Policy for Health Act, 2003 (Act No. 61 of 2003). Government Gazette. 2004;469:66–79.
28. Joyner K. Aspects of forensic medicine – An introduction for healthcare professionals. Cape Town: Juta and Co Ltd.; 2010.
29. Pfeiffer S, Heinrich J, Beresheim A, Alblas M. Cortical bone histomorphology of known-age skeletons from the Kirsten Collection, Stellenbosch University, South Africa. Am J Phys Anthropol. 2016;160:137–147. https://doi.org/10.1002/ajpa.22951.
30. Holgate RL, Steyn M. Diffuse idiopathic skeletal hyperostosis: Diagnostic, clinical, and paleopathological considerations. Clin Anat. 2016:870–877. https://doi.org/10.1002/ca.22716.
31. Liebenberg L, L'Abbé EN, Stull KE. Population differences in the postcrania of modern South Africans and the implications for ancestry estimation. Forensic Sci Int. 2015;257:522–529. https://doi.org/10.1016/j.forsciint.2015.10.015
32. Steyn M, Buskes J. Skeletal manifestations of tuberculosis in modern human remains. Clin Anat. 2016:854–861. https://doi.org/10.1002/ca.22688.
33. Golmakani MM, Niknam MH, Hedayat KM. Transplantation ethics from the Islamic point of view. Med Sci Monit. 2005;11:105–109.
34. Van Tonder JL. Fertility survey 1981: Data concerning the coloured population of South Africa. Pretoria: Human Sciences Research Council; 1984.

Palaeodemographics of individuals in Dinaledi Chamber using dental remains

AUTHORS:
Debra R. Bolter[1,2]
John Hawks[2,3]
Barry Bogin[2,4]
Noel Cameron[2,4]

AFFILIATIONS:
[1]Department of Anthropology, Modesto Junior College, Modesto, California, USA
[2]Evolutionary Studies Institute, School of Geosciences, University of the Witwatersrand, Johannesburg, South Africa
[3]Department of Anthropology, University of Wisconsin-Madison, Madison, Wisconsin, USA
[4]School of Sport, Exercise & Health Sciences, Loughborough University, Leicestershire, United Kingdom

CORRESPONDENCE TO:
Debra Bolter

EMAIL:
bolterd@yosemite.edu

DATES:
Received: 02 Mar. 2017
Revised: 14 June 2017
Accepted: 30 Aug. 2017

KEYWORDS:
Homo naledi; life stages; demographic profile; MNI; life history

HOW TO CITE:
Bolter DR, Hawks J, Bogin B, Cameron N. Palaeodemographics of individuals in Dinaledi Chamber using dental remains. S Afr J Sci. 2018;114(1/2), Art. #2017-0066, 6 pages. http://dx.doi.org/10.17159/sajs.2018/20170066

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
National Geographic Society; National Research Foundation (South Africa); University of Wisconsin-Madison

Hominin skeletal remains from the Dinaledi Chamber, South Africa, represent a minimum of 15 individuals of the extinct species *Homo naledi*. We examined the dental material from this sample in order to assess the life-history stages of individuals in the sample, in particular to determine the minimum number of individuals in the sample as a whole, and within each of six age classes. We found evidence of individuals within every age class: infant, early juvenile, late juvenile, subadult, young adult and old adult. The Dinaledi Chamber sample is notable in comparison to other samples of human, chimpanzee and fossil hominins in that it has a relatively high representation of juvenile remains, as compared to infants and adults. With 15 individuals, the sample size presented by the Dinaledi dental material is too small to test the hypothesis of attritional versus catastrophic accumulation. The data here provide a basis for further investigation of individual associations within this commingled assemblage, and provide an important comparative data set as a basis for the consideration of life history in *H. naledi* and other extinct hominin populations.

Significance:

- We identified a minimum number individuals so far recovered in the assemblage and document the use of molar eruptions as biomarkers of life-history stages to sort the individuals into age classes.
- We provide a demographic profile of individuals from the chamber and establish a comparative data set for life history in extinct hominin populations.

Introduction and background

The evolution of life history is fundamentally important to many of the anatomical and behavioural changes in human evolution, yet understanding the age structure of ancient hominin populations is challenging. The fossil evidence for human evolution is fragmentary, and most fossil hominin sites represent the remains of single individuals. Only a few sites preserve remains of large numbers of hominin individuals. Some of these sites, such as Sterkfontein and Swartkrans, reflect the accumulation of individuals by heterogeneous processes over very extended ranges of time. Such time-averaged assemblages – like multiple occurrences of single, isolated individuals – have limited utility for understanding the age structure and other demographic aspects of ancient populations. A mere handful of fossil assemblages may represent individuals drawn from a comparatively narrow interval of time, or even from single ancient groups, such as the Hadar A.L.333 locality, the Sima de los Huesos, and the El Sidrón assemblage. The comparative context for understanding the age structure at death in ancient hominins must be built on such fossil assemblages. However, the mortality events and subsequent taphonomic processes that formed these assemblages may exert unique biases upon them. These matters can be understood only by close comparison of such assemblages and their taphonomic circumstances.

The Dinaledi Chamber, South Africa, may present one such occurrence of multiple individuals representing one hominin population. The hominin remains excavated from this chamber are morphologically consistent with a single-species assemblage, and their distinctiveness from other hominins led to their diagnosis as a new species, *Homo naledi*.[1] Approximately 1550 numbered specimens, including cranial and postcranial remains, were recovered from the chamber during excavations in 2013 and 2014. The situation of the fossil assemblage, with hominins attributable to one geological unit, suggests that the remains reached the Dinaledi Chamber over a short geological time span, although several aspects of their taphonomic condition provide evidence that the remains did not enter the chamber in a single instantaneous event.[2] The deposition of the hominin remains occurred between 236 000 and 335 000 years ago[3] – placing them in the later Middle Pleistocene. The degree of morphological variability within this assemblage is very slight; dental and postcranial dimensions are consistent with the variability found within single populations of living humans. Several aspects of the context of these fossil remains distinguish the depositional circumstances from those of other South African cave assemblages. These aspects include the absence of highly calcified breccia encasing the remains, the absence of non-hominin macrofaunal remains, and the present inaccessibility of the Dinaledi Chamber itself.[2-5]

The Dinaledi assemblage presents an uncommon opportunity to examine a fossil species at the population-level perspective. We have undertaken a preliminary study of the dental remains from this assemblage to assess them as biomarkers of life-history stages of these hominins. The basic assessment includes an estimation of the minimum number of individuals (MNI) and the number of individuals that can be confidently attributed to age classes, enabling a demographic profile of the assemblage. We compared the finds to mortality patterns in living groups and to other hominin fossil assemblages from the Plio-Pleistocene, establishing a solid basis for future comparative work.

Research methods and data

A total of 190 teeth or partial teeth from the Dinaledi Chamber assemblage, recovered during excavations in 2013 and 2014, were used in the present study. Of these teeth, 60 are in situ within seven partial mandibles and one partial maxilla. The remaining teeth in the assemblage were isolated and include 16 specimens that are isolated roots or crown fragments, which provide relatively little evidence for assessment of MNI or age class.

Assessment of individuals

The MNI and age classes represented in a commingled dental assemblage are interrelated with each other. Two isolated molars that clearly represent different life-history stages (i.e. a highly worn M3 and an unworn M2) cannot represent a single individual, and so assessing age is fundamental to testing the number of individuals represented, and vice versa. We therefore proceeded to establish conservatively how many individuals the teeth could represent, erring in all cases toward a minimal number; the teeth may represent more individuals and future excavations may test this assessment.

Age classes

We divided the dental materials into four life/maturity stages within six age classes. We slightly modified the standardised age class assessments of immatures[6-8] in that we merged Juv III (canine eruption) and Subadult (M3 eruption) into one class – Subadult – based only on M3 eruption. This approach more conservatively relies on molar eruptions for MNI in the fossil sample and reduces possible overinflation of an age class category if canine and molar eruptions are close in sequence. We adopted the classification of age classes as follows (Figure 1):

1. Infant, no permanent molars erupted (INF);
2. Early juvenile, M1 erupted (E-JUV);
3. Late juvenile, M2 erupted (L-JUV);
4. Subadult, M3 erupted, unworn (S-AD);
5. Young adult, all molars erupted, moderate wear (Y-AD);
6. Old adult, all fully erupted, wear well into dentin on M2 or sufficient to obliterate most occlusal detail on M3 (O-AD).

Molars and MNI

Of the 190 teeth in the assemblage, 64 are permanent molars, molar germs or roots from molars. In our assessment, permanent molars provide the primary identification for the MNI and assignment into an age class. In the living non-human primates, eruption times of permanent molars correlate with life-stage transitions; for example, first molars (M1) erupt to lay the foundation toward weaning and feeding on an adult diet, and the third molars (M3) erupt before the transition to reproductive maturity.[8-13]

By using a simple count of total molar teeth by type and side, not considering in-situ placement, stage of development or wear, an absolute minimum of nine individuals was identified (Table 1). In this fossil assemblage, one complete mandible, six partial hemi-mandibles and one hemi-maxilla, with a total of 18 molars in position, were recovered from the Dinaledi Chamber[14] (Table 2). Given duplication of tooth type, side and wear, and different stages of permanent tooth eruptions, each of the seven mandibular specimens represent a separate individual. The left partial mandible U.W.101-1400 has only deciduous teeth (canine and molars) with an M1 crown near completion in the crypt (unerupted), assigned as INF (Figure 1a). The right partial mandible U.W.101-377 contains a permanent canine, premolars and first and second molars, but the canine is only partially erupted, and the second molar erupted but not quite into full occlusion. We assigned this L-JUV (Figure 1b). Mandible U.W.101-1261 (Figure 1c) and associated partial maxilla U.W.101-1277 have fully erupted molar teeth with moderate wear, assigned here as a Y-AD. Of the remaining four adult partial mandibles, only U.W.101-361 exhibited heavy attrition on the left second and third molars. We assigned this specimen as O-AD. (Figure 1d).

Mandible U.W.101-1261 articulates with partial maxilla U.W.101-1277. These two elements are both part of DH1, the holotype specimen of *H. naledi*[1], and they provide a complete representation of all mandibular and maxillary tooth classes for *H. naledi.* We relied first upon these in-situ dentitions to identify permanent molar types (M1, M2, M3), and then began the assessment of MNI on the remaining 46 isolated molar teeth.

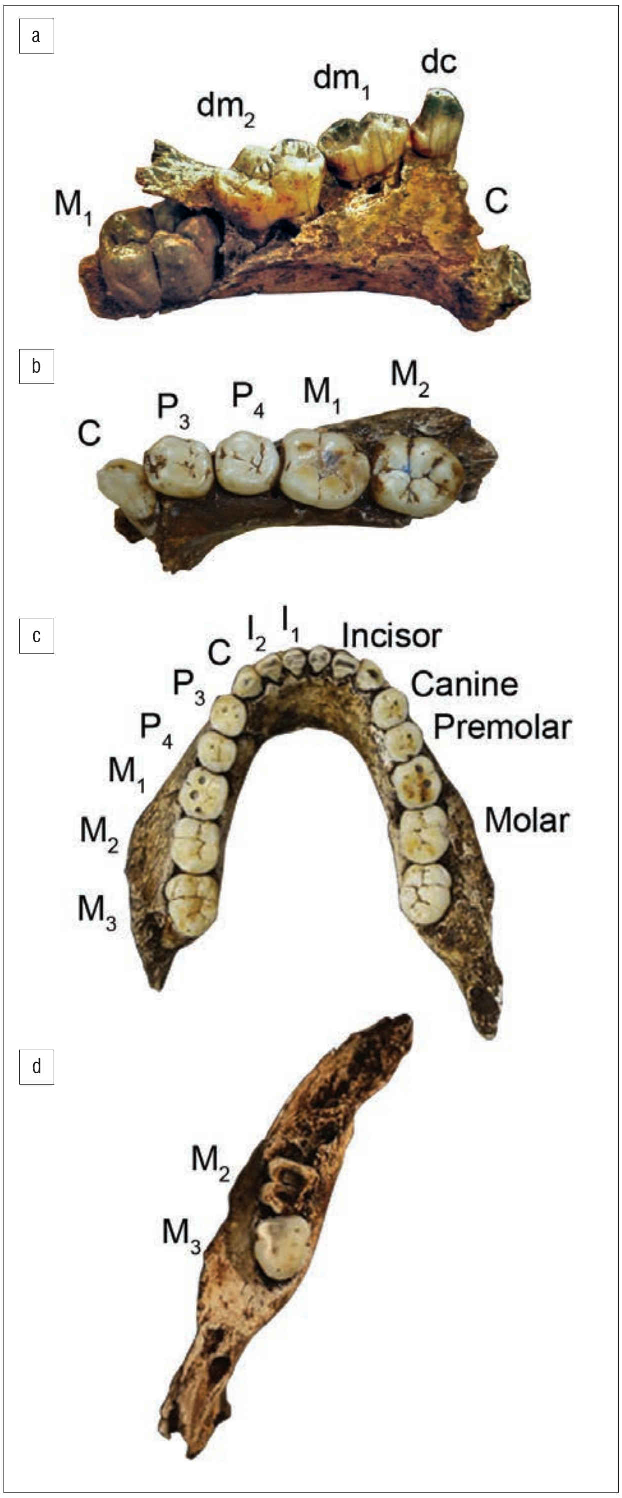


Figure 1: (from top to bottom, not to scale) (a) U.W.101-1400 infant left partial mandible with deciduous teeth and M_1 crown in the crypt (unerupted). (b) U.W.101-377 late juvenile right partial mandible with permanent erupted teeth labelled. (c) U.W.101-1261 adult full mandible with all permanent teeth labelled. (d) U.W.101-361 old adult left partial mandible with permanent teeth very worn.

Table 1: Count of 64 permanent molars, roots and germs, separated by left and right sides, divided into age classes. Absolute minimum number of individuals (MNI) based solely on molar counts shown at far right.

Left	M_1	M_2	M_3	M^1	M^2	M^3	MNI
Total count: 33	**7**	**5**	**3**	**8**	**6**	**4**	
Age category							
INF	2	–	–	2	–	–	2
E-JUV	2	1	–	2	2	–	2
L-JUV	1	1	–	1	–	1	1
SUB-AD	1	1	–	1	1	1	1
Y-AD	1	1	2	1	2	1	2
O-AD	–	1	1	1	1	1	1
Absolute MNI							9

Right	M_1	M_2	M_3	M^1	M^2	M^3	MNI
Total count: 31	**9**	**6**	**4**	**6**	**5**	**1**	
Age category							
INF	2	–	–	1	–	–	2
E-JUV	1	1	–	1	1	–	1
L-JUV	1	1	–	1	1	–	1
SUB-AD	1	–	–	1	1	1	1
Y-AD	3	3	3	2	1	–	3
O-AD	1	1	1	-	1	–	1
Absolute MNI							9

Table 2: Dental individuals as assessed from in-situ teeth, and with the number of associated molars identified. Dental individual 6 is repeated in the table because U.W.101-1261 preserves the mandibular and U.W.101-1277 the maxillary dentition.

Dental individual	Specimen	Side and elements	In-situ molars	Associated molars
1	U.W.101-001	Right: P_3-M_3	3	1
2	U.W.101-010	Right: C-P_3	0	0
3	U.W.101-361	Left: M_2-M_3	2	7
4	U.W.101-377	Right: C-M_2	2	6
5	U.W.101-1142	Right: M_2-M_3	2	4
6	U.W.101-1261	Complete mandibular dentition	6	0
6	U.W.101-1277	Right: I^1-M^2	2	2
7	U.W.101-1400	Left: dc-dm_2, M_1	1	3

We fine-tuned the MNI by associating molar remains using standard approaches based on matching occlusal and interproximal contact facets, identifying antimeres, and identifying comparable stages of tooth development and attrition. This method follows previous work on the Krapina Neanderthal dental sample[15], which in turn modified an approach developed for MNI assessment on the Zhoukoudian *Homo erectus* dental sample[16]. Building from the mandibular evidence, we examined the isolated teeth in the collection to identify possible antimeres of teeth in mandibles, possible interproximal facet matches with teeth adjacent to teeth in mandibles and maxillary post-canine teeth that occlude well and match the wear stages of teeth present in mandibles. Using these methods, we identified 23 additional molars, roots and germs that refit or are otherwise consistent with six of the dental individuals identified from mandibles. These dentitions comprise a total of 41 molar associations. We could not attribute any isolated molars to U.W.101-010, a partial mandible with only moderately worn anterior teeth, based on developmental stage.

Building from these seven individuals identified from in-situ teeth and the isolated molars to which they were attributed, we next prioritised identifying cases of matching interproximal facets, tooth types and sides, and developmental consistency for the remaining 23 isolated molars. Among these isolated teeth, we identified evidence for a minimum of five additional individuals:

- Dental individual 8 to which we attribute 7 molars: 3- M1, 4- M2: unerupted, which we assign as E-JUV;
- Dental individual 9 to which we attribute 1- mandibular M1: forming germ, which we assign as INF;
- Dental individual 10 to which we attribute 1 maxillary and 1 mandibular M1, both partially formed germs, which we assign as INF;
- Dental individual 11 to which we attribute 9 molars: 4- M1; 3- M2; 2- M3, which we assign as S-AD; and
- Dental individual 12 to which we attribute 4 molars: 3- M1; 1- M2: unerupted, which we assign as E-JUV.

These additional five individuals increased the MNI to 12.

Anterior teeth

The study of the molars left unanswered whether the anterior teeth could be associated with individuals as identified from molars. We therefore continued by asking whether anterior teeth could be conservatively included within the existing hypothetical molar associations, or whether any inconsistencies required the addition of more individuals to the MNI count. We could accommodate all anterior teeth into this MNI of 12 dental individuals, except in three instances, in which anterior teeth presented duplications beyond the number of individuals identified from molars within an age class. Thus, three additional individuals must be present in the collection because of the duplication of anterior teeth. One of these individuals is clearly identifiable to age class, a third E-JUV, based on a left lower deciduous canine (U.W.101-824). Given the canine's stage of development and wear, the individual is older than the infants identified in the collection and more akin to an early juvenile. However, the canine cannot belong to the existing two E-JUV already identified because one already has an associated mandibular left deciduous canine, and the other has considerably less tooth wear than is consistent with U.W.101-824. A 14th individual is represented by a single upper left canine (U.W.101-347). There are 13 fully formed adult canine teeth (6 lower and 7 upper) in the assemblage. However, based on the differences in wear, left/right and size differences, this tooth represents an extra canine that does not fit with any of the five adults represented by partial mandibles, although it is consistent with adult life-history stage. A 15th individual is recognised for MNI purposes based on three adult incisors consistent with each other on the bases of minimal wear and appearance. These incisors belong to a juvenile or subadult individual. However, the incisors cannot be associated with the existing individuals in any E-JUV, L-JUV or S-AD age class based on the inconsistent stage of associated tooth wear.

Accessibility of data

We have numbered the dental individuals for convenience of analysis and discussion but consider each of these to be hypothetical. As such, future work may change their composition or provide evidence that additional individuals may be represented. All the Dinaledi hominin remains are curated at the University of the Witwatersrand, and access to original material, scans and records is by application to the curator.

Comparative data

The Dinaledi assemblage may be one of the most representative of a life-stage collection for *Homo*[2,8,17], despite the fact that the current collection is as yet a sub-set of the total assemblage and more materials will become available from excavation. At the few fossil hominin sites with multiple immature finds, dentition is relied upon to refine the categories beyond immature and adult, and to calculate the MNI.[17-19] We compared the representation of broad age categories against those found at these other hominin fossil sites and within age-at-death distributions of contemporary human and wild chimpanzee populations, thereby investigating the palaeodemographic implications of the assemblage.

Results

We were able to identify a minimum number of 15 individuals in the Dinaledi Chamber, and provide an age class assessment for 13 of them (Table 3). The immature fall mostly within the INF (n=3) and E-JUV (n=3) age classes; the adults are predominantly Y-AD (n=4) with only a single O-AD by this classification. For two individuals that are present in the MNI, we cannot be confident about the age class because of the lack of associated molars; one is adult but cannot be confidently assigned to either the Y-AD or O-AD class, and the other is immature. This classification results in nine immature and six adult individuals.

Table 3: Age classes based on dental associations for 13 dental individuals

Life stage	Number of individuals based on in-situ molars	Number of individuals based on isolated teeth	Dental individual	Total assigned
Infant (INF)	U.W.101-1400	2	7, 9, 10	3
Early juvenile (E-JUV)	0	3	8, 12, 13	3
Late juvenile (L-JUV)	U.W.101-377	0	4	1
Subadult (S-AD)	0	1	11	1
Young adult (Y-AD)	U.W.101-001 U.W.101-010 U.W.101-1142 U.W.101-1261/1277	0	1, 2, 5, 6	4
Old adult (O-AD)	U.W.101-361	0	3	1

Discussion

The quantification of MNI and age class attribution for the dental sample from the Dinaledi Chamber allows this sample to be placed into a comparative context. This classification provides a basis for examining the possible relations of dental with postcranial remains within the sample, and further provides data relevant to understanding the formation of the site and disaggregation of remains of some individuals within it. At the same time, this classification itself must to some extent reflect the limited amount of excavation of the Dinaledi Chamber, as well as the events leading to preservation of the fossils, both of which may lead to biases in the composition of the dental sample. We consider each of these issues.

Remains within the Dinaledi Chamber have been recovered both from the surface of the chamber (approximately 20 m^2), and from an excavation area of approximately 0.8 m^2 of the deposit. The majority of fossil specimens, including teeth (~80%), derive from this excavation area. Despite the density of bone material in this excavation field, it is unclear if the material in this area is an unbiased representation of the total assemblage. Abundant fossil remains are still within the chamber, although the relative density of remains in the deposit compared with that of the present excavation is unknown.

The small excavation sample and targeted excavation area may bias the representation of individuals. The 2013–2014 excavation area produced immature and adult remains from multiple individuals. The surface collection recovered a smaller number of specimens, but these specimens also represent multiple individuals. Some individuals in the present collection have an impressively complete dental representation, and others are represented provisionally by only a small number of teeth – in the extreme by only a single tooth. This distribution suggests that while further excavation may recover more parts of the same individuals, it is also highly likely that individuals remain in the deposit that have not yet been represented within our sample. At the very least, our dental individuals 14 and 15, which are insufficiently represented to assess age class with confidence, might be resolved with a few additional dental remains. The present MNI is more likely to underrepresent adults than immature individuals because differences in developmental age between isolated deciduous and recently erupted permanent teeth are more apparent than differences in age among adults with substantial occlusal wear. Thus, permanent teeth of adults are more difficult to eliminate from possible associations for MNI purposes.

In some other sites, spatial proximity of specimens can assist in the assessment of MNI. That is, it is sometimes possible to use the location of remains to help identify individuals. However, spatial proximity is not particularly insightful in the Dinaledi Chamber assemblage, in part because of the unusually dense clustering of the remains, and in part because it is evident that some of the deposit has been reworked after the initial deposition of the remains.[2,3] Some parts of the deposit preserve articulated remains, such as parts of a lower limb, hand and foot remains, some thoracic elements and dentition in situ. The majority of elements (94%) were recovered out of articulation, with fragmentary elements from different individuals intermingled with each other. For example, a group of teeth (beginning with U.W.101-1002, including lower and upper molars, a premolar, incisors and a canine) were found in close association during recovery in the excavation pit. However, based on the different stages of dental development, the teeth are clearly from different age classes, and represent at least three separate immature individuals.

Because of the unusual context of the hominin remains, it is potentially of great interest to know whether they represent attritional mortality or whether they might have resulted from a catastrophic mortality event. Assessing palaeodemographic parameters in archaeological and palaeontological collections remains challenging.[20,21] Thirteen fossil individuals of known life stage from one species at one site is a relatively large number compared to most assemblages, but is nonetheless small in a statistical sense. We considered whether the high fraction of infants and early juveniles (6 out of 13) might indicate something about the nature of the deposit that distinguishes the assemblage as attritional mortality or catastrophic mortality. However, a sample size of 13 individuals is not sufficient to statistically distinguish these distributions from each other even under the assumption of a stable demographic profile. The reality of fluctuating population size and group composition in a natural population means that substantially more than 50 individuals would be required to separate hypotheses of mortality profiles at the 95% confidence level. For this reason, we view it as appropriate to consider only general aspects of the life-stage pattern of death distributions for *H. naledi*.

With nine immature and six adult individuals, the fraction of immature remains in the present Dinaledi Chamber sample can be compared generally to the mortality distributions observed in living foraging groups. Again, we distinguish here between immature, which includes all individuals prior to adulthood, and more narrow life-history stages of infant, juvenile and subadult. The Hadza have immature mortality rates of 65.0%, with most of these deaths in the infant life-history stage, and 12.3% as juveniles.[22] In Dobe !Kung, immature deaths are less frequent at 40.5%, with a lower juvenile mortality at 7.4%.[23] Chimpanzee mortality rates at two African sites range between 30% and 60% during infancy, depending on environmental conditions and diet, whereas juvenile mortality is typically lower at 15–27%.[24-26] The relatively high representation of juvenile individuals in the Dinaledi Chamber sample is interesting, considering the lower representivity in mortality distributions of modern human and chimpanzee populations.

Other fossil hominin sites that preserve evidence of multiple individuals vary substantially in their representation of immature remains. South African cave assemblages range from a low of 18% immatures at Sterkfontein to a high of 57% at Kromdraai.[27,28] The wide variability in representation of immature remains in the South African caves may reflect the difference in taphonomic processes, as the fossil accumulation in these sites occurred by heterogeneous processes, in contrast to Dinaledi, which may represent a comparatively more limited variability.[3] In particular, it has been argued that the high representation of young male adults at Swartkrans may reflect the effects of social structure and dispersal on predation risk.[29]

The A.L.333 *Australopithecus afarensis* locality at Hadar, Ethiopia, may be more comparable with Dinaledi in representing a limited time horizon, and includes at least 17 individuals – 9 adults and a minimum of 8 immature individuals.[30-32] The majority of the immature individuals compare to our INF category based on deciduous dentition with no permanent teeth, and are 'very young'[31]. This high fraction of infants is similar to the age-at-death distributions noted above for modern humans and chimpanzees. The taphonomic conditions at this Hadar site support death by attrition, such as a predator accumulation, and not a high-energy, catastrophic event such as a flash flood[18], although deliberate body accumulation by hominins has also been suggested for this assemblage[33]. Dinaledi Chamber contrasts with this sample in the higher number of *H. naledi* juveniles (E-JUV and L-JUV) compared to the Hadar A.L.333 site.

In contrast to the Pliocene A.L.333 fossil assemblage, several samples of Middle to Late Pleistocene *Homo* represent contexts in which the hominins were clearly the principal accumulating agents.[2] Sima de los Huesos (SdH), Spain, has been characterised as an intentional disposal site dated at 430 000 kya.[17,34] Like the Dinaledi assemblage, the 28 individuals at SdH are morphologically homogeneous and confined to one horizon, findings that support the assemblage represent one population.[17,34] The age-at-death distribution of the SdH hominins has a high fraction of immature remains – older juveniles and subadults, with a much lower proportion of infants and early juveniles than Dinaledi, a difference that is unlikely to be due to taphonomic processes at that site.[17] Peri-mortem injury suggests interpersonal violence attributed to the assemblage at SdH.[35] The 49 kya El Sidrón Neanderthal site is an assemblage of at least 13 intermingled individuals that present evidence of cannibalism.[19,36] There, one infant, two juveniles, three subadults and seven adults are represented. Dinaledi preserves more infant and juvenile remains, but the small sample size does not give rise to any statistically significant difference.

These descriptive comparisons provide some additional context, but do not by themselves provide any strong test of hypotheses about the formation processes of the Dinaledi assemblage.[37-39] The deposition of at least 15 individuals with particularly high proportions of infants and young juveniles establishes Dinaledi as unusual compared to other fossil hominin assemblages.

Remains of three additional *H. naledi* individuals (two adults and one immature) have been recovered from the Lesedi Chamber, a separate region inside the Rising Star Cave system approximately 60 m NNE from the Dinaledi Chamber.[39,40] The context of the Lesedi Chamber remains is similar to that within the Dinaledi Chamber, and a similar depositional process is a possible explanation, although the age of the Lesedi Chamber sample remains unknown.[40] We have not here considered these individuals within the age classification of the Dinaledi Chamber hominins, and they will require additional study. If these remains represent the same or a similar population, a second assemblage within the Rising Star Cave system gives rise to the possibility that additional skeletal and dental material will be discovered. If so, a larger sample of hominin remains may in the future allow formal statistical and demographic analyses that are not yet possible on the sample of individuals from the Dinaledi Chamber.

Acknowledgements

We thank Zach Cofran for input during the Rising Star Workshop and three anonymous reviewers whose comments strengthened the paper. We also thank the National Geographic Society and the South African National Research Foundation for particularly significant funding of the discovery, recovery and analysis of this material. Further funding was provided by the University of Wisconsin-Madison. We thank the University of the Witwatersrand and the Evolutionary Studies Institute as well as the South African National Centre of Excellence in PalaeoSciences for curating the material and hosting the authors while studying the material, and Lee Berger for the opportunities to work on the fossil collections. We thank the South African Heritage Resource Agency for the necessary permits to work on the Rising Star site; the Jacobs family and Lee R. Berger Foundation for Exploration for granting access; our exploration team comprising Pedro Boshoff, Rick Hunter and Steve Tucker; excavators K. Lindsay Eaves, Marina Elliot, Elen Feuerriegel, Alia Gurtov, Hannah Morris and Becca Peixotto; and Wilma Lawrence, Bonita De Klerk, Natasha Barbolini, Merrill Vanderwalt and Justin Mukanku for their assistance during all phases of the project. We appreciate the collegial dialogue and discussion with participants during the Rising Star Workshop. We thank Carol Underwood for help on the figure.

Authors' contributions

D.R.B. and J.H. evaluated age classes of dental remains and conducted comparative work; D.R.B, J.H., B.B. and N.C. wrote the paper, added comparative data, oversaw the research and edited the paper. All authors discussed content and results, and contributed to the manuscript.

References

1. Berger L, Hawks J, De Ruiter D, Churchill S, Schmid P, Delezene L, et al. A new species of *Homo* from the Dinaledi Chamber, South Africa. *eLife*. 2015;4, e09560, 35 pages. https://doi.org/10.7554/eLife.09560

2. Dirks P, Berger L, Roberts E, Kramers J, Hawks J, Randolph-Quinney P, et al. Geological and taphonomic context for the new hominin species *Homo naledi* from the Dinaledi Chamber, South Africa. *eLife*. 2015;4, e09561, 37 pages. https://doi.org/10.7554/eLife.09561

3. Dirks P, Roberts E, Hilbert-Wolf H, Kramers J, Hawks J, Dosseto A, et al. The age of *Homo naledi* and associated sediments in the Rising Star Cave, South Africa. eLife. 2017;6, e24231, 59 pages. https://doi.org/10.7554/eLife.24231

4. Randolph-Quinney PS. A new star rising: Biology and mortuary behaviour of *Homo naledi*. S Afr J Sci. 2015;111(9/10), Art. #a0122, 4 pages. https://doi.org/10.17159/sajs.2015/a0122

5. Val A. Deliberate body disposal by hominins in the Dinaledi Chamber, Cradle of Humankind, South Africa? J Hum Evol. 2016;96:145–148. https://doi.org/10.1016/j.jhevol.2016.02.004

6. Zihlman A, Bolter D, Boesch C. Wild chimpanzee dentition and its implications for assessing life history in immature hominin fossils. Proc Natl Acad Sci USA. 2004;101:10541–10543. https://doi.org/10.1073/pnas.0402635101

7. Bolter D, Zihlman A. Skeletal development in *Pan pansicus* with comparisons to *Pan troglodytes*. Am J Phys Anthropol. 2012;147:629–636. https://doi.org/10.1002/ajpa.22025

8. Kelley J, Bolter D. Growth, development, and life history in hominin evolution. In: Begun D, editor. A companion to paleoanthropology. New York: Wiley; 2013. p. 97–116. https://doi.org/10.1002/9781118332344.ch6

9. Bolter D, Zihlman A. Primate growth and development: A functional and evolutionary approach. In: Bearder S, Campbell C, Fuentes A, McKinnon K, editors. 2nd ed. Primates in perspective. New York: Oxford University Press; 2011. p. 408–422.

10. Schultz A. Growth and development of the chimpanzee. Contrib Embryol. 1940;28:1–63.

11. Smith BH. Dental development as a measure of life history in primates. Evolution. 1989;43:683–688. https://doi.org/10.1111/j.1558-5646.1989.tb04266.x
12. Godfrey L, Samonds K, Jungers W, Sutherland M. Teeth, brains, and primate life histories. Am J Phys Anthropol. 2001;114:192–214. https://doi.org/10.1002/1096-8644(200103)114:3<192::AID-AJPA1020>3.0.CO;2-Q
13. Bogin B, Smith H. Evolution of the human life cycle. In: Stinson S, Bogin B, O'Rourke D, editors. Human biology: An evolutionary and biocultural perspective. 2nd ed. New York: Wiley; 2012. p. 515–586. https://doi.org/10.1002/9781118108062.ch11
14. Laird M, Schroder L, Garvin H, Scott J, Dembo M, Radovčić D, et al. The skull of *Homo naledi.* J Hum Evol. 2017;104:100–123. https://doi.org/10.1016/j.jhevol.2016.09.009
15. Wolpoff M. The Krapina dental remains. Am J Phys Anthropol. 1979:50(1):67–113. https://doi.org/10.1002/ajpa.1330500110
16. Weidenreich F. The dentition of *Sinanthropus pekinensis*: A comparative odontography of the hominids. Palaeont Sinica NSD. 1937;1:109–120.
17. Bermúdez de Castro J, Martinón-Torres M, Lozano M, Sarmiento S, Muela A. Paleodemography of the Atapuerca: Sima De Los Huesos hominin sample: A revision and new approaches to the paleodemography of the European Middle Pleistocene population. J Anthropol Res. 2004;60:5–26. https://doi.org/10.1086/jar.60.1.3631006
18. Behrensmeyer K. Paleoenvironmental context of the Pliocene A.L. 333 "First Family" hominin locality, Denen Dora Member, Hadar Formation, Ethiopia. In: Quade J, Wynn J, editors. The geology of early humans in the horn of Africa. Boulder, CO: Geological Society of America; 2008. p. 203–214.
19. Rosas A, Estalrrich A, García-Vargas S, García-Tabernero A, Huguet R, Lalueza-Fox C, et al. Identification of Neandertal individuals in fragmentary fossil assemblages by means of tooth associations: The case of El Sidrón (Asturias, Spain). C R Palevol. 2013;12:279–291. https://doi.org/10.1016/j.crpv.2013.06.003
20. Buikstra J, Konigsberg L. Paleodemography: Critiques and controversies. Am Anthropol. 1985;87:316–333. https://doi.org/10.1525/aa.1985.87.2.02a00050
21. Meindl R, Russel K. Recent advances in method and theory in paleodemography. Annu Rev Anthropol. 1998;27:375–399. https://doi.org/10.1146/annurev.anthro.27.1.375
22. Blurton Jones N, Smith L, Hawkes K, O'Connell J, Kamuzora C. Demography of the Hadza, an increasing and high density population of savanna foragers. Am J Phys Anthropol. 1992;89:159–181. https://doi.org/10.1002/ajpa.1330890204
23. Howell N. Demography of the Dobe !Kung. New York: Academic Press; 1979.
24. Boesch C, Boesch-Achermann H. The chimpanzees of the Taï Forest: Behavioural ecology and evolution. Oxford: Oxford University Press; 2000.
25. Hill K, Boesch C, Goodall J, Pusey A, Williams J. Mortality rates among wild chimpanzees. J Hum Evol. 2001;40:437–450. https://doi.org/10.1006/jhev.2001.0469
26. Muller M, Wrangham R. Mortality rates among Kanyawara chimpanzees. J Hum Evol. 2014;66:107–114. https://doi.org/10.1016/j.jhevol.2013.10.004
27. McKinley K. Survivorship in gracile and robust australopithecines: A demographic comparison and a proposed birth model. Am J Phys Anthropol. 1971;34:417–426. https://doi.org/10.1002/ajpa.1330340311
28. Mann A. Paleodemographic aspects of the South African australopithecines. Philadelphia, PA: University of Pennsylvania; 1975.
29. Lockwood C, Menter C, Moggi-Cecchi J, Keyser A. Extended male growth in a fossil hominin species. Science. 2007;318:1443–1446. https://doi.org/10.1126/science.1149211
30. Johanson D, Taieb M, Coppens Y. Pliocene hominids from the Hadar Formation, Ethiopia (1973–1977): Stratigraphic, chronologic, and paleoenvironmental contexts, with notes on hominid morphology and systematics. Am J Phys Anthropol. 1982;57:373–402. https://doi.org/10.1002/ajpa.1330570402
31. Behrensmeyer K, Harmon E. Taphonomy and paleoecology of the A.L. 333 hominin fossil assemblage. Am J Phys Anthropol (Suppl). 2010;50:22–23.
32. Johanson D. The paleoanthropology of Hadar, Ethiopia. C R Palevol. 2017;16:140–154. https://doi.org/10.1016/j.crpv.2016.10.005
33. Pettitt P. The Palaeolithic origins of human burial. London: Routledge; 2013.
34. Arsuaga J, Martínez I, Arnold L, Aranburu A, Gracia-Téllez A, Sharp W, et al. Neandertal roots: Cranial and chronological evidence from Sima de los Huesos. Science. 2014;344(6190):1358–1363. https://doi.org/10.1126/science.1253958
35. Sala N, Arsuaga JL, Pantoja-Pérez A, Pablos A, Martínez I, Quam RM, et al. Lethal interpersonal violence in the Middle Pleistocene. PLoS ONE. 2015;10(5), e0126589, 12 pages. https://doi.org/10.1371/journal.pone.0126589
36. Rosas A, Martínez-Maza C, Bastir M, García-Tabernero A, Lalueza-Fox C, Huguet R, et al. Paleobiology and comparative morphology of a late Neandertal sample from El Sidrón, Asturias, Spain. Proc Natl Acad Sci USA. 2006;103:19266–19271. https://doi.org/10.1073/pnas.0609662104
37. Randolph-Quinney PS. The mournful ape: Conflating expression and meaning in the mortuary behaviour of *Homo naledi*. S Afr J Sci. 2015;111(11/12), Art. #a0131, 5 pages. https://doi.org/10.17159/sajs.2015/a0131
38. Dirks PHGM, Berger L, Hawks J, Randolph-Quinney PS, Backwell LR, Roberts EM. Comment on "Deliberate body disposal by hominins in the Dinaledi Chamber, Cradle of Humankind, South Africa?" J Hum Evol. 2016;96:149–153. https://doi.org/10.1016/j.jhevol.2016.04.007
39. Berger L, Hawks J, Dirks P, Elliott M, Roberts E. *Homo naledi* and Pleistocene hominin evolution in subequatorial Africa. eLife. 2017;6, e24234, 19 pages. https://doi.org/10.7554/eLife.24234
40. Hawks J, Elliott M, Schmid P, Churchill S, De Ruiter D, Roberts E, et al. New fossil remains of *Homo naledi* from the Lesedi Chamber, South Africa. eLife 2017;6, e24232, 63 pages. https://doi.org/10.7554/eLife.24232

Black living standards in South Africa before democracy: New evidence from height

AUTHORS:
Bokang Mpeta[1]
Johan Fourie[1]
Kris Inwood[2]

AFFILIATIONS:
[1]Department of Economics, Stellenbosch University, Stellenbosch, South Africa
[2]Department of Economics, University of Guelph, Guelph, Canada

CORRESPONDENCE TO:
Johan Fourie

EMAIL:
johanf@sun.ac.za

DATES:
Received: 01 Mar. 2017
Revised: 29 June 2017
Accepted: 11 Sep. 2017

KEYWORDS:
apartheid; anthropometric; 20th century; stature; colonialism

HOW TO CITE:
Mpeta B, Fourie J, Inwood K. Black living standards in South Africa before democracy: New evidence from height. S Afr J Sci. 2018;114(1/2), Art. #2017-0052, 8 pages. http://dx.doi.org/10.17159/sajs.2018/20170052

ARTICLE INCLUDES:
✓ Supplementary material
× Data set

FUNDING:
National Research Foundation (South Africa); South African Agency for Science and Technology Advancement; Economic Research Southern Africa

Very little income or wage data were systematically recorded about the living standards of South Africa's black majority during much of the 20th century. We used four data sets to provide an alternative measure of living standards – namely stature – to document, for the first time, living standards of black South Africans over the course of the 20th century. We found evidence to suggest that living standards in the first three decades of the century were particularly poor, perhaps because of the increasingly repressive labour policies in urban areas and famine and land expropriation that weighed especially heavily on the Basotho. The decade following South Africa's departure from the gold standard, a higher international gold price and the demand for manufactured goods from South Africa as a consequence of World War II seem to have benefitted both black and white South Africans. The data also allowed us to disaggregate by ethnicity within the black population group, revealing levels of inequality within race groups that have been neglected in the literature. Finally, we compared black and white living standards, and revealed the large and widening levels of inequality that characterised 20th-century South Africa.

Significance:

- We provide the first long-run estimates of black living standards in South Africa and evidence of inter-group differences in the effects of 20th-century events and policies.

Introduction

The history of living standards in South Africa is complex but highly incomplete. For the period before democracy, we have at our disposal more individual-level statistical records of white descendants of European immigrants than of black South Africans, the indigenous, Bantu-speaking population that inhabited most of modern-day South Africa before the arrival of Europeans and who have since formed the majority of the population. Meticulous records documenting white living standards – including production, wealth, income and wage series – were kept from the beginning of settlement[1-5], but comparable information for black South Africans, with few exceptions, is frequently missing or unrepresentative of the entire population. A different approach is thus necessary to provide a more complete picture of the evolution of South Africa's living standards before the advent of democracy.

Our alternative route considers the biological measure of height, or human stature, that is documented in four unique data sources. Adult stature is a sensitive indicator of childhood well-being because individuals cannot realise their potential for physical growth if they are encumbered by poor nutrition, exposure to disease or undue physical labour.[6-8] Stature typically correlates with income and other measures of welfare except where the nature of economic change brings adverse consequences for child health.[9,10] Average height rises with socio-economic class, because higher class status brings improvements in nutrition and access to medical care.[11,12] Admittedly, the relationship between socio-economic status and average height may be confounded by factors such as high food prices, and unsanitary or congested living conditions as a result of industrialisation. Nevertheless, by analysing the mean height of a sample of black male South Africans over the 20th century, we shed light on the standard of living for a subsection of the population that has remained hidden for too long.

Our results address important questions in South African economic history. Were poor black living standards a result of apartheid-era policies, or did they worsen even before South Africa's most infamous era? When did white and black living standards diverge? Finally, and most difficultly, can we explain the level and trend within the black population over the 20th century?

Answering these questions complements the analyses of current-day inequalities that rely on modern surveys with limited recourse to the past.[13,14] We already know, for example, that black men born towards the end of apartheid are on average at least 7 cm shorter than their white counterparts. This example is one of the highest within-country differences in the world, but we do not know when it emerged. A similar gap between white and coloured South Africans is known to extend to the start of the 20th century but as yet there is no comparable study of black South Africans.[15]

We used four unique sources of heights of South African men. Firstly, we examined a sample of black southern African men born between 1895 and 1927 who enlisted in the South African military between 1940 and 1945. Secondly, we considered a group of black men whose skeletons are archived in the Raymond A. Dart Collection of Human Skeletons in the School of Anatomical Sciences at the University of the Witwatersrand (WITS).[16] Thirdly, we used the 1998 South African Demographic and Health Survey for men born after 1947. Lastly, we used the 2008 National Income Dynamics Study (NIDS) survey data for the heights of men born after 1958.[17] Each of these sources required careful analysis of its origin and the implications for sample selection and inference.

Our results show that black living standards as measured by height improved little over the 20th century, in contrast to that of other South Africans and people in other countries, most of whom experienced considerable growth in physical size. But this finding does not imply that the heights of black men were unchanging. The events of the 20th century had varying effects in different periods and on different ethnic groups. The post-gold standard mining boom seems to have had large beneficial effects on black male heights, even though whites seem to have benefitted more. In particular, Sotho men experienced the most change (at first negative and later positive) in living standards, while that of Xhosa men remained constant throughout the century. The number of observations is limited but sufficient to provide the first quantitative evidence of the adverse effects of early colonial labour policies and a new long perspective on black living standards over the entire 20th century.

A brief history

The discovery of diamonds around 1870 transformed the economy of southern Africa. Men of all races flocked to Kimberley to dig for diamonds.[18] The demand for labour meant salaries for young black men whose purchases of guns and ammunition, agricultural equipment and other sundries brought them influence and status back in their kingdoms.[19] Discrimination soon followed with a prohibition on claim ownership by black men. A system of migrant labour that initially developed to limit wage increases in the diamond mines was extended to gold mining following discoveries on the Witwatersrand two decades later. By the end of the 19th century, white miners earned eight times as much as black miners.[20] Repressive and discriminatory labour practices in the early 20th century institutionalised the wage gap.[21] A 'colour bar', for example, essentially reserved skilled and semi-skilled jobs for white workers.[22] The consequences for physical health were stark: infant mortality in the Cape Colony among black Africans and coloureds was twice the level of that among whites.[23]

An erosion of agricultural incomes and thus bargaining power for non-agricultural work reinforced the effect of labour laws. Locusts, drought, rinderpest and wheat blight during the 1890s all but decimated subsistence agriculture and further drove down black bargaining power.[24] Nevertheless, legislation remained the most serious peril. The 1913 *Land Act* – which prohibited, amongst other things, the ownership of land by blacks – had devastating effects on the prospects of black farmers, forcing many into the non-agricultural job market.[25] In July 1913, Sol Plaatje undertook to investigate and publicise effects of the *Native Land Act*.[26] Plaatje reported that in the Cape Province, the Act drove many black farmers to 'overcrowded locations' with poor sanitation.[26(p. 149)] Grazing ground was limited, which led to the loss of cattle – an important source of nutrition and a crucial store of value. Not surprisingly, a series of medical studies confirmed extensive malnourishment among black Africans.[27-29]

Yet some improvement was underway. By the late 1930s, infant mortality among black Africans and coloureds was declining, and real wages for black miners returned to pre-World War I levels.[20,23] Admittedly, mining remained relatively unhealthy, especially for black workers.[30,31] The gains in welfare, instead, reflect South Africa's departure from the gold standard in December 1932, which initiated a gold boom and a rise in mining's share of GDP from 15.6% in 1930 to 21.3% in 1933. Real GDP per capita increased to 5.1% annually during the 1930s compared with 2.2% in the previous decade.[32] Fedderke and Simkins[33] argue that the stimulus of World War II extended the boom triggered by rising gold prices. Black workers benefitted as mining was their largest employer after agriculture and the war-time diversion of white men created new opportunities for black as well as female labour.

The National Party's electoral victory in 1948 and the imposition of even more repressive policies changed the fortunes of black South Africans again. The 1951 *Bantu Authorities Act* and the 1959 *Promotion of Black Self-Government Act*, for example, had devastating consequences for blacks living in the new homelands. Not surprisingly, qualitative and quantitative evidence points to a marked increase in malnutrition among black Africans in the 1950s.[34] These and other apartheid-era policies – including unbalanced spending on education, health and pensions for different racial groups – entrenched stark inequalities in income, living standards and life expectancy.[35] Yet already by the 1970s, social spending on black South Africans, mostly with the purpose of allaying black unrest, began to increase rapidly, with likely positive effects for black living standards.[36]

Despite ample evidence of race-based inequality over the 20th century, trends in black living standards are difficult to determine, as Nattrass and Seekings suggest:

> *It is not possible to identify precise levels and trends in poverty prior to the 1990s because the apartheid state made little or no effort to measure poverty among the black majority of the population, showing serious interest only in the living standards and conditions of white citizens.*[37(p.28)]

As a result, no single indicator is available to construct a clear picture of the evolution of black living standards over the course of the entire 20th century. A directly comparable measure such as height can help in this regard.

Sources of height evidence

There is a long tradition of using height to monitor human welfare and the biological standard of living.[11,38] While genetic characteristics explain about 80% of stature variation within most populations, it is clear that nutrition, energy expenditure and disease exposure during childhood influence the ability of individuals to realise their height potential. A considerable body of literature now shows that environmental and socio-economic conditions rather than genetics explain most of the variation in height across societies, or even groups within a society.[10,38-40] Heights have also been used to study living standards in other African countries, like Kenya, Ghana and Côte d'Ivoire.[40-42] In a recent analysis of individuals born between 1951 and 1992 in 39 developing countries, Akachi and Canning[43] found that a 1-cm gain in cohort height was associated with a 6% increase in income per capita and a 1.25-year increase in life expectancy.

We used four data sets to investigate black living standards in 20th-century South Africa. Data describing 8172 black military recruits in World War II includes men born between 1895 and 1927 in and around South Africa. A smaller set of 500 observations was compiled from cadavers from the WITS collection with birth years between 1897 and 1980. The Demographic and Health Survey measured the height of 2777 black South African men in 1998. Finally, the first wave of the NIDS included 2886 black men born between 1958 and 1990. Table 1 provides summary statistics for the four samples.

Although the average height across the samples is similar – increasing from 167.1 cm to 168.8 cm over the century – each sample represents a different subset of the population. We need to know what kind of men enlisted in the military in order to compare with the other samples and make inferences about the entire population. Similar selection issues apply to men whose cadavers are recorded. The Demographic and Health Survey is restricted to a subpopulation of men who are in a household with a woman aged 15 to 49. The NIDS data are largely representative of the black male population, although the small sample size creates some imprecision at lower aggregate level. These selection issues are discussed below. Although our full sample includes men between the ages of 18 and 50, most of the analysis was done on those between the ages of 23 and 50. This age selection is because almost nobody grows taller beyond the age of 23 and men older than 50 years may start to shrink.[44] We undertook the analysis for men 18–50 years and again for men 23–50 years. See Supplementary figure 1 in the supplementary material for a visual comparison.

We transcribed a randomly selected 14% of enlistment records for World War II black soldiers, totalling 9128 records of which 8172 had minimally useful information. During the war these men worked in construction, as telephone operators or drivers, or fulfilled other non-combatant roles.[45] Figure 1 shows that there was little or no evidence of truncation at a minimum height (not surprisingly for non-combatants). Nevertheless, the standard deviation is smaller than in the other samples, suggesting a preference for men of a certain height. As long as this truncation is not skewed, which it does not appear to be, our use of average height is unaffected. Some military enlistments tended to recruit men who were otherwise unemployed, and hence were more likely to have grown up in resource-poor households and to be shorter than average.

Table 1: Summary of the statistics relating to heights of black men from four data sources

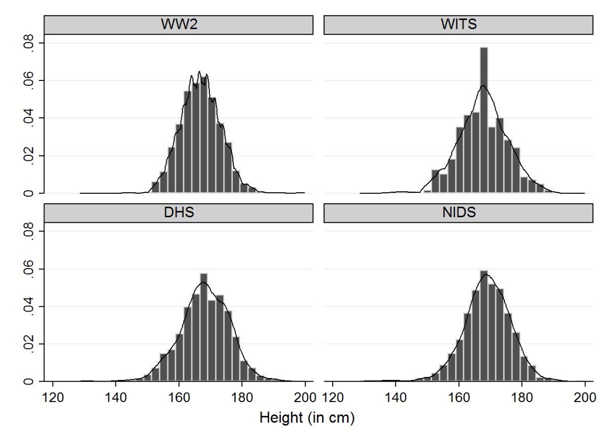
Data source	*n*	Mean	Standard deviation	Median	Minimum	Maximum	Mean age
All black men							
WW2	8172	167.1	6.41	167.6	142.2	199.4	27.0
WITS	500	167.6	7.66	168.0	139.0	188.0	38.8
DHS	2777	168.1	7.97	168.2	128.5	198.4	30.9
NIDS	2886	168.8	7.63	169.0	128.5	199.8	30.1
Total	14 335	167.7	7.07	167.6	128.5	199.8	28.9
Only South African black men							
WW2	6612	166.8	6.36	167.6	142.2	199.4	27.0
WITS	500	167.6	7.66	168.0	139.0	188.0	38.8
DHS	2777	168.1	7.97	168.2	128.5	198.4	30.9
NIDS	2770	168.9	7.61	169.0	128.5	199.8	30.0
Total	12 659	167.6	7.12	167.6	128.5	199.8	29.1
Only South African black men >22 years							
WW2	4420	167.4	6.41	167.6	142.2	199.4	30.7
WITS	491	167.6	7.69	168.0	139.0	188.0	39.1
DHS	2043	168.2	7.95	168.2	128.5	198.4	34.9
NIDS	1922	169.1	7.37	169.2	132.0	193.5	34.0
Total	8876	168.0	7.10	167.6	128.5	199.4	32.9

WW2, World War II records; WITS, Raymond A. Dart Skeletal Collection; DHS, Demographic and Health Survey; NIDS, National Income and Dynamics Study

This does not appear to be the case here. The black soldiers reported a wide range of pre-war occupations. Subsistence agriculture is under-represented but in other respects the occupational profile reflects the diversity of work undertaken by black men at the time.

Our second source was the Raymond A. Dart Collection of Human Skeletons at the University of the Witwatersrand, derived from 2605 bodies that were otherwise unclaimed from regional (southern African) hospitals. Most (76%) of the skeletons are of black southern Africans, and most (71%) are male individuals.[16] Although most of the men died between the ages of 20 and 70 – the reason for death is often included – we limited the sample to 500 skeletal measures describing men between the ages of 18 and 50 years. The WITS collection is not demographically representative, but it has the advantage of identifying ethnicity, place of birth and cause of death recorded over an extended time span.[16] Although this sample is small, it shows no evidence of truncation at either side of the distribution. The mean and standard deviation of height are similar to that of the NIDS data, which are nationally representative.

Because the principal aim of the South African Demographic and Health Survey was to produce reliable demographic estimates, it included a stratified sample of approximately 12 000 women between the ages of 15 and 49. In addition to the main survey of households and women, however, an adult health module was administered to a sample of adults, including men, aged 15 and over in half of the households selected for the main survey. The survey, therefore, only includes men that are members of a household in which a woman between the ages of 15 and 49 resides. This criterion may have introduced a bias in the sample, although the direction of any bias is unclear.



WW2, World War II records; WITS, Raymond A. Dart Skeletal Collection; DHS, Demographic and Health Survey; NIDS, National Income and Dynamics Study

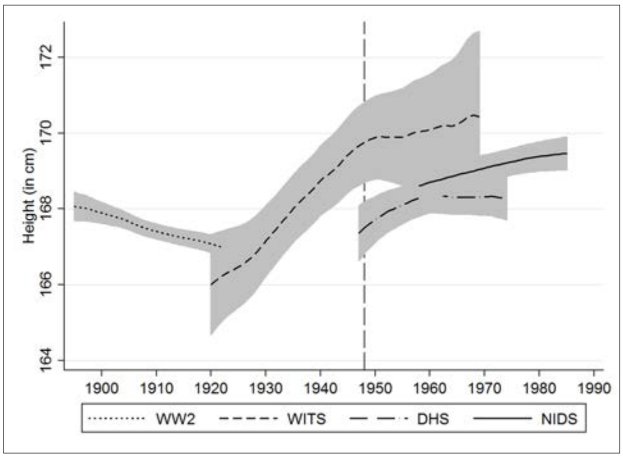
Figure 1: Histograms of heights of black men from four data sources.

Our final sample comes from the 2008 NIDS, a nationally representative survey.[17] We used data describing black men born after 1958 and before 1990. Several outliers indicate men who were implausibly short; we removed all outliers shorter than 125 cm – which is about four standard deviations from the mean. Figure 1 is a plot of the distribution of heights in the NIDS sample.

Black living standards in the 20th century

We first plotted the height of black men over the 20th century for each of the samples separately. Figure 2 shows the results for black

South African men between 23 and 50 years of age. The grey area indicates the 95% confidence interval.



WW2, World War II records; WITS, Raymond A. Dart Skeletal Collection; DHS, Demographic and Health Survey; NIDS, National Income and Dynamics Study

Figure 2: Height of black men by year of birth, 1895–1990, from four data sources.

The World War II sample reflects a clear decline in living standards during the first two decades of the century. The small sample size of the WITS collection is reflected in the wide confidence intervals around the trend. Average height in the mid-1920s was nevertheless similar in both the World War II and WITS samples, at 167 cm.

The most obvious disconnect is between the WITS and Demographic and Health Survey samples in 1947, with a 2 cm difference. Both samples most likely suffer from a downward bias. Support for this downward bias in the Demographic and Health Survey sample is found when compared to the nationally representative NIDS data set. The WITS sample, however, seems to be upwardly biased in comparison to NIDS. The true average for 1947 is therefore likely somewhere in between these two samples, at just above 168 cm.

We combined the four sources into one series in Figure 3, which plots a locally smoothed polynomial (of bandwidth 8) of heights of black men by birth year (for men 23 years and older) across the 20th century. This figure is the first representation of male black living standards using micro-level evidence for such a long period.

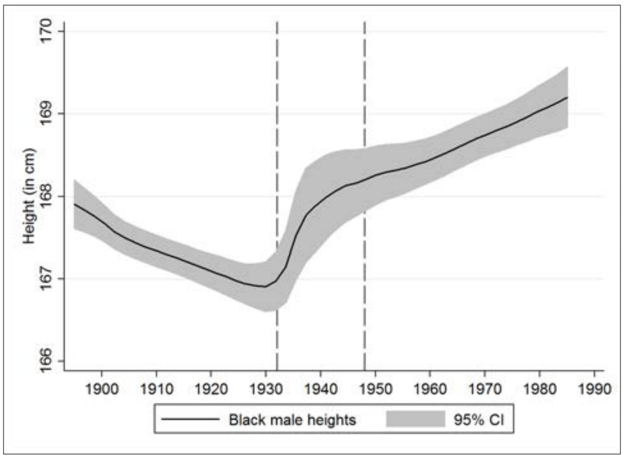


Figure 3: Height of black men by year of birth, 1895–1990.

Black men born during the late-19th century were on average 168 cm tall. Average height then fell by 1 cm to 167 cm over the course of the next three decades, suggesting a strong deterioration in living standards. A decline in height from 1910 to 1930 occurred during the introduction of increasingly more repressive and discriminatory legislation against black workers, as noted above. Figure 3 shows a sharp turnaround around 1930, when heights of black men increased by around 1 cm in 10 years. The most likely explanation for this turnaround is South Africa's decision to leave the gold standard in December of 1932 (indicated by the first vertical line), which boosted production in the mines and with it employment for black men. This increase in heights seems to slow down after 1940. Although this rapid rise may be overstated because of a small sample size, there is no doubt that the heights of black men increased by at least 1 cm between 1930 and 1948, when the National Party won the elections and introduced its policy of apartheid (indicated by the second vertical line). The rise in the 1930s is somewhat less steep if the WITS sample is removed, but the general trend remains (see Supplementary figure 2). After 1948, heights of black men increased by another 1 cm until the mid-1980s, when our sample period ends.

Whether the samples are representative of the national population is just one of many possible selection biases when using height as a measure of living standards. Bodenhorn et al.[46] caution that changing labour market conditions may influence a worker's decision to opt for military service. In particular, an increase in private sector wages may have diverted the strongest (i.e. tallest) from military service, thereby creating the appearance of stature decline in enlistment records. This kind of selection effect is not immediately relevant here because height and private sector real wages in 1930s South Africa moved in the same rather than opposite directions.

As a further check to determine whether we are not simply capturing 'class' effects, we restricted consideration to black men who worked in mining. The WITS data have no occupational detail so we instead assumed all deaths related to 'lung', 'pneumonia' or 'respiratory' diseases were mine workers, based on the strong correlation between these diseases and mining employment.[47] The trend reflected the same pattern as above, although with larger confidence bands owing to the smaller sample size.

Figure 4 overlays remuneration in gold mining with the heights of black men by year of birth. A positive correlation is evident: employment and real wages in gold mining remuneration expanded significantly during the 1930s just as height increased. Rising mining profits also increased local municipal tax revenue. A part of this additional revenue was used to finance, in 1934, the construction of a new suburb – the southwestern township (Soweto), to improve the living conditions of mine workers.

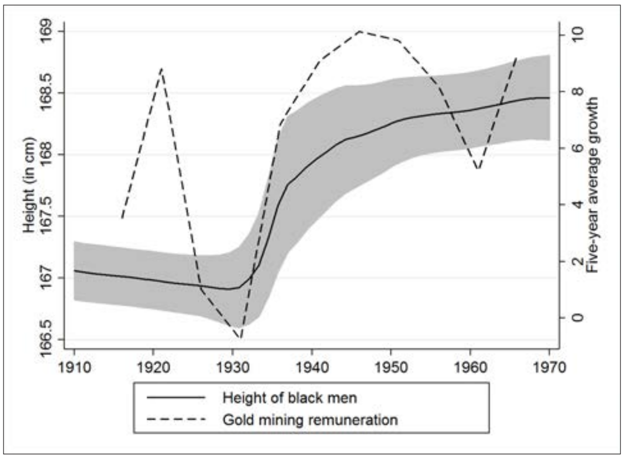


Figure 4: Height of black men and growth in gold mining remuneration.

We posit that income growth for mine and other urbanised workers would have been key in improving health and nutritional outcomes for their children, which in turn contributed to the growing stature of men born in the 1930s. Admittedly, these are mere correlations. But, as Mariotti[48] shows for South Africa in the 1970s, there is some evidence to causally link higher mining wages of fathers to improved stature of sons. We argue that the trend in remuneration is, in the least, supportive of our hypothesis that heights increased significantly during the 1930s because of an expanding mining and manufacturing sector. It was not only in mining in which employment opportunities for black workers improved. Terreblanche notes:

> *Although the creation of job opportunities for whites was an important justification for launching ESKOM and ISCOR, both deviated from this intention. Even before World War II both corporations were increasingly replacing whites with blacks, gaining significant control over their workforce and their ability to make profits.*[22(p.344)]

We emphasise the impact of the mining sector because it employed large numbers of black men throughout the 20th century. In 1911, 21.7% of adult black men in South Africa were employed in the mining sector.[49] By 1996, mining still employed 12.8% of all adult black men.[50] But by emphasising mining's contribution to the improvement in black living standards, we do not wish to dismiss other possible causes, including improvements in public health, urbanisation and general income levels. We hope that future research will be able to identify the economic significance of these and other causes.

Within-group dynamics

We move beyond these general trends to examine the diversity of well-being within the black population – a topic that has not received a lot of attention in South African economic history. Each of our sources identifies either the ethnicity or the language group of each individual. For this analysis we excluded records for which ethnicity is missing, or is simply indicated as 'black' or 'African'. Here, however, we included individuals born outside South Africa's borders if they shared the ethnicity of South Africans, like the Basotho of Lesotho. In the end, we classified nine black ethnic groups using contemporary classifications of those ethnicities: Ndebele, Pedi, Sotho, Swazi, Tsonga, Tswana, Venda, Xhosa and Zulu (Table 2).

There is some height variation between the different groups. The average gap over the century between the shortest, the Xhosa, and the tallest, the Tsonga, is almost 2 cm. These differences may be attributed, in part, to the distribution of observations by ethnicity across the century. All nine ethnicities are represented in each of the sources, although relative proportions differ. Xhosa and Zulu men, for example, are proportionally less important than Sotho in the sources describing the first half of the 20th century and greater than that of the Sotho in the second half of the century. Accordingly, we describe in Figure 5, temporal change within each of three large groups: the Xhosa, Sotho and Zulu.

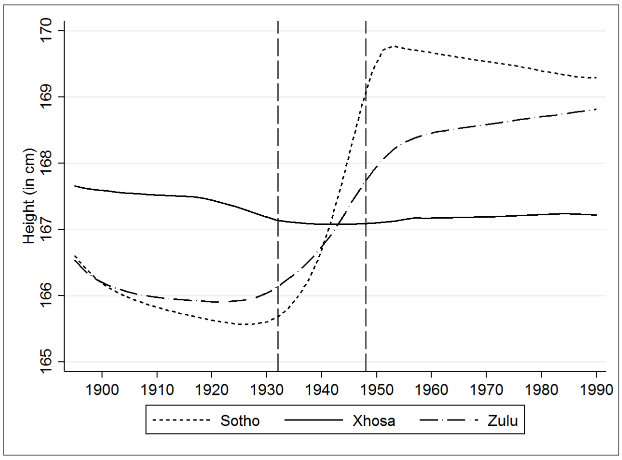


Figure 5: Height of black men by ethnicity, 1895–1990.

Figure 5 clearly shows that the three ethnicities experienced different patterns of change over the century. Heights of Xhosa men changed little over the 20th century, while the stature of Sotho men fell during the first three decades. The historical literature suggests two possible explanations for the divergence. Firstly, Sotho men in the early 20th century increasingly moved to urban areas around the mines of Johannesburg and to poorly remunerated employment requiring limited skills. Secondly, and perhaps more importantly, the great famine in Basutoland had long-lasting effects for the Sotho. Although there was some reprieve during the Anglo–Boer War as Basotho horses were in high demand by the British, disaster struck again in 1903, when food was imported into Basutoland for the first time. 'Lesotho, once the grain basket of the Cape Colony and the Orange Free State, was no longer self-sufficient in food production'[51(p.81)].

The ranking between the three ethnicities shown in Figure 5 changed after 1932, when South Africa left the gold standard and mining production soared, when the heights of Zulu men and especially Sotho men increased rapidly. This finding is not surprising; of the three groups, Sotho men would have been most likely to work in and around the mines and thus benefit from the increased labour opportunities and better living conditions available after the 1930s. Heights of Zulu men also increased significantly, and then flattened somewhat during the later period.

Table 2: Summary of the statistics relating to heights of black men by ethnicity, 1895–1990

Ethnicity	*n*	Mean	Standard deviation	Median	Minimum	Maximum	Mean age
Ndebele	215	167.7	6.51	167.6	146.8	185.4	33.8
Pedi	1409	168.0	6.52	167.6	141.3	190.5	29.3
Sotho	1654	167.4	7.13	167.6	130.5	198.1	28.6
Swazi	428	168.8	7.09	168.3	148.8	193.5	29.2
Tsonga	410	169.1	7.45	170.2	135.0	192.7	27.7
Tswana	1419	167.3	7.27	167.6	128.5	198.4	28.5
Venda	303	168.4	7.23	167.6	132.0	185.0	29.3
Xhosa	1947	167.2	7.56	167.5	128.5	199.8	29.6
Zulu	2223	167.9	7.47	167.8	132.4	199.4	29.9
Total	10 077	167.7	7.25	167.6	128.5	199.8	29.3

Table 3: Summary of the statistics relating to heights of white men from four data sources

Data source	*n*	Mean	Standard deviation	Median	Minimum	Maximum	Mean age
WW1	2066	173.8	6.55	174.0	144.8	196.9	27.1
WW2	4960	174.3	6.72	174.6	149.9	208.3	31.6
WITS	27	175.0	7.36	176.0	157.0	188.0	43.3
DHS	233	179.1	6.85	179.1	160.0	198.0	36.6
NIDS	139	178.2	7.15	178.2	153.0	198.5	37.8
Total	7425	174.4	6.76	174.6	144.8	208.3	30.7

WW1, World War I records; WW2, World War II records; WITS, Raymond A. Dart Skeletal Collection; DHS, Demographic and Health Survey; NIDS, National Income and Dynamics Study

Black living standards in comparison

Black living standards did not evolve in isolation. We compared the trend in height for black and white men. We used the same four sources of data for whites, and in addition we used early 20th-century police and military data from World War I, the Cape Mounted Police, the South African Constabulary and attestations of 16 smaller forces. Fourie et al.[52] describe this source. Supplementary figure 3 shows the number of observations by year. Some of these forces had a minimum height requirement, implying that the stature of these men may have been slightly greater than that of the general population. The effect of the minimum height requirements was limited because South African whites were tall relative to the minimum and, as is argued elsewhere, the requirements became less relevant over the course of the 20th century because of technological changes in warfare.[53] Summary statistics are provided in Table 3.

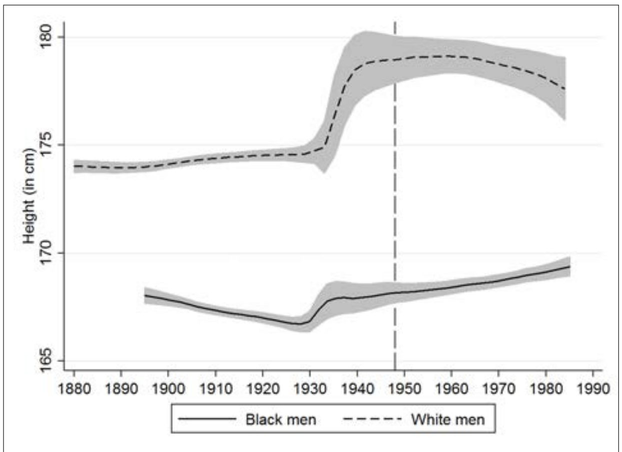


Figure 6: Height of black and white men over the 20th century.

Figure 6 compares heights of white and black men over the 20th century. Three things are immediately apparent. Firstly, whites were markedly taller than blacks throughout the 20th century. The confidence intervals at some stages are large owing to the few observations available to us, but the two lines never overlap. Secondly, the prodigious increase of the 1930s was not a unique experience for black workers. In fact, the heights of white men seem to have increased 3 cm over less than two decades, confirming the economy-wide impact of the mining and World War II booms. Unfortunately, it is hard to say more about this important experience given the few observations and explanatory variables for this period. Thirdly, the seeming decline of white stature during the apartheid era (in contrast to a small rise in the heights of black men) must be regarded with caution; the current sample size is insufficient to be confident about whites in this period.

Conclusions

Owing to the lack of adequate micro-level evidence, the living standards of black South Africans before democracy remain poorly understood. This paper contributes to filling this gap. We used four data sources on the heights of black South African men to confirm the experience of persistently poor living standards across the 20th century.

We found evidence to suggest that living standards in the first three decades of the century were particularly poor, perhaps as a result of the increasingly repressive labour policies in urban areas and famine and land expropriation that weighed especially heavily on the Basotho. The decade following South Africa's departure from the gold standard, a higher international gold price and the demand for manufactured goods from South Africa as a result of World War II seem to have benefitted both black and white South African men. Unfortunately this progress slowed down in the late 1940s, which coincided with the introduction of further repressive and discriminatory policies that comprised apartheid. Chief Albert Luthuli summarised the overall impact of these laws on black South Africans:

> *The past thirty years have seen the greatest number of Laws restricting our right and progress until today we have reached a stage where we have almost no rights at all: no adequate land for our occupation, our only asset, cattle, dwindling, no security of homes, no decent and remunerative employment, more restrictions to freedom of movement through passes, curfew regulations, influx control measures; in short we have witnessed in these years an intensification of our subjection to ensure and protect white supremacy.*[54(p.233)]

Our evidence attests to the importance of these comments and points to an important way in which the welfare of black South Africans stagnated as other populations were able to realise a considerable growth of physical stature during the second half of the 20th century.[55] The slow increase in heights of black men during the second half of the 20th century suggests that economic growth, continued urbanisation, public health provision and the redistributive policies towards the end of the apartheid era, even if from a very low base, contributed to an improvement in black living standards.

The average trend in heights of black men masks important within-ethnic trends. Such inequalities within the black population have, as far as we know, not been adequately examined or explained. Our analysis of heights shows that, while the heights of Xhosa men remained relatively unaffected over the 20th century, those of Sotho men declined and then increased significantly during the 1930s. The decline, we posit, might be explained by the expropriation of land, and the increase by greater access to employment, even of semi-skilled and skilled positions.

These results allow us to compare black South African heights to those of white South Africans. The roots of the interracial inequality, we show, are not limited to South Africa's apartheid era, but lie deep in the history of segregation, exploitation and appropriation that characterised 19th and early 20th century South Africa.

And what about the future? What are the prospects for a convergence and reduction of the black–white stature gap? Is it possible that genetic inheritance perhaps via epigenetic pathways contributes to the patterns identified in this paper, thus reducing the prospects for improvement? From a biogenetic perspective, the question cannot be answered clearly because gene-level understanding of human stature remains incomplete.

A possible answer is to look for societies in which genetic inheritance is similar, but where there are large within-group differences that can only be attributed to socio-economic factors. Korea provides one example. Pak[56] shows that while South and North Koreans born during the 1940s were of similar height, the adult heights of North Koreans in subsequent generations have stagnated while the heights of South Koreans have increased by 6 cm – the same gap as that between black and white men in South Africa at the start of the 20th century. Examples of different ethnic groups converging in heights as socio-economic conditions improve comes from the experience of Māori and white (Pākehā) New Zealanders since World War II.[57] While the height gap between the Māori and whites was 3 cm for those born during World War II, this gap disappeared for children born during the 1980s as a result of economic growth and better public health and other social policies. These and other population-level anthropometric studies point to the possibility, at least in the long run, for convergence of stature among different ethnic groups in South Africa.

Acknowledgements

This project is funded by the Elite Project Fund of the Faculty of Economic and Management Sciences at Stellenbosch University, the National Research Foundation's Thuthuka Programme (grant 87966) and Competitive Programme for Rated Researchers (grant 98921) and Economic Research Southern Africa. We thank Emmanuel Akyeampong, Gareth Austin, Joerg Baten, Rulof Burger, Michiel de Haas, Ewout Frankema, Holly Hanson, Martine Mariotti, Alexander Moradi, Johannes Norling, Nathan Nunn, Dieter von Fintel, Marisa von Fintel, Dmitri van den Bersselaar and participants at conferences and seminars at the following institutions: European Social History Conference (Valencia), Graduate Institute (Geneva), Workshop on African History and Economics (Harvard), African Economic History Workshop (Sussex) and the departmental seminars at Stellenbosch University and Mount Holyoke College.

Authors' contributions

B.M. was responsible for the initial analysis and results. J.F. was responsible for the final analysis and write-up. K.I. was responsible for the data collection and cleaning.

References

1. Du Plessis S, Du Plessis S. Happy in the service of the Company: The purchasing power of VOC salaries at the Cape in the 18th century. Econ Hist Dev Reg. 2012;27(1):125–149. https://doi.org/10.1080/20780389.2012.682398
2. De Zwart P. South African living standards in global perspective, 1835-1910. Econ Hist Dev Reg. 2011;26(1):49–74. https://doi.org/10.1080/20780389.2011.583003
3. Mariotti M. Labour markets during apartheid in South Africa. Econ Hist Rev. 2012;65(3):1100–1122. https://doi.org/10.1111/j.1468-0289.2011.00621.x
4. Fourie J. The remarkable wealth of the Dutch Cape Colony: Measurements from eighteenth-century probate inventories. Econ Hist Rev. 2013;66(2):419–448. https://doi.org/10.1111/j.1468-0289.2012.00662.x
5. Fourie J, Von Fintel D. A history with evidence: Income inequality in the Dutch Cape colony. Econ Hist Dev Reg. 2011;26(1):16–48. https://doi.org/10.1080/20780389.2011.582990
6. Bailey R, Hatton T, Inwood K. Health, height, and the household at the turn of the twentieth century. Econ Hist Rev. 2016;69(1):35–53. https://doi.org/10.1111/ehr.12099
7. Komlos J. Access to food and the biological standard of living: Perspectives on the nutritional status of native Americans. Am Econ Rev. 2003;93(1):252–255. https://doi.org/10.1257/000282803321455250
8. Baten J, Komlos J. Height and the standard of living. J Econ Hist. 1998;58(03):866–870. https://doi.org/10.1017/S0022050700021239
9. Steckel RH. Heights and human welfare: Recent developments and new directions. Explor Econ Hist. 2009;46(1):1–23. https://doi.org/10.1016/j.eeh.2008.12.001
10. Steckel RH. Stature and the standard of living. J Econ Lit. 1995;33(4):1903–1940.
11. Steckel RH. Height and per capita income. Hist Method. 1983;16(1):1–7. https://doi.org/10.1080/01615440.1983.10594092
12. Komlos J, Lauderdale BE. The mysterious trend in American heights in the 20th century. Ann Hum Biol. 2007;34(2):206–215. https://doi.org/10.1080/03014460601116803
13. Wilson F. Historical roots of inequality in South Africa. Econ Hist Dev Reg. 2011;26(1):1–5. https://doi.org/10.1080/20780389.2011.583026
14. Wittenberg M. Wages and wage inequality in South Africa 1994-2011: Part 2 – inequality measurement and trends. S Afr J Econ. 2017;85(2):298–318. https://doi.org/10.1111/saje.12147
15. Inwood K, Masakure O. Poverty and physical well-being among the coloured population in South Africa. Econ Hist Dev Reg. 2013;28(2):56–82. https://doi.org/10.1080/20780389.2013.866382
16. Dayal MR, Kegley AD, Štrkalj G, Bidmos MA, Kuykendall KL. The history and composition of the Raymond A. Dart Collection of human skeletons at the University of the Witwatersrand, Johannesburg, South Africa. Am J Phys Anthropol. 2009;140(2):324–335. https://doi.org/10.1002/ajpa.21072
17. Woolard I, Leibbrandt M, De Villiers L. The South African national income dynamics study: Design and methodological issues. Stud Econ Economet. 2010;34(3):7–24.
18. Etherington N, Harries P, Mbenga B. From colonial hegemonies to imperial conquest, 1840-1880. In: Hamilton C, Mbenga B, Ross R, editors. The Cambridge history of South Africa. Volume 1: From early times to 1885. New York: Cambridge University Press; 2010. p. 319–391.
19. Trapido S. Imperialism, settler identities, and colonial capitalism: The hundred-year origins of the 1899 South African War. In: Ross R, Mager A, Nasson B, editors. The Cambridge history of South Africa. Volume 2: 1885-1994. New York: Cambridge University Press; 2011. p. 66–101. https://doi.org/10.1017/CHOL9780521869836.005
20. Wilson F. Labour in the South African gold mines 1911-1969. Cambridge: Cambridge University Press; 2011.
21. Marks S. Class, culture and consciousness in South Africa, 1880-1899. In: Ross R, Mager A, Nasson B, editors. The Cambridge history of South Africa. Volume 2: 1885-1994. New York: Cambridge University Press; 2011. p. 102–156. https://doi.org/10.1017/CHOL9780521869836.005
22. Terreblanche SJ. A history of inequality in South Africa, 1652-2002. Pietermaritzburg: University of KwaZulu-Natal Press; 2002.
23. Simkins C, Van Heyningen E. Fertility, mortality, and migration in the Cape Colony, 1891–1904. Int J Afr Hist Stud. 1989;22(1):79–111. https://doi.org/10.2307/219225
24. Nattrass N, Seekings J. The economy and poverty in the twentieth century. In: Ross R, Mager A, Nasson B, editors. The Cambridge history of South Africa. Volume 2: 1885-1994. New York: Cambridge University Press; 2011. p. 518–572. https://doi.org/10.1017/CHOL9780521869836.013
25. Freund B. South Africa: The Union years, 1910–1948 – political and economic foundations. In: Ross R, Mager A, Nasson B, editors. The Cambridge history of South Africa. Volume 2: 1885-1994. New York: Cambridge University Press; 2011. p. 211–253. https://doi.org/10.1017/CHOL9780521869836.007
26. Plaatje S. Native life In South Africa. 3rd ed. Johannesburg: Picador Africa; 2007.
27. Maynard G. Food deficiency states in African natives. Med J S Afr. 1918;14(3):271–272.

28. Fox CFW. Some nutritional problems among the Bantu in South Africa. S Afr Med J. 1939;13(3):87–95.

29. Brock JF, Lasky JM. The findings of the Cape Nutrition Survey. S Afr Med J. 1942;16(13):255–260.

30. Marks S. The silent scourge? Silicosis, respiratory diseases and gold mining in South Africa. J Ethn Migr Stud. 2006;32(4):569–589. https://doi.org/10.1080/13691830600609975

31. Packard RM. White plague, black labor: Tuberculosis and the political economy of health and disease in South Africa. Los Angeles, CA: University of California Press; 1989.

32. South African Government. Gross domestic product at factor cost, 1910-1968. Report 09-10-01. Government Reports 1970.

33. Fedderke J, Simkins C. Economic growth in South Africa. Econ Hist Dev Reg. 2012;27(1):176–208. https://doi.org/10.1080/20780389.2012.682408

34. Abramson JH, Slome C, Ward NT. Diet and health of a group of African agricultural workers in South Africa. Am J Clin Nutr. 1960;8(6):875–884.

35. Bromberger N. Government policies affecting the distribution of income, 1940-1980. In: Schrire R, editor. South Africa: Public policy perspectives. Cape Town: Juta; 1982. p. 165–203.

36. Van der Berg S. The transition from apartheid: Social spending shifts preceded political reform. Econ Hist Dev Reg. 2014;29(2):234–244. https://doi.org/10.1080/20780389.2014.955277

37. Seekings J, Nattrass N. Policy, politics and poverty in South Africa. London: Springer; 2015. https://doi.org/10.1057/9781137452696

38. Fogel RW, Engerman SL, Floud R, Friedman G, Margo RA, Sokoloff K, et al. Secular changes in American and British stature and nutrition. J Interdiscipl Hist. 1983;14(2):445–481. https://doi.org/10.2307/203716

39. Baten J, Blum M. Growing tall but unequal: New findings and new background evidence on anthropometric welfare in 156 countries, 1810–1989. Econ Hist Dev Reg. 2012;27(suppl.1):S66–S85. https://doi.org/10.1080/20780389.2012.657489

40. Moradi A. Towards an objective account of nutrition and health in colonial Kenya: A study of stature in African army recruits and civilians, 1880–1980. J Econ Hist. 2009;69(3):719–754. https://doi.org/10.1017/S0022050709001107

41. Moradi A, Austin G, Baten J. Heights and development in a cash-crop colony: Living-standards in Ghana, 1870-1980. African Economic History Network. Working paper #7. 2013.

42. Cogneau D, Rouanet L. Living conditions in Côte D'Ivoire and Ghana, 1925-1985: What do survey data on height stature tell us? Econ Hist Dev Reg. 2011;26(2):55–82. https://doi.org/10.1080/20780389.2011.625240

43. Akachi Y, Canning D. Inferring the economic standard of living and health from cohort height: Evidence from modern populations in developing countries. Econ Hum Biol 2015;19:114–128. https://doi.org/10.1016/j.ehb.2015.08.005

44. Moradi A, Baten J. Inequality in sub-Saharan Africa: New data and new insights from anthropometric estimates. World Dev. 2005;33(8):1233–1265. https://doi.org/10.1016/j.worlddev.2005.04.010

45. Mohlamme JS. Soldiers without reward: Africans in South Africa's wars. Unknown publisher; 1995.

46. Bodenhorn H, Guinnane T, Mroz T. Sample-selection biases and the industrialization puzzle. J Econ Hist. 2017;77(1):171–207. https://doi.org/10.1017/S0022050717000031

47. Marks S. The silent scourge? Silicosis, respiratory disease and gold-mining in South Africa. J Ethn Migr Stud. 2006;32(4):569–589. https://doi.org/10.1080/13691830600609975

48. Mariotti M. Father's employment and sons' stature: The long-run effects of a positive regional employment shock in South Africa's mining industry. Econ Dev Cult Change. 2015;63(3):485–514. https://doi.org/10.1086/679755

49. South Africa. Census of the Union of South Africa 1911, UG32-1912. Pretoria: Government Printer; 1912.

50. Statistics South Africa. Census 2001: Primary tables South Africa, Census '96 and 2001 compared. Report no. 03/02/04. Pretoria: Statistics South Africa; 2004.

51. Eldredge EA. A South African kingdom: The pursuit of security in nineteenth-century Lesotho. Cambridge: Cambridge University Press; 2002.

52. Fourie J, Grundlingh A, Mariotti M. 'Poor South Africa! Will no nice English people ever come out here?'—The South African Constabulary of the Second South African War. J Imp Commonw Hist. 2017;45(4):580–606.

53. Fourie J, Inwood K, Mariotti M. Can historical changes in military technology explain the industrial growth puzzle? Mimeo. London: London School of Economics; 2014.

54. Luthuli A. Let my people go. Cape Town: Tafelberg; 2006.

55. Grasgruber P, Sebera M, Hrazdíra E, Cacek J, Kalina T. Major correlates of male height: A study of 105 countries. Econ Hum Biol. 2016;21:172–195. https://doi.org/10.1016/j.ehb.2016.01.005

56. Pak S. The biological standard of living in the two Koreas. Econ Hum Biol. 2004;2(3):511–521. https://doi.org/10.1016/j.ehb.2004.09.001

57. Inwood K, Oxley L, Roberts E. Physical growth and ethnic inequality in New Zealand prisons, 1840–1975. Hist Fam. 2015;20(2):249–269. https://doi.org/10.1080/1081602X.2015.1006653

Assessment of transit transport corridor efficiency of landlocked African countries using data envelopment analysis

AUTHORS:
Enagnon H. Fanou[1]
Xuping Wang[1]

AFFILIATION:
[1]School of Management Science and Engineering, Dalian University of Technology, Dalian, China

CORRESPONDENCE TO:
Enagnon Fanou

EMAIL:
fanoufabrice@yahoo.fr

DATES:
Received: 11 Nov. 2016
Revised: 23 Mar. 2017
Accepted: 13 Oct. 2017

KEYWORDS:
DEA; trade; comparative analysis; transport systems; technical efficiency; scale efficiency

HOW TO CITE:
Fanou EH, Wang X. Assessment of transit transport corridor efficiency of landlocked African countries using data envelopment analysis. S Afr J Sci. 2018;114(1/2), Art. # 2016-0347, 7 pages. http://dx.doi.org/10.17159/sajs.2018/20160347

ARTICLE INCLUDES:
✓ Supplementary material
× Data set

FUNDING:
National Natural Science Foundation of China (grant nos. 71471025, 71421001)

We used a data envelopment analysis (DEA) to examine the efficiency and performance of transport systems of landlocked African countries (LLACs). We conducted a comparative performance efficiency analysis of transfer transport systems for LLACs' corridors. Three different types of DEA models were proposed and used to measure the relative efficiencies of transit transport using a 6-year data set (2008–2013) of some selected LLACs. The results show that the average pure technical and scale efficiency scores are 90.89% and 37.13%, respectively. Two units (13.33%) are technically efficient (technical and scale efficiency) while four units (26.66%) are only purely technically efficient over the observed period. Swaziland was the most efficient corridor while the Central African Republic corridor was the least efficient throughout the monitored years. The results indicate the relevance of minimising trade costs to stimulate landlocked countries' exports.

Significance:

- This study is the first efficiency study on transit transport corridors of landlocked African countries.
- DEA is an effective analytical tool for corridors evaluation and can help decision-makers in finding practical solutions.
- Some corridors are efficient, which means that other landlocked countries can learn from these efficient corridors to improve their corridor services.

Introduction

Landlocked can be defined as 'the geographical situation of a country without direct access to the sea'[1]. Because of the lack of direct access to the sea, landlocked African countries (LLACs) are marginalised from major transportation and services (e.g. logistics, information technology) networks. In addition to their long distance to world markets, uncooperative transit procedures (e.g. red tape) and poor infrastructure contribute to an increase in transport and trade costs, thereby reducing international trade and subsequently economic growth.[2]

Landlocked countries in Africa (Figure 1) are entirely dependent on their neighbour's transit infrastructure and administrative procedures to transport their goods to and from the ports. In many cases, transit neighbours of LLACs are also developing countries, often with similar economic structure and beset by similar scarcities of resources. Their fragile infrastructures, complex customs and administrative setup result in higher transaction costs of trade through the transit country, which restricts the capacity of LLACs to compete favourably in international markets.[3] Companies in LLACs are struggling to get their goods to their destination without major delays, which increases their operating costs. It is reported that landlocked developing countries (LLDCs) have to endure, on average, about 50% higher international transport costs than their neighbouring transit/coastal countries.[4] Many authors have shown that these high barriers to trade are not only a result of geographical location but also have institutional and physical factors.[5]

Problems encountered by landlocked countries in trade through other territories are numerous, and range from long distances from the sea to insufficient transport services and infrastructure, and inefficient institutional and operational transit networks.[6] Over the past 10 years, various studies on transit economics[7-9] have shown that the undependability of the transit logistics system is the greatest barrier faced by manufacturers in LLDCs. A recent study by the World Bank shows that while greater attention has been given to road infrastructure and administration of international road services, accessibility of markets is still based on rules favouring and protecting national haulers.[10] The costs of being landlocked are extensively documented by the United Nations.[11] Figure 2 and Table 1 exemplarily show a comparative analysis of a recent survey.

Despite the progress achieved on many fronts regarding LLDCs, scepticism remains as to the possibility of finding effective and comprehensive solutions to the transport challenges.[8] In order to increase the competitiveness of landlocked countries and improve the efficiencies of the corridors, transit agreements that aim at diminishing these constraints need to be taken into account, especially regarding international trade facilitation, multimodal transport, information systems and transport security. The contribution of efficient corridors to the economic development of a country is undeniable. It is important to analyse the efficiency of transit corridors to be able to improve the service of these corridors.

The evaluation of efficiency is imperative to stay competitive and flourish in a global business environment. Efficiency has been analysed from various perspectives using different techniques.[12] However, analysis of these efficiencies is multi-dimensional and requires the support of multi-criteria decision-making tools.[13] Therefore, the management of international trade corridors requires development of appropriate decision-support models that will provide adequate support for strategic decisions. One of the most promising decision-support models for evaluating corridor performance efficiency is the non-parametric method called data envelopment analysis (DEA).

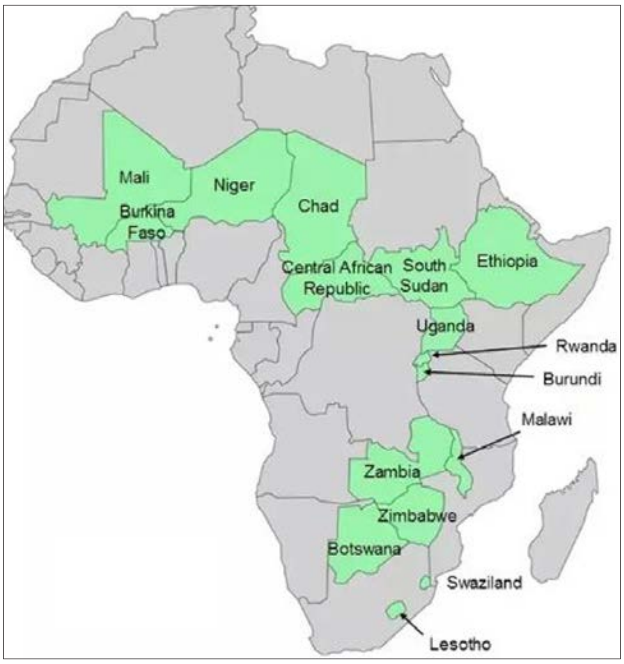


Figure 1: Landlocked African countries. The Republic of South Sudan was not included in the analysis as data were not available.

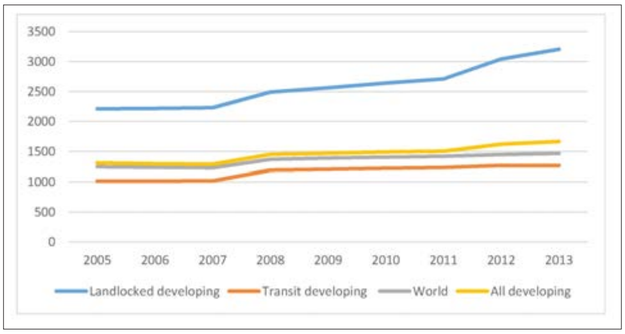


Figure 2: Cost to export (USD per container), modified according to the UN-OHRLLS[11] indicators.

This analysis has been applied in assessing the performances of various kinds of entities engaged in many activities of varying contexts[14] and to compare the efficiencies of non-profit and profit organisations[15]. In the transportation industry, DEA has been implemented in the following areas: ports[16], railways[17], airlines[18] and urban transit[19]. To date, DEA has not been applied in the transit transport of LLACs. It should be noted that the African transfer transport system is one of the major focal areas towards sustainable transport development for landlocked export products through transit countries.

Problem statement

Nearly a third of African countries are landlocked. However, there is a dearth of literature on the efficiency and performance of their transport systems in terms of inland transport infrastructure, customs and trade facilitation, cross-border cooperation, port and terminal handling in transit countries. The objectives of this study were to: (1) evaluate the efficiencies of the transit corridors of LLACs in order to identify sources of inefficiencies and (2) determine the best performing corridor through efficiency ranking. To achieve these objectives, the DEA method was applied using data available from the United Nations.

The contributions of this study are twofold. Firstly, the application of DEA in the transit transport of LLACs is non-existent in the literature. To the best of our knowledge, this study was the first to apply DEA in this context. Secondly, the results provide guidelines to policymakers and regional organisations in LLACs who are dealing with the transport sector in framing strategies that will promote transact trade efficiently.

Literature review

The two most important concepts in performance measurements are productivity and efficiency.[20] There are two classifications of productivity measurement: parametric frontier approach and non-parametric frontier approach.[21] Regarding the parametric frontier approach, Wang et al.[22] state that 'the productivity frontier is estimated in a particular functional form with constant parameters'. They further note that 'the non-parametric frontier approach assumes no particular functional form for the frontier'. The non-parametric frontier technique that is used most is DEA.[14]

However, in some studies, a combination of DEA and parametric frontiers has been used to identify the differences among the efficiency indexes obtained from the two approaches.[23] The findings are very similar, which supports the application of DEA. This verification can be seen in many studies carried out in several countries, such as Norway[24], Turkey[25] and the USA[26].

In recent years, many studies have attempted to evaluate transport efficiency using DEA. Among these include a study by García Sánchez[27] who used DEA to compare the efficiency of Spain's public bus transport system. The paper focused on the estimation of technical and scale efficiency. In another study by Petrović et al.[28], DEA was used to investigate multi-year rail freight transportation efficiency of some selected European nations. Their results provided each country's efficiency scores and suggested areas of improvement together with a discussion on factors that 'drive' efficiency. Savolainen and Hilmola[29] applied DEA to estimate the relative technical efficiency of three European transportation systems – air, rail and maritime.

The application of DEA to the port industry is fundamentally not new. DEA has been successfully applied to analyse container terminals at seaports. The research papers in this field can be classified into two main groups according to the data analysed: cross-sectional data and panel data.

The DEA approach was applied by Barros[30] using cross-sectional data to analyse the allocative and technical efficiency of five Portuguese ports from 1999 to 2000. The key objective of that study was to examine how port regulatory processes impact on port productivity. The study concluded that the incentive regulation for improving productive efficiency was not helping to achieve its aims and made policy recommendations to enforce efficiency. In another study, Martinez-Budria et al.[31] divided 26 Spanish ports into three groups – high complexity ports, medium

Table 1: Average number of days (TT) and costs (TC, USD per TEU) to export by year, 2008–2013 (modified based on UN-OHRLLS[11] indicators)

	2008		2009		2010		2011		2012		2013	
	TT	TC	TT	TC	TT	TC	TT	TC	TT	TC	TT	TC
Landlocked developing countries	48	2490	46	2560	44	2640	43	2710	42	3040	42	3204
Transit developing countries	25	1190	24	1205	23	1221	23	1235	23	1268	22	1268
All developing countries	28	1370	27	1392	26	1405	26	1420	26	1450	26	1468
World	25	1452	24	1470	23	1493	23	1503	23	1620	22	1667

complexity ports and low complexity ports – and assessed their efficiencies using the DEA CCR (Charnes, Cooper and Rhodes) model and the DEA BCC (Banker, Charnes and Cooper) model.[32] They found that high complexity ports were associated with high efficiency, while the other two groups had a random mix of medium and low efficiency.

Using DEA windows analysis, Cullinane et al.[33] combined panel data and cross-sectional data to evaluate the efficiency of the world's major container seaports and showed that the cross-sectional data did not offer a comprehensive view of the ports' performances. The panel data indicated a dissimilarity between the absolute performance of the port and its relative performance in contrast to others over the same period. Min and Park[34] and Pjevcevic et al.[35] proposed DEA window analysis to evaluate the efficiencies of ports and container terminals over a period of 4 years. The DEA window analysis applied helped to observe the changes in the ports and terminal efficiencies. Cullinane and Wang[36] used DEA to examine the efficiencies of 69 Europe container terminals with an annual throughput of over 10 000 TEU (twenty-foot equivalent unit). They argued that there were significant inefficiencies for most of the terminals. It was also evident that the average efficiency of container terminals in different geographical locations differed, either to a large or to a small extent.

In Africa, there is a fairly large body of literature in regard to 'landlockedness' and related issues such as port efficiencies[37] and hinterland relationships[8]. Some of this literature is in the form of reports by government agencies and regional or international organisations (e.g. the United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States or UN-OHRLLS[11]). In 1982, the United Nations Convention on the Law of the Sea announced the 'Right of Access of Landlocked States to and from the Sea and Freedom of Transit'. It stated that landlocked countries may have the admittance to and from the sea, and the freedom of transit through transit countries zone by all means of transport without any restriction.[38] However, in practice, the application of this elementary rule undergoes various operational difficulties, resulting in long transit times and high transport costs.[39] More recently, higher costs and longer transit times have also been seen by the World Bank as the causes for the lack of competitiveness of traders from LLACs. [3]

Over the past decade, under the 'Almaty Programme of Action' initiated in 2003, new research and comprehensive studies have brought fresh knowledge on the transfer transport systems of landlocked countries. Among these is the study of Djankov et al.[2] who offered a clear diagnostic of the current situation of LLDCs. They took a closer look at the dependence of landlocked countries on export goods and measured the impact of transit policy on transport costs and services. They further pointed out specific problems that affect operation, improvement and maintenance of transit transport infrastructure in LLACs and discussed promising options for the more efficient mutual use of infrastructure in landlocked and transit countries.

Although the problem of enclosure has been discussed in studies in Africa, there is sparse literature on the transport system of LLACs especially with regard to inland transport infrastructure, customs and trade facilitation, port and terminal handling. A comparative analysis of the efficiency of transit transport corridors of LLACs has not yet been undertaken. A few studies have described briefly the specific problem faced by LLACs in their respective transit corridors.[6,7] Empirical analysis in this area is still insufficient and real data need to be collected for analysis. In this study we focused on evaluation of the performance of corridors using DEA.

Research methodology

CRS and VRS DEA techniques

Data envelopment analysis is a linear programming method that uses multiple inputs and outputs to evaluate the relative efficiency of homogeneous units (termed decision-making units or DMUs).[14] DEA aids in the computation of the efficiency as a ratio of the weighted sum of outputs to the weighted sum of inputs. As it is impossible to determine the 'absolute efficiency' that is evaluated based on the ideational datum point, the degree of efficiency is measured by comparing the units with a reference set that has identical input and output structure.[40]

Considering a set of input and output variables, DEA provides a unified performance efficiency measurement (efficiency score) for each DMU. This measurement is completed by developing an empirically based 'best-practice' or efficient frontier as a result of an identified set of efficient DMUs (on the frontier) and inefficient DMUs (not on the frontier). According to Wu and Liang[41], inputs are considered as resources used by a DMU while outputs are products produced and/or performance outcomes of the DMU.

Reflecting the type of frontier (i.e. envelopment surface), there are two forms of DEA models: CRS and VRS models. The CRS model was proposed by Charnes et al.[42] and the key concept of this model is to assume constant returns to scale (hence the name CRS, or alternatively CCR after Charnes, Cooper and Rhodes). The CRS assumption is suitable when all DMUs are operating at an optimal scale. Limited competition, financial difficulties, etc., may cause a DMU to not operate at optimal scale.[43] Banker et al.[32] proposed an extension of the CRS-DEA model to account for variable returns to scale (hence the name VRS, or alternatively BCC for Banker, Charnes and Cooper).

Using CRS specifications will result in measures of technical efficiency which are confounded by scale efficiency when not all DMUs are operating at the optimal scale. The use of VRS specifications will allow the computation of technical efficiency devoid of these scale efficiency effects. The CRS technical efficiency measure is decomposed into 'pure' technical efficiency (VRS efficiency) and scale efficiency as in Equation 1[27]:

$$\textit{Scale efficiency (SE)} = \frac{\textit{CRS efficiency}}{\textit{VRS efficiency}} \qquad \text{Equation 1}$$

The DEA model can be used either as input or output orientation. On one hand, 'input-oriented technical efficiency measures' maintain the output constant while the proportion of potential decrease in the input usage is investigated. On the other hand, 'output-oriented technical efficiency measures' prevent any change to input (fixed input) while the proportional expansion in output quantities is considered.[36] Under CRS, the DEA results are similar in both input and output orientation, whereas under VRS, the two results are not generally equivalent. Because it was considered challenging to capture and ensure the stability of transport conditions, both CRS and VRS models were used in this work. Also, we decided to use an input-oriented model to measure CRS and VRS efficiency because the aim was to determine the possibility of input reduction by maintaining the same level of output.

Benefits and limitations of DEA

When applying a DEA model effectively and wisely, there are various advantages; however, some conditions need to be taken into account.[15] DEA permits efficiency evaluation over time and can deal with multiple inputs and outputs with different units. Also, DMUs are directly compared against a peer or combination of peers. Furthermore, in DEA, no assumption of a functional form relating inputs to outputs is required. Nevertheless, some limitations become inevitable with a DEA model.

Firstly, DEA leads to results that are especially sensitive to measurement error and only assesses efficiency relative to the best practice within the specific sample. Therefore, it cannot be used to compare scores between two different studies. In addition, DEA estimates the 'relative' efficiency of a DMU; it converges very gradually to 'absolute' efficiency. DEA clarifies the significance of a DMU compared with its peers regardless of a 'theoretical maximum'. Finally, all efficient units in DEA are assigned the same score (1.00), therefore their further ranking is not possible.

In order to increase the effectiveness of DEA and correct these limitations, unnecessary imputations of missing data influencing the corridor sample size were nullified. To determine the best performing corridor (i.e. to rank the efficient corridor), we relied on the modified DEA model proposed by Andersen and Petersen[44]. This model allows the ranking of efficient units, through the calculation of so-called 'super-efficiency scores'. Andersen and Petersen[44] have pointed out that the attribution of a score greater than 1.000 to the efficient units by relaxing the constraint that bounds the score of the evaluated unit *k,* explicitly the primary problem of unit *k,* can be defined as in M1 and M2 below.

The DEA model M1 is mathematically expressed as[14,15]:

$$M1 \begin{cases} Max\ h_k(u,v) = \dfrac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \text{ for all } k = 1,2, \dots, n & \text{Equation 2} \\ \text{subject to} & \\ \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, j=1,2, \dots, n & \text{Equation 3} \\ u_r \ge 0, r=1,2, \dots, s & \text{Equation 4} \\ v_r \ge 0, i=1,2, \dots, m & \text{Equation 5} \end{cases}$$

where:

- h_k is the relative efficiency of *k*-th DMU;
- y_{rj} is the amount of output *r* generated by DMU *j;*
- x_{ij} is the amount of input *i* utilised by DMU *j*;
- *n* is the number of DMUs;
- *m* is the number of inputs;
- *s* is the number of outputs;
- u_r is the weight assigned to output *r;*
- v_i is the weight assigned to input *i*.

Model M1 is resolved *n* times to measure the relative efficiency of each DMU. Mathematically, the non-negative constraints in Equations 4 and 5 are not sufficient for the fractional Equation 3 to have a value greater than zero. On this basis, all weights for inputs and outputs assumed non-zero values. As the efficiency of *k*-th DMU is maximised by resolving the expressions in Equations 2–5, it can be seen that h_k takes values from 0 to 1. If the value for h_k is 1, then the *k*-th DMU is efficient relative to other DMUs. Otherwise, the value of h_k shows the inefficiency of *k*-th DMU. However, if the value of h_k tends to 1, it can be considered as 'less efficient'.

This problem can be addressed using fractional linear programming model M1, known as 'CCR ratio model', which can be mitigated using transformations to the linear programming model M2. The DEA model M2 is proposed in the following forms:

$$M2 \begin{cases} Max\ h_k(\mu,v) = \sum_{r=1}^{s} \mu_r y_{rk} \text{ for all } k = 1,2, \dots, n & \text{Equation 6} \\ \text{subject to} & \\ \sum_{i=1}^{m} v_i x_{ik} = 1 & \text{Equation 7} \\ \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, j=1,2, \dots, n & \text{Equation 8} \\ \mu_r \ge 0, r=1,2, \dots, s & \text{Equation 9} \\ v_i \ge 0, i=1,2, \dots, m & \text{Equation 10} \end{cases}$$

where:

- y_{rj} is the amount of output *r* generated by DMU *j;*
- x_{ij} is the amount of input *i* to unit *j;*
- h_k is the relative efficiency of the unit *k*;
- *n* is the number of DMUs under investigation;
- *m* is the number of inputs;
- *s* is the number of outputs;
- μ_r is the weight coefficient of output *r*;
- v_i is the weight coefficient of input *i*.

The *k*-th DMU is relatively efficient if the value of h_k in the objective function is equal to 1, and DMU*k* is relatively inefficient if h_k is less than 1. In that case, the value of h_k indicates the percentage by which DMU should reduce its inputs. DMU*k* is considered to be fully efficient only if the other DMU values do not indicate that any of its inputs or outputs can be improved without impairing any other input or output.

The super-efficiency model defined above was used in this paper to rank the efficient corridors and determine the best performing ones. For VRS, CRS and super-efficiency, we used Efficiency Measurement System (EMS) – software that computes efficiency scores.[45] A detailed explanation of these DEA models is in the supplementary material.

Description of the data

We employed three inputs and one output in the DEA efficiency computations. For inputs we selected: transaction costs (USD per TEU), transaction time (days) and the number of documents for exporting a standard shipment of goods by sea transport. For output, we used exports handled by each DMU (corridor) measured by TEU. Our choice of these variables is in line with those of Djankov et al.[2] and are applied in this paper with minor modifications by considering a third factor (number of documents for export). A detailed explanation for the selection of these variables is in the supplementary material. Efficiency was calculated for 15 corridors over the period 2008–2013. Input data were obtained from the World Bank Doing Business database[46] and the output data were sourced from the UN Comtrade database[47]. Supplementary table 1a and 1b provides more details on the data sample.

Doing Business measures the time and cost (excluding tariffs) associated with exporting and importing a standardised cargo of goods by sea transport. For exporting goods, official procedures start from packing the goods into the container at the warehouse to their departure from the port of exit and includes processes at the inland border post. However, the time and cost for sea transport are excluded. All the necessary documents required from the trader to export the goods across the border are also recorded.

To make the data comparable across economies and to avoid special cases, several assumptions about the business and the traded goods were used by the Doing Business data survey.[3] All exporters (100% domestically owned) had at least 60 employees and were located in the economy's largest business city. The goods traded were one of the economy's leading export products. The goods traded travelled in a dry cargo, 20-foot full container load that weighed 10 tons and was priced at USD20 000. Each year, more than 10% of gross revenue must have been from international trade. Additionally, the exporter should not have operated in an export processing area or industrial zone for which special export privileges existed. Furthermore, the goods traded did not constitute hazardous or military items, nor did they require refrigeration or any other special environmental safety standards other than internationally accepted standards. Our first intention was to evaluate all 16 main transit corridors servicing landlocked countries in Africa. However, South Sudan was excluded from the analysis because of the unavailability of data.

Results and discussions

The results obtained from DEA CRS and VRS models are shown in Table 2. These results contain VRS efficiency, scale efficiency and CRS efficiency scores denoted by Evrs, Ese and Ecrs, respectively. The DEA super-efficiency model results are also listed in Table 3.

The results on DEA CRS efficiency indicate that only Botswana's and Zambia's corridors were technically efficient throughout the whole period. Yet some corridors were efficient in the case of DEA with VRS. Swaziland's, Botswana's and Zambia's corridors were efficient based on the VRS model in the observed period while Lesotho's, Malawi's and Mali's were relatively efficient over the period. Furthermore, the average index of VRS efficiency was better than the average scores for CRS efficiency.

A corridor may be considered efficient in terms of VRS and inefficient in CRS terms. This distinction is as a result of scale inefficiency.

Table 2: Efficiency scores ('pure' technical - Evrs, scale - Ese and technical - Ecrs) for 15 corridors, 2008–2013

Corridor	2008			2009			2010			2011			2012			2013		
	Ecrs	Evrs	Ese	Ecrs	Evrs	Ese	Ecrs	Evrs	Ese	Ecrs	Evrs	Ese	Ecrs	Evrs	Ese	Ecrs	Evrs	Ese
Botswana	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Burkina Faso	0.09	0.79	0.11	0.22	0.79	0.28	0.22	0.80	0.28	0.45	0.77	0.58	0.45	0.80	0.57	0.46	0.86	0.53
Burundi	0.02	0.68	0.03	0.02	0.67	0.03	0.02	0.70	0.03	0.02	0.67	0.03	0.03	0.70	0.05	0.02	0.71	0.03
Central African Republic	0.02	0.75	0.02	0.02	0.75	0.02	0.01	0.67	0.02	0.01	0.67	0.02	0.01	0.67	0.02	0.00	0.67	0.01
Chad	0.75	0.86	0.88	0.61	0.86	0.71	0.47	0.86	0.55	0.51	0.86	0.60	0.42	0.86	0.49	0.42	0.86	0.50
Ethiopia	0.34	0.97	0.35	0.42	0.84	0.50	0.39	0.91	0.42	0.56	0.92	0.62	0.62	0.97	0.64	0.69	0.96	0.71
Lesotho	0.06	**1.00**	0.06	0.25	**1.00**	0.25	0.15	0.99	0.16	0.33	**1.00**	0.33	0.26	0.98	0.27	0.23	**1.00**	0.23
Malawi	0.22	**1.00**	0.22	0.44	**1.00**	0.44	0.23	**1.00**	0.23	0.39	1.00	0.39	0.24	0.78	0.30	0.23	0.81	0.28
Mali	0.38	0.97	0.39	0.55	0.98	0.57	0.43	**1.00**	0.43	0.51	**1.00**	0.51	0.50	**1.00**	0.50	0.47	**1.00**	0.47
Niger	0.17	0.85	0.20	0.13	0.75	0.17	0.06	0.75	0.08	0.14	0.75	0.18	0.17	0.75	0.22	0.16	0.75	0.21
Rwanda	0.05	0.86	0.05	0.06	0.75	0.08	0.04	0.79	0.05	0.07	0.86	0.09	0.09	0.92	0.10	0.08	0.87	0.09
Swaziland	0.53	**1.00**	0.53	0.63	**1.00**	0.63	0.47	**1.00**	0.47	0.51	**1.00**	0.51	0.50	**1.00**	0.50	0.29	**1.00**	0.29
Uganda	0.36	0.98	0.37	0.40	0.87	0.46	0.31	0.88	0.35	0.37	0.86	0.43	0.38	0.87	0.44	0.33	0.86	0.39
Zambia	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Zimbabwe	0.31	0.93	0.34	0.53	0.86	0.61	0.44	0.86	0.52	0.44	0.86	0.51	0.52	0.86	0.61	0.45	0.86	0.53
Average efficiency	0.35	0.91	0.37	0.42	0.87	0.45	0.35	0.88	0.37	0.42	0.88	0.45	0.41	0.88	0.45	0.39	0.88	0.42
Efficiency units	2	5	2	2	5	2	2	5	2	2	5	2	2	4	2	2	5	2
Inefficiency units	13	10	13	13	10	13	13	10	13	13	10	13	13	11	13	13	10	13

Table 3: Data envelopment analysis super-efficiency scores in terms of variable returns to scale (VRS), 2008–2013

2008			2009			2010			2011			2012			2013		
Rank	Corridor	VRS	Rank	Corridor	VRS	Rank	Corridor	VRS	Rank	Corridor	VRS	Rank	Corridor	VRS	Rank	Corridor	VRS
1	SZ	**1.57**	1	SZ	**1.48**	1	SZ	**1.43**	1	SZ	**1.44**	1	SZ	**1.44**	1	BW	**1.49**
2	BW	**1.56**	2	BW	**1.40**	2	BW	**1.29**	2	BW	**1.30**	2	BW	**1.29**	2	SZ	**1.44**
3	MW	**1.17**	3	LS	**1.17**	3	MW	**1.14**	3	ML	**1.10**	3	ML	**1.07**	3	LS	**1.11**
4	LS	**1.06**	4	MW	**1.01**	4	ML	**1.12**	4	LS	**1.04**	4	ZM	**big**	4	ML	**1.08**
5	ZM	**big**	5	ZM	**big**	5	ZM	**big**	5	ZM	**big**	5	LS	0.98	5	ZM	**big**
6	UG	0.98	6	ML	0.98	6	LS	0.99	6	MW	1.00	6	ET	0.97	6	ET	0.96
7	ML	0.97	7	UG	0.87	7	ET	0.91	7	ET	0.92	7	RW	0.92	7	RW	0.87
8	ET	0.97	8	TD	0.86	8	UG	0.88	8	TD	0.86	8	UG	0.87	8	BF	0.86
9	ZW	0.93	9	ZW	0.86	9	TD	0.86	9	RW	0.86	9	TD	0.86	9	TD	0.86
10	RW	0.86	10	ET	0.84	10	ZW	0.86	10	UG	0.86	10	ZW	0.86	10	UG	0.86
11	TD	0.86	11	BF	0.79	11	BF	0.80	11	ZW	0.86	11	BF	0.80	11	ZW	0.86
12	NE	0.85	12	CF	0.75	12	RW	0.79	12	BF	0.77	12	MW	0.78	12	MW	0.81
13	BF	0.79	13	NE	0.75	13	NE	0.75	13	NE	0.75	13	NE	0.75	13	NE	0.75
14	CF	0.75	14	RW	0.75	14	BI	0.70	14	BI	0.67	14	BI	0.70	14	BI	0.71
15	BI	0.68	15	BI	0.67	15	CF	0.67	15	CF	0.67	15	CF	0.67	15	CF	0.67

BW, Botswana; BF, Burkina Faso; BI, Burundi; CF, Central African Republic; TD, Chad; ET, Ethiopia; LS, Lesotho; MW, Malawi; ML, Mali; NE, Niger; RW, Rwanda; SZ, Swaziland; UG, Uganda; ZM, Zambia; ZW, Zimbabwe

A typical example here is Swaziland, which is observed to be VRS efficient over the whole period but inefficient in CRS and scale terms. Average efficiency scores were constant over the years, except for 2008. This exception may be seen as a need for new reform in transfer transport systems to facilitate exports. This also shows that implementing the DEA methods can produce good results and help LLACs in their strategic decisions.

The results on CRS efficiency indicate that Botswana and Zambia have the most successful corridors, but in terms of VRS more than two corridors showed efficiency (five countries in 2008 to 2011, four in 2012, and five in 2013). To determine the best performing corridor in the study, we applied super-efficiency in VRS terms. The results are depicted in Table 3. Super-efficiency DEA allows efficiency scores greater than 1.00 (i.e. bigger than 1.00 for input-oriented model) and enables the ranking of DMUs using the level of efficiency. Further discussion of the rankings is in relation to the results from applying super-efficiency.

Swaziland's corridor was ranked the highest (Rank 1) within the observed period, with the exception of 2013. Burundi's and the Central African Republic's corridors were in the last position in the observed period. The meaning of 'big' in Table 3 indicates that the DMU remains efficient under an arbitrary large increase in outputs. Nevertheless, if the same process is used in CRS terms, Zambia (2008, 2010 to 2012) and Botswana (2009, 2013) become the best exemplars. This change in results is because of the scale efficiency included in the CRS efficiency estimation (see Supplementary table 2).

The general findings suggest that there is no substantial difference in the estimation of super-efficiency throughout the observed period, as seen in the first five and the last five corridors (Table 3). This demonstrates that the performances of the corridors analysed were stable over the period. The explanations can be seen in the 'fixed' nature of inputs (no big difference for the number of documents and time spent over the years) and that transit transport services need more investment along with longer periods for their implementation. As suggested by Peter et al.[48], decision-makers must put effort into selecting or encouraging the right type of infrastructure for the right period. Furthermore, the results show that there is a difference in the efficiency scores obtained between the intra-regional member and non-member states.

Apart from the efficiency scores, DEA records each inefficient unit (corridor) with its respective benchmark (efficiency reference set). The benchmark refers to an efficient corridor which is the closest corridor to the projection of an inefficient corridor on the frontier. For example, in 2013, DEA VRS indicated Botswana as a corresponding benchmark corridor for Niger (see Supplementary table 2c for more details). Further and broader analysis is required for the final decision on which country to benchmark against, which suggests that other criteria – such as demography, sociology or geography – ought to be considered.

In summary, within the 15 corridors considered in the study, only 5 were efficient. The results confirm that landlocked economies in Africa have the most challenging environments with regard to business regulations.[7,10] Indeed, of the 10 most difficult places in the world to carry out business, a disproportionate number are LLACs: the Central African Republic, Burundi, Chad and Niger.[49] In a recent study, the UN-OHRLLS revealed that the transport costs of LLDCs were 45% higher than those of representative coastal countries. According to Arvis et al.[6], the basic import and export costs of LLDCs were nearly twice those of their transit neighbours. These findings prove that there is a great need for better African trade integration.[50]

Previous studies have predominantly focused on the impact on economies of being landlocked in comparison to coastal[8], without explicitly identifying the relative efficiency of the transfer transport system of those countries. Thus, this paper contributes towards filling this gap. Our results show some efficient corridors, e.g. Botswana and Swaziland, indicating that some landlocked countries are making progress and that LLACs can learn from one another. The findings prove that the implementation of DEA can be beneficial and useful for the evaluation of the performance of LLACs. A better understanding of the efficiency of the transit transport corridors of LLACs may lead to better decision-making for trade facilitation measures and was the core focus of this paper. We have demonstrated the applicability of DEA in this strategic decision-making.

Conclusions and recommendations

This study was primarily done to evaluate the efficiency of the main transit corridors linking landlocked countries and sea ports in Africa for the years 2008–2013. We further determined the sources of inefficiencies (higher transaction costs/time) and make proposals for their improvement. Our results have important implications for LLDCs seeking to expand their exports by helping decision-makers to find practical solutions that will promote trade efficiently.

The results reveal that 10 of the 15 corridors were relatively inefficient (Swaziland being the most efficient). The top five corridors are located in southern Africa and the bottom five are in Central and West Africa. This suggests that trade facilitation measures and port performance (such as multimodal transports, terminals, reformed policies, procedures and regulations) are better implemented in the south than in the rest of the continent. The average performance of the 15 corridors examined was also stable over time, pointing to the fact that the need for regional transit reform is felt urgently. For the more efficient use of transit transport infrastructures in both the transit and landlocked countries, the removal of physical and non-physical barriers to trade (e.g. bureaucracy) remains a major challenge. Simplification and harmonisation of customs and administrative documentation, new technologies, trade facilitation and procedures which can be attained with modest investment can achieve immediate benefits in terms of improving transit times and reducing transit transport costs.

Efficiency is the key performance indicator in transport. The DEA method can aid in the evaluation of efficiency for cross-country comparisons of transfer transport systems in LLACs. DEA super-efficiency allows the ranking of efficient corridors and the determination of the best-performing corridors. The estimated efficiencies are relative and depend on the selection of corridors. We want to emphasise that additional inputs and outputs – for example, indicators on sector investments (for input) and revenues (output) – can improve the findings and can be the subject of future research.

Acknowledgements

We acknowledge Lucienne and Pierre Fanou for their financial support and Dr Simonov Kusi-Sarpong and Dr Henry Musoke Semakula who provided critical comments and important suggestions.

Authors' contributions

E.H.F. was responsible for collecting information, computing and interpreting the data, and writing the manuscript. X.W. was the supervisor of this research project and provided advice on the data analysis and manuscript structure.

References

1. Bayeh E. The rights of land-locked states under the international law: The role of bilateral/multilateral agreements. Soc Sci. 2015;4(2):27–30. http://dx.doi.org/10.11648/j.ss.20150402.12

2. Djankov S, Freund C, Pham CS. Trading on time. Rev Econ Stat. 2010;92:166–173. http://dx.doi.org/10.1162/rest.2009.11498

3. The World Bank. Trading across borders. In: Doing Business 2013: Smarter regulations for small and medium-size enterprises. Washington DC: World Bank Group; 2013. p. 123–124. http://dx.doi.org/10.1596/978-0-8213-9615-5

4. United Nations. Transport and trade facilitation series no. 4. In: The way to the ocean: Transit corridors servicing the trade of landlocked developing countries. New York and Geneva: United Nations; 2013. p. 1–27.

5. Foroutan F, Pritchett L. Intra-sub-Saharan African trade: Is it too little? J Afr Econ. 1993;2(1):74–105. https://doi.org/10.1093/oxfordjournals.jae.a036775

6. Arvis JF, Raballand G, Marteau JF. The cost of being landlocked: Logistics costs and supply chain reliability. World Bank Policy Research Working Paper 4258. Washington DC: World Bank Group; 2007. p. 1–81. http://dx.doi.org/10.1596/1813-9450-4258

7. Venables AJ. Infrastructure, geographical disadvantage, and transport. World Bank Policy Research Working Paper 2257. Washington DC: World Bank Group; 1999. p. 1–37.

8. Faye ML, McArthur JW, Sachs JD, Snow T. The challenges facing landlocked developing countries. J Hum Dev. 2004;5(1):31–68. http://dx.doi.org/10.1080/14649880310001660201

9. Collier P. The bottom billion: Why the poorest countries are failing and what can be done about it. New York. Oxford University Press; 2007.

10. Kunaka C, Tanase V, Latrille P, Krausz P. Quantitative analysis of road transport agreements (QuARTA). Washington DC: The World Bank; 2013.

11. United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS). The development economics of landlockedness: Understanding the development costs of being landlocked. New York: UN-OHRLLS; 2013.

12. Du Plessis W. Energy efficiency and the law : A multidisciplinary approach. S Afr J Sci. 2015;111(1/2), Art. #2013-0302, 8 pages. http://dx.doi.org/10.17159/sajs.2015/20130302

13. Wit M De, Crookes DJ. Improved decision-making on irrigation farming in arid zones using a system dynamics model. S Afr J Sci. 2013;109(11/12), Art. #2013-0191, 8 pages. http://dx.doi.org/10.1590/sajs.2013/20130191

14. Cooper W, Seiford LM, Zhu J. Data envelopment analysis: History, models, and interpretations. J Econometrics. 2011;46:1–39. http://dx.doi.org/978-1-4419-6150

15. Cooper WW, Seiford LM, Tone K. Introduction to data envelopment analysis and its uses: With DEA-solver software and references. New York: Springer; 2006. http://dx.doi.org/10.1007/0-387-29122-9

16. Liu C-C. Evaluating the operational efficiency of major ports in the Asia-Pacific region using data envelopment analysis. Appl Econ. 2008;40(13):1737–1743. http://dx.doi.org/10.1080/00036840600905126

17. Hilmola O-P. European railway freight transportation and adaptation to demand decline: Efficiency and partial productivity analysis from period of 1980-2003. Int J Product Perform Manag. 2007;56(3):205–225. http://dx.doi.org/10.1108/17410400710731428

18. Ha H-K, Yoshida Y, Zhang. A. Comparative analysis of efficiency for major northeast Asia airports. Transp J. 2010;49(4):9–23.

19. Boame AK. The technical efficiency of Canadian urban transit systems. Transp Res Part E. 2004;40:401–416. http://dx.doi.org/10.1016/j.tre.2003.09.002

20. Isaksson K, Huge-Brodin M. Understanding efficiencies behind logistics service providers' green offerings. Manag Res Rev. 2015;36(3):216–238. http://dx.doi.org/10.1108/01409171311306382

21. Graham DJ. Productivity and efficiency in urban railways: Parametric and non-parametric estimates. Transp Res Part E Logist Transp Rev. 2008;44(1):84–99. http://dx.doi.org/10.1016/j.tre.2006.04.001

22. Wang T, Song D, Cullinane K. Container port production efficiency: A comparative study of DEA and FDH approaches. J East Asian Soc Transp Stud. 2003;5:698–713.

23. Obeng K. Bus transit technical efficiency using latent class stochastic indirect production frontier. Appl Econ. 2013;45(28):3933–3942. http://dx.doi.org/10.1080/00036846.2012.736946

24. Odeck J, Alkadi A. Evaluating efficiency in the Norwegian bus industry using data envelopment analysis. Transportation (Amst). 2001;28(3):211–232. https://doi.org/10.1080/03081060108717663

25. Kasap Y. The effect of work accidents on the efficiency of production in the coal sector. S Afr J Sci. 2011;107(5/6):77–85. http://dx.doi.org/10.4102/sajs.v107i5/6.513

26. Karlaftis MG. A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. Eur J Oper Res. 2004;152(2):354–364. https://doi.org/10.1016/S0377-2217(03)00029-8

27. García Sánchez IM. Technical and scale efficiency in Spanish urban transport: Estimating with data envelopment analysis. Adv Oper Res. 2009;2009, Art. #721279, 15 pages. http://dx.doi.org/10.1155/2009/721279

28. Petrović M, Pejčić-Tarle S, Vujičić M, Bojković N. A DEA based approach for cross-country evaluation of rail freight transport: Possibilities and limitations. Belgrade: University of Belgrade; 2012.

29. Savolainen VV, Hilmola OP. The relative technical efficiency of European transportation systems concerning air transport and railways. Int J Bus Perform Manag. 2009;11(1–2):19–42. http://dx.doi.org/10.1504/ijbpm.2009.023799

30. Barros CP. The measurement of efficiency of Portuguese sea port authorites with DEA. Int J Transp Econ. 2003;30(3):335–354.

31. Martinez-Budria E, Diaz-Armas R, Navarro-Ibanez M, Ravelo-Mesa T. A study of the efficiency of Spanish port authorities using data envelopment analysis. Int J Transp Econ. 1999;26: 237–253.

32. Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci. 1984;30(9):1078–1092. http://dx.doi.org/10.1287/mnsc.30.9.1078

33. Cullinane K, Song D-W, Ji P, Wang T-F. An application of DEA windows analysis to container port production efficiency. Rev Netw Econ. 2004;3(2):184–206.

34. Min H, Park B-I. Evaluating the inter-temporal efficiency trends of international container terminals using data envelopment analysis. Int J Integr Supply Manag. 2005;1(3):258–277. http://dx.doi.org/10.1504/IJISM.2005.005950

35. Pjevcevic D, Radonjic A, Hrle Z, Colic V. DEA window analysis for measuring port efficiencies in Serbia. Promet-Traffic Transp. 2012;24(1):63–72. http://dx.doi.org/10.7307/ptt.v24i1.269

36. Cullinane K, Wang T-F. The efficiency of European container ports: A cross-sectional data envelopment analysis. Int J Logist Res Appl. 2006;9(1):19–31. http://dx.doi.org/10.1080/13675560500322417

37. Van Dyck GK. Assessment of port efficiency in West Africa using data envelopment analysis. Am J Ind Bus Manag. 2015;5(April):208–218. http://dx.doi.org/10.4236/ajibm.2015.54023

38. Hummels D, Schaur G. Time as a trade barrier. Am Econ Rev Am Econ Assoc. 2013;103(7):2935–2959. https://doi.org/10.1257/aer.103.7.2935

39. Nordquist M, Nandan S, Rosenne S, editors. United Nations Convention on the Law of the Sea 1982. Leiden: Martinus Nijhoff; 2011.

40. Despić O, Despić M, Paradi JC. DEA-R: Ratio-based comparative efficiency model, its mathematical relation to DEA and its use in applications. J Product Anal. 2007;28:33–44. http://dx.doi.org/10.1007/s11123-007-0050-x

41. Wu J, Liang N. Performances and benchmarks of container ports using data envelopment analysis. Int J Shipp Transp Logist. 2009;1(3):295. http://dx.doi.org/10.1504/IJSTL.2009.027536

42. Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. Eur J Oper Res. 1978;2(6):429–444. https://doi.org/10.1016/0377-2217(78)90138-8

43. Jahanshahloo GR, Soleimani-damaneh M, Mostafaee A. A simplified version of the DEA cost efficiency model. Eur J Oper Res. 2008;184(2):814–815. http://dx.doi.org/10.1016/j.ejor.2006.11.043

44. Andersen P, Petersen NC. A procedure for ranking efficient units in data envelopment analysis. Manage Sci. 1993;39(10):1261–1264. http://dx.doi.org/10.1287/mnsc.39.10.1261

45. Scheel H. EMS: Efficiency measurement system. A data envelopment analysis (DEA) software [software on the Internet]. c2000 [cited 2015 Jan 13]. Available from: http://www.holger-scheel.de/ems/#down

46. The World Bank. Doing business: Measuring business regulation [homepage on the Internet]. c2014 [cited 2015 Feb 12]. Available from: http://www.doingbusiness.org/data/exploretopics/trading-across-borders

47. United Nations. UN trade statistics [homepage on the Internet]. c2014 [cited 2015 Feb 15]. Available from: http://unstats.un.org/unsd/trade/data/tables.asp#annual

48. Peter P, Fedderke J, Luiz J. An analysis of economic infrastructure investment in South Africa. S Afr J Econ. 2005;73(2):211–228. http://dx.doi.org/10.1111/j.1813-6982.2005.00014.x

49. The World Bank. Business regulations. In: Doing business in landlocked economies. Washington DC: World Bank Group; 2009.

50. Sachs JD, Warner A, Åslund A, Fischer S. Economic reform and the process of global integration. Brookings Pap Econ Act. 1995;1:1–118. http://dx.doi.org/10.2307/2534573

Public perceptions of biotechnology in South Africa

AUTHORS:
Michael Gastrow[1]
Ben Roberts[1]
Vijay Reddy[2]
Shameelah Ismail[3]

AFFILIATIONS:
[1]Human Sciences Research Council – Education and Skills Development, Cape Town, South Africa
[2]Human Sciences Research Council – Education and Skills Development, Durban, South Africa
[3]Faculty of Business and Management Sciences, Cape Peninsula University of Technology, Cape Town, South Africa

CORRESPONDENCE TO:
Michael Gastrow

EMAIL:
mgastrow@hsrc.ac.za

DATES:
Received: 11 Aug. 2017
Revised: 16 Oct. 2017
Accepted: 16 Oct. 2017

KEYWORDS:
science engagement; science communication; science policy; technology policy; public understanding of science

HOW TO CITE:
Gastrow M, Roberts B, Reddy V, Ismail S. Public perceptions of biotechnology in South Africa. S Afr J Sci. 2018;114(1/2), Art. #2017-0276, 9 pages. http://dx.doi.org/10.17159/sajs.2018/20170276

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
National Research Foundation (South Africa); South African Agency for Science and Technology Advancement

A nationally representative survey of the South African public's perceptions of biotechnology provides new insights into the position of the sector in the public sphere. Familiarity with the concept of biotechnology, and awareness of GM food, have increased over the last decade, although these changes have occurred from a low base. Compared to Europeans, South Africans are more positive about the health implications of GM food, less critical about the environmental impact of GM food, and more positive about the economic consequences of GM food. Knowledge about biotechnology is positively correlated with younger age, higher educational attainment and higher living standard. For marginalised groups, particularly low-income groups in rural areas and traditional authority areas, engaging on the basis of indigenous knowledge systems may prove to be the most effective platform for communication. The concepts of DNA and genes are far better understood than those of genetic modification or GM food, and would therefore present a better starting point for engagement and knowledge transfer. Together, these considerations point towards new strategic imperatives for public engagement in the South African biotechnology sector. Public policy, and broader sectoral engagement strategies, need to take into account: (1) the highly dynamic nature of public perceptions, (2) the diversity of views held by different demographic groups and (3) the diversity of sources of information utilised and preferred by different demographic groups. These considerations would support a strategically targeted engagement approach that would leverage the rapidly growing public awareness of biotechnology in a constructive manner.

Significance:

- Provides new insights into public perceptions of biotechnology in South Africa
- Informs new strategic imperatives for public engagement in the South African biotechnology sector
- Quantifies changes over time and differences across demographic groups in biotechnology perceptions

Introduction

Biotechnology is widely seen as one of the critical domains of science and technology for the 21st century. It has a growing role, and further enormous potential, in the development and production of new classes of medicine, food, energy and industrial processes. These areas all offer great opportunities for sustainable human development and economic growth. However, despite this recognition, biotechnology faces several challenges in the public sphere. The public have a limited understanding of what biotechnology is, how it is governed, how knowledge is produced, and how the benefits are distributed and accrued. This limited understanding provides fertile ground for reservations about biotechnology's ethical, health and environmental implications. It also creates challenges for policymakers and other stakeholders who seek to foster constructive engagement between biotechnology institutions and the broader public. In a stratified society such as South Africa, with a wide range of economic activities characterised by varying degrees of technological intensity, and a diversity of social and economic strata with distinct attitudes towards and engagements with science[1], understanding public attitudes towards biotechnology is an essential prerequisite for developing evidence-based science engagement policy.

Recognising this need, in 2015 the Public Understanding of Biotechnology Programme of the South African Agency for Science and Technology Advancement commissioned a national survey of the South African public's perceptions of biotechnology. This paper reflects on the high-level findings emanating from this survey, in the context of the main theoretical approaches towards understanding public perceptions of biotechnology, and reviews of extant South African evidence and policy in this area. The full report[2] on which this paper is based provides an in-depth analysis, including regression analysis models and one-way analysis of variance (ANOVA) models.

Public perceptions of biotechnology: Theory and evidence

Biotechnology, in its broad sense, refers to 'any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use'[3]. In this sense, biotechnology has been evolving along with human civilisation for thousands of years, and is deeply embedded in the indigenous and local knowledge systems of all cultures. In its contemporary usage, biotechnology is often referred to as specifically related to applications of technologies for manipulating DNA.[4] This usage frames biotechnology as an inherently high-technology and knowledge-intensive activity, closely tied to advanced biological sciences. The juxtaposition between these two usages is particularly evident in and relevant to South Africa. The country's indigenous knowledge systems (IKS) harbour extensive knowledge related to using biological systems. At the same time, genetically modified (GM) organisms are commonly produced through commercial agriculture, and many research centres practise various forms of genetic manipulation, thus adding to the global biotechnology knowledge frontier.

It has been in the more restricted contemporary sense that biotechnology has entered global public discourse and been a source of contestation and controversy. The use of GM crops has prompted debates about food safety, genetic integrity, labelling policies and traceability of food.[4-7] These debates, including public actions such as anti-GM campaigns and protests, have played out in various aspects of the public sphere, including the media, policymaking, and in public perceptions and attitudes.

Public perceptions of biotechnology are commonly studied within the broad theoretical ambit of the 'public understanding of science'.[8,9] Early efforts to promote an improved relationship between the public and science focused on increasing levels of knowledge about science, which was seen as a factor that was likely to enhance the capacity of the public to engage with science questions and decisions[10], and to foster public support for science[11]. However, the assumption that increased scientific knowledge causes more positive attitudes and relationships with science institutions came to be critiqued[12], and a broad spectrum of evidence from around the world has failed to provide a positive correlation between knowledge about science and positive attitudes towards science[13,14].

At the same time, the emphasis shifted from a 'deficit model', which viewed the public as being deficient in science knowledge, and requiring guidance and education, to more participative models which emphasise the agency of citizens to contribute to the relationship between science and society.[6,7] Subsequent efforts directed at better understanding these complexities in the relationship between knowledge and attitudes have served to shape the contemporary framework of the 'public understanding of science'. Questions were raised about the influence of demographics and cultural, social and political contexts.[15,16] The role of communication in shaping attitudes has also been re-appraised.[16,17]

The public understanding of science has remained the dominant framework for major empirical research projects focused on public perceptions of biotechnology, which includes a focus on science communication matters such as governance and trust relationships with institutions. The largest of these is the Eurobarometer[18-21], which provides nationally representative data for the European Union countries. Smaller surveys have been undertaken in certain developing and low-income country contexts[22-26], including India, China, Kenya and Ghana. Surveys in India have addressed the question of biotechnology and IKS[22], seeking to establish the extent of indigenous knowledge in terms that are more likely to be aligned with the knowledge bases of the broader population, particularly marginalised groups. In the African context, analyses of public debate and media representations have explored the position of biotechnology in the public sphere.[27,28] However, previous surveys in developing countries have all had small sample sizes, comprised of biotechnology stakeholders rather than the general public. None has therefore provided nationally representative data. In this sense, South Africa is the first country from the global South to develop national data on public perceptions of biotechnology. A consequence and limitation of this position is that developed countries provide the only direct international comparators.

Evidence and policy in South Africa

Two nationally representative surveys addressing perceptions of biotechnology have been undertaken in South Africa to date, the first in 2004[29], and the second in 2015[2]. The first survey, which was conducted by the Human Sciences Research Council, included questions related to food labelling, biotechnology knowledge constructs, attitudes towards biotechnology, trust in biotechnology institutions, sources of information about biotechnology, and interest in biotechnology. This survey highlighted the very limited public understanding of biotechnology at that time: 80% of respondents did not have any knowledge of biotechnology. Selected results from this survey serve as a baseline against which to chart change. As such, some of the measures were repeated in the 2015 survey.

Since the demise of apartheid, and the contemporaneous rise of biotechnology as a key technology platform, the South African government has developed a policy portfolio that is highly supportive of the biotechnology sector, providing a regulatory framework and overarching sectoral strategies. These national strategies have included measures to improve engagement between the institutions of biotechnology and the broader public. The national biotechnology strategy (2001)[30] aimed to address perceived shortfalls in the relationship between biotechnology institutions and the public through the inclusion of biotechnology issues in the school curriculum, as well as the provision of balanced information to the media. The Public Understanding of Biotechnology Programme was established by the Department of Science and Technology in 2003, with the aim of promoting awareness, knowledge, dialogue and debate related to biotechnology in South Africa. *The Bio-economy Strategy* (2013)[31] included similar measures of support for public engagement activities.

Methodology

Survey design

As a basis for measuring public perceptions of biotechnology, use was made of a longstanding national household survey research infrastructure – the South African Social Attitudes Survey (SASAS) – that has been designed in accordance with international best practice, and which is also able to accommodate the unique characteristics of the South African public and South African biotechnology. The survey instrument included questions from surveys undertaken in Australia, the European Union and the USA, as well as selected questions from the 2004 nationally representative South African study.

Issues of comparability or equivalence required a carefully constructed response to meet the challenge of measuring South Africa's diverse biotechnology landscape with low levels of formal education and high levels of linguistic diversity. The methodology needed to address the challenges that have emerged from prior South African studies, the most significant of which is the issue of high levels of 'don't know' responses. It was imperative that research instruments be designed in such a way as to minimise the frequency of such a response. This required greater efforts to make questionnaire items more accessible to a broader South African public, including greater attention to issues of translation across all South African official languages and careful and discrete unpacking of the science constructs. Constructs for measuring perceptions of biotechnology as manifested in IKS were also included in order to benefit from the diversity of biotechnology knowledge, meanings and applications in the South African context, and make questionnaire items more accessible to broader sections of the South African population.

Survey methods

The survey was administered as part of the 13th annual round of the SASAS, which was conducted in 2015. The SASAS infrastructure consists of nationally representative, repeated cross-sectional surveys that have been conducted annually since 2003. Each survey round consists of a drawn sample of 3500 target respondents aged 16 years and older living in private residence and in workers' hostels. A sample of 500 Population Census enumeration areas is drawn, using probability to proportionate to size as primary sampling units, stratified by province, geographical sub-type and majority population group. Within each drawn area, seven dwelling units are randomly selected as visiting points, and finally one person is selected with equal probability from all persons that are age eligible at the visiting point using a Kish grid. In the case of the 2015 survey round, the final realised sample consisted of 2940 adult South Africans. Data are weighted to the representative of the South African population by means of benchmarking to the latest Mid-Year Population Estimates produced by Statistics South Africa.

Analytical methods

Analysis of the survey results presented here examines aggregate, national-level perceptions of biotechnology, in addition to differences in perceptions across select socio-demographic groups, including variation based on education, income, geographical location and racial group. The total margin of error for the SASAS data at the 95% level is 0.8%. This margin increases up to a maximum of 3.9% for the smallest subgroup examined in this paper. The margin of error on point estimates for different subgroups varies based on the sub-sample size. We therefore undertook one-way analysis of variance (ANOVA) with post-hoc tests to determine whether the observations and conclusions we report on were statistically valid.

Knowledge about biotechnology

Most South Africans (73%) reported having little or no knowledge about biotechnology; 27% reported being 'somewhat knowledgeable' or 'very knowledgeable' about biotechnology; and almost half of the public (46%) felt that biotechnology is 'too specialised for me to understand'. However, both bivariate and multivariate analysis (ordered logistic regression) revealed that more privileged groups (with higher living standards and higher educational attainment) reported considerably greater knowledge than less privileged groups, and were more confident in their ability to access biotechnology knowledge (for regression models see Gastrow et al.[2]). This finding holds true irrespective of whether one evaluates knowledge using subjective or objective indicators.

A review of changes in public perceptions of biotechnology between 2004 and 2015 (Table 1) shows a major increase in public awareness of biotechnology. Public familiarity with the term 'biotechnology' more than doubled during this period, from 21% of the population to 53%. Public awareness that GM foods form a part of their diet more than trebled, from 13% to 48%. We can hypothesise that these changes result from increased levels of education, increased access to information, and greater prominence of biotechnology in the public discourse during this period. It may be the case that the labelling of (some) GM foods has played a role. It is possible that the patterns of change could be partly methodologically determined, as the questions in the 2004 and 2015 SASAS surveys were not strictly identical. In 2004, a definition was firstly provided and then respondents were asked whether they had heard of the concept before, whereas in 2015 respondents were asked to report their level of familiarity with the term 'biotechnology' without a definition being provided beforehand. One could debate whether the 2004 approach of providing a definition led to a more definitive response or biased estimates of knowledge.

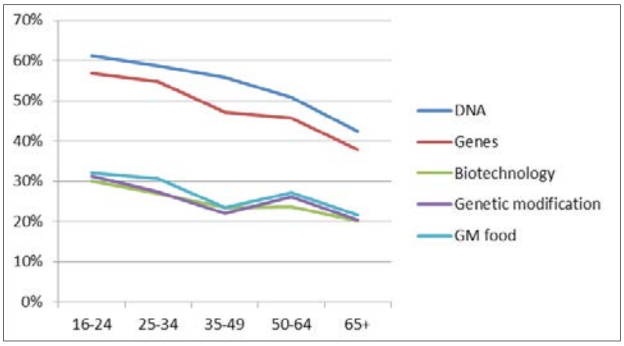
Consideration of a strong age gradient in relation to knowledge of biotechnology also suggests that as younger cohorts have come to account for larger proportions of the population, overall knowledge levels have increased – this points towards an inherent dynamism that over time articulates inter-generational changes in perceptions with overall societal perceptions. However, testing these hypotheses would require further research, including qualitative research.

Table 1: Comparison of biotechnology knowledge, 2004 and 2015 (% respondents)

	Are you familiar with the term 'biotechnology'?		Have you ever eaten GM food?	
	2004	**2015**	**2004**	**2015**
Yes	21	41	12	48
No	68	53	26	17
Don't know	11	7	63	36

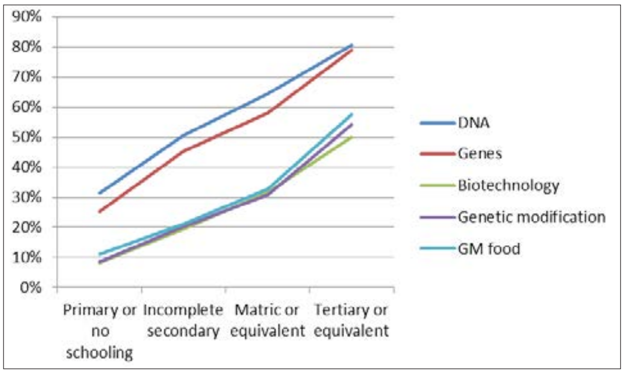
Note: Because of decimal rounding, totals may not add up to 100%.

Within the cluster of concepts that underpin the notion of biotechnology, some concepts are better understood by the public than others (Table 2). The terms 'genes' and 'DNA' are far more widely understood than 'biotechnology', 'genetic modification' or 'GM food'. In the case of DNA and genes, approximately a third expressed sufficient familiarity with the concept to be able to explain it to a friend, a figure that drops to barely a tenth for the other terms. We again find that those of a younger age and greater privilege consistently report higher levels of knowledge of all the core biotechnology concepts in the survey (Figures 1–3). Despite the clear gradient of variation in levels of knowledge of biotechnology concepts that exists based on age, educational attainment and standard of living, the knowledge gap between DNA and genes on the one hand and 'biotechnology', 'genetic modification' or 'GM food' on the other remains intact. There is little sign of convergence in knowledge between these different concepts among those with higher levels of education or standards of living. Although close to 80% of the tertiary educated feel able to explain the concepts of DNA and genes, this figure falls to barely half for the other concepts. This difference suggests that education alone is not the sole factor driving levels of biotechnology-related knowledge. Education certainly matters, and is likely to partly explain the inverse association observed between age and knowledge of biotechnology concepts.



South African Social Attitudes Survey 2015

Figure 1: Knowledge of core biotechnology concepts, by age group.



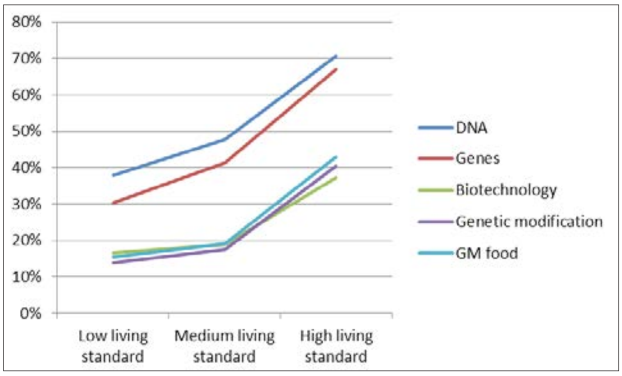
South African Social Attitudes Survey 2015

Figure 2: Knowledge of core biotechnology concepts, by education level.

Table 2: Knowledge of core biotechnology concepts (% respondents)

How familiar are you with the following terms?	Have not heard of it	Have heard of it, but know very little or nothing about it	Know enough about it to explain it to a friend	Do not know
DNA	19	45	34	3
Genes	25	43	29	4
Biotechnology	53	30	11	7
Genetic modification	53	27	13	7
Genetically modified food or GM food	51	29	14	7

Source: South African Social Attitudes Survey 2015



South African Social Attitudes Survey 2015

Figure 3: Knowledge of core biotechnology concepts, by standard of living.

Perceptions of GM food

Perceptions of food made from genetically modified crops (termed 'GM food') take the centre stage in terms of biotechnology-related media coverage and public controversy, both globally and in South Africa.[32] Internationally, debates about the ethical and environmental implications of agricultural biotechnology have had a significant impact on the sector, for example leading to the emergence of contrasting governance structures and market mechanisms in different jurisdictions.[33] In South Africa, media analysis has revealed polarised debates about health, safety and governance.[32] We examined summary results of the analysis of knowledge of GM food and attitudes towards GM food.

Knowledge of GM food

The South African public have generally low levels of knowledge and awareness of GM food. About half of the public (54%) were aware that GM crops are legally grown in South Africa. Looking at specific crops, 40% of the public were aware that GM maize is grown in South Africa, but awareness of GM cotton (4%) and GM soya (7%) was low. Similarly, in Australia, 41% of the public were aware of the country's main GM food crop (canola) compared to only 9% reporting awareness of a secondary crop (cotton).[34]

About half of the South African public (48%) were aware that their food contains GM products. Those who could identify GM maize as a legally grown crop in South Africa were substantially more likely to understand that they eat GM food, suggesting cognitive connections between understanding both the production and consumption of GM food. To determine the relative influence of different predictors on knowledge, ordered logistic regression analysis was performed. This analysis was based on a dependent variable that was an index of GM food knowledge constructed by combining a set of variables that focused on: (1) the belief that GM crops are allowed to be grown in South Africa, (2) how many of the three legally grown GM crops in South Africa (white and yellow maize, soya and cotton) respondents were able to correctly identify and (3) whether the respondent reported ever having eaten GM food. Again, the modelling revealed a positive age and social privilege effect.[2] Having previously engaged in traditional farming practices also increased the odds of being more knowledgeable about GM food – revealing a significant stratification between urban and rural areas, and an interplay between indigenous knowledge and biotechnology knowledge.

Attitudes towards GM food

As for attitudes towards biotechnology as a whole, attitudes towards GM food are highly dynamic. Since 2004 there has been a major increase in attitudes that favour the purchasing of GM food (Table 3). The proportion of the public that would purchase GM foods on the basis of health considerations increased from 59% to 77%, on cost considerations increased from 51% to 73%, and on environmental considerations from 50% to 68%. The share of adults providing 'don't know' answers to the three GM food statements (13% on average) is markedly lower than one might anticipate given that 51% indicated that they had not previously heard of GM food (Table 2). Although it is difficult to explain definitively why this might be the case, one possibility is that the questions are framed in a way that requires less cognitive effort to respond.[35]

The attitudes that underpin the general increase in awareness and acceptance of GM food between 2004 and 2015 are complex.

Table 4 summarises aggregated responses to questions related to ethics, safety, labelling, benefits and risks. As a consequence of generally low levels of knowledge, the South African public do not have strongly formed opinions about GM foods. Large proportions of the public did not engage with attitudinal questions about GM food, with 'don't know' responses averaging 29% on the items on the ethics of GM food, 26% on the items relating to the safety and labelling of GM food, and 33% on the items dealing with the benefits and risks of GM food. The main exception for which item non-response falls below the 20% threshold is in relation to the labelling of GM foods, which is an issue that the South African public are strongly in favour of.

Ethics

Public attitudes towards the ethics of GM food were polarised, with 41% agreeing and 36% disagreeing with the notion of GM foods as 'interfering in God's plan', or otherwise ethically wrong (30% and 44%, respectively, for agreeing and disagreeing). These data suggest that while on average South Africans do not reject GM food on general moral grounds, they do express some reservation on religious grounds. In comparison, the public were largely disengaged from assessing the ethics of the international corporations that play a role in the sector, with the largest share (39%) providing a 'don't know' response. This finding is conceivably a reflection of a lack of information or awareness of the behaviour of such corporations. Regression analysis revealed that level of self-rated religiosity, which was measured using a 0–10 end anchored scale where 0 represented 'not at all religious' and 10 'very religious', was not a significant predictor of these GM food ethics items.

Safety

In comparison to available data from the European Union, South Africans are considerably more positive about the health implications of GM food. While 49% of the South African public believe that 'GM foods are safe to eat', a Eurobarometer study[18] found that only 21% of Europeans share this view. South Africans also appear slightly less critical of the environmental impact of GM crops, with 45% of South Africans viewing GM crops as having a higher environmental cost than traditional farming methods, a view held by 52% of Europeans.

Benefits and risks

South Africans are also more positive about the economic consequences of GM food, with 53% believing that 'GM foods are good for the economy', compared to only 31% of Europeans.[19] Levels of engagement with the issue were lower: 31% responded 'don't know', compared to 19% in Europe. Younger South Africans were more positive than older South Africans about the economic benefits of GM food. Farmers were perceived to benefit from GM crops, but commercial farmers were seen to benefit more than subsistence farmers. The environmental impact of GM crops was commonly seen to be higher than traditional farming methods. The overall risk–benefit assessment of GM foods was positive, with 46% perceiving a net benefit, and 19% a net risk. Younger generations and those with higher levels of education were more likely to regard GM foods as a benefit to society.

Perceptions of medical biotechnology

The constructs chosen to test knowledge about medical biotechnology were questions related to genetic testing to treat inherited diseases, gene therapy to treat inherited diseases, and the production of medicine using GM organisms (Table 5). The aggregated results for these are similar, with approximately half of the sample indicating no knowledge, a quarter having heard of it, but not having much more knowledge, and 6–7% having substantial knowledge. Bivariate and ordered logistic regression analyses revealed that greater knowledge about medical applications of biotechnology is associated with lower age and higher levels of privilege. Educational attainment appears to exert the strongest positive association with knowledge of medical biotechnology.

Table 3: Summary of key changes in responses to GM maize (% respondents), 2004–2015

	I would buy GM maize if it were healthier		I would buy GM maize if it cost less than ordinary maize		I would buy GM maize if it were grown in a less damaging way to the environment	
	2004	2015	2004	2015	2004	2015
Agree	67	77	53	73	56	68
Disagree	15	11	27	15	24	16
Don't know	18	12	20	12	20	16

Table 4: Summary of attitudes towards GM food (% respondents)

	Agree	Disagree	Don't know
Ethics of GM food			
The genetic modification of food is interfering in God's plan	41	36	23
The genetic modification of food is wrong	30	44	26
The international corporations that make GM foods act in an ethical manner	38	24	39
Safety and labelling			
GM foods are safe to eat	49	21	30
The long-term health effects of eating GM foods are unknown	52	18	31
Products containing GM foods should be labelled	75	7	18
Benefits and risks			
GM foods are good for the economy	53	16	31
GM foods benefit large-scale commercial farmers	56	13	31
GM foods benefit small-scale subsistence farmers	43	23	34
GM foods provide more secure access to food for my family	47	22	31
The environmental cost of farming GM crops is higher than that of traditional farming methods	45	17	38
Overall, GM foods provide more benefits than risks for society	46	19	36

Source: South African Social Attitudes Survey 2015

Table 5: Perceptions of medical applications of biotechnology (% respondents)

Biotechnology is also used in medicine. How familiar are you with the following medical uses of biotechnology?	Have not heard of it	Have heard of it, but know very little or nothing about it	Know enough about it to explain it to a friend	Don't know
Genetic testing to detect inherited diseases	49	28	7	16
Gene therapy to treat genetic conditions	52	25	7	16
Production of medicines using GM organisms	52	23	7	18
		Agree	Disagree	Don't know
Using GM organisms in the production of medicine is intervening in God's work		39	33	28
Using GM organisms in the production of medicine is wrong		26	43	31
The international corporations that use biotechnology to make new medicines act in an ethical manner		38	22	41

Source: South African Social Attitudes Survey 2015

In the context of a high level of 'don't know' responses, the public were polarised in their views about medical biotechnology 'intervening in God's work' (39% agreed and 33% disagreed) and in their views about whether it is 'ethically wrong' (26% agreed and 43% disagreed). The public demonstrated greater cognitive difficultly in responding to the issue of corporate ethics in medical biotechnology, with 41% answering 'don't know' to the related question. This response is conceivably a consequence of constrained knowledge and information with which to make an assessment. Only 22% of the public were concerned with the ethics of these corporations. While this concern is commonly shared across age groups, there was a moderate positive association with education and living standard levels. While 19% of those with primary or no formal schooling expressed such concern, this progressively rose to a high of 31% among those with a tertiary qualification. Similarly, only 14% of those with a low living standard expressed concern about corporate ethics in the field of medical biotechnology, rising to 22–23% for those with medium and high living standards.

Governance and regulation

Understanding preferences regarding the governance and regulation of biotechnology is critical for the policy formulation process, particularly with regard to communication and public engagement related to biotechnology. A total of 44% of South Africans felt that GM foods were effectively regulated by the government, although 38% responded 'don't know' to the question. The South African public felt that the governance of biotechnology should be most strongly influenced by commercial farmers, university scientists, and environmental groups/NGOs (Table 6). The least favoured institutions for this purpose are seen to be international corporations, the media and religious organisations. However, the public appear to favour a mode of 'consensus governance', in which all the main stakeholders play a role.

Indigenous knowledge systems and biotechnology

South Africans have commonly used biotechnology in the context of indigenous knowledge systems and practices. As indicated in Table 7, 47% reported using traditional medicines with varying frequencies, 44% reported using biological processes to prepare food, and 38% reported using traditional farming practices. South Africans have a greater experience of biotechnology-related traditional practices and knowledge bases than they do of biotechnology in the narrower sense. High levels of awareness and usage in daily life position IKS-based biotechnology as a potential platform for engagement with the majority of the South African population. Groups with low incomes and low levels of education may find it difficult to engage with concepts of mainstream biotechnology, but harbour rich traditions of knowledge and the practice of IKS that may be successfully leveraged to build greater awareness of biotechnology in the more modern sense.

Sources of information

On aggregate, radio and television are the most preferred channels through which people would want to receive information about biotechnology, particularly for those in rural areas and with lower incomes (Table 8). Younger age cohorts are more likely to prefer a mix of all sources of information, except for radio. Younger generations are also far more likely than older generations to favour the Internet to obtain information. Those with higher levels of education and living standards are more inclined to opt for the Internet and print media, and less likely to report a preference for the radio. Those living on rural farms are significantly less likely to select any of the media channels as a source for obtaining information about biotechnology relative to those residing in other geographical locations. This array of preferences highlights the communications challenge that confronts public engagement efforts, and points to the need for a diversified and targeted approach.

Table 6: Summary of responses to governance and the institutions of biotechnology (% respondents)

The development and use of biotechnology is governed by various laws and policies. I am going to list a number of groups in society. How much influence do you think they should have in making these laws and policies?					
	A great deal of influence	**A fair amount**	**A little influence**	**None at all**	**Don't know**
Commercial farmers	45	23	7	7	18
University scientists	41	26	8	8	18
Environmental groups/NGOs	39	28	5	9	18
South African businesses	38	27	9	9	18
Small scale/subsistence farmers	38	26	10	9	18
South African government	39	24	10	10	18
International corporations	29	30	12	10	20
The general public	27	29	13	12	19
Media	23	30	14	15	18
Religious organisations	20	26	17	19	18

Source: South African Social Attitudes Survey 2015

Table 7: Summary of responses to biotechnology and indigenous knowledge systems (% respondents)

How often have you engaged in the following traditional practices?	Often	Sometimes	A few times	Rarely	Never	Don't know
Using traditional medicines (such as wild herbs)	12	24	11	11	37	5
Making food that uses biological processes (such as brewing traditional beer or processing sour milk)	11	21	12	10	42	5
Traditional farming practices (such as growing crops using the traditional knowledge of your community)	12	17	9	9	47	6

Source: South African Social Attitudes Survey 2015

Table 8: Sources of information on biotechnology (% respondents)

If you wanted to learn more about biotechnology, how likely would you be to get your information from the following sources?	Very likely	Somewhat likely	Not very likely	Not likely at all	Don't know
TV	51	21	12	12	4
Radio	35	25	17	18	5
Print media (books, newspapers and magazines)	27	29	19	20	5
Internet	34	20	12	29	5
School or college	26	20	15	34	5
Science centre	29	16	14	36	6
Friends or family	23	23	19	30	5

Source: South African Social Attitudes Survey 2015

The risks and benefits of biotechnology

Only about half of the South African public (53%) were able to conclusively evaluate biotechnology as 'more of a benefit' or 'more of a risk' in general, with a marginal tendency among this group towards a benefit perspective (30% vs 23%). The other half (47%) were fairly evenly split between those registering neutrality or indifference (25%) and those offering a 'don't know' response (22%). This pattern shows that on aggregate the South African public is divided on this matter, with virtually equivalent shares opting for each of the four categories (beneficial, risky, indifferent, uncertain). There are nonetheless distinct variations relative to this average perspective when one analyses the results by various socio-demographic attributes.

White and Indian South Africans were more likely to see biotechnology as an overall risk to society compared to black and coloured South Africans. This finding is largely because lower levels of uncertainly and neutrality/indifference have been replaced by a greater awareness of risk. In the case of Indian respondents, a sense of risk outweighs declaring it as more beneficial (37% vs 24%), but among white respondents lower indifference and uncertainty levels have resulted in a rise in shares reporting risky and beneficial evaluations, to the extent that both are equally mentioned (37% vs 36%). Higher living standards were associated with an decreased likelihood of viewing biotechnology as beneficial or of being uncertain, a rise in neutrality or indifference, and virtually unchanged levels of perceived risk.

Increased educational attainment was associated with lower levels of item non-response, falling from 31% for those with primary or no schooling to 10% among those with a tertiary qualification, as well as fairly indistinguishable levels of neutrality/indifference (ranging between 23–26%). For those with an incomplete secondary education or matric qualification, the decreased level of uncertainty translates into higher shares reporting biotechnology as more of a benefit, so that the percentage point difference for these adults ranges between 9 and 11 percentage points higher in general than the share mentioning it as more of a risk. However, for those with tertiary education, the further decrease in uncertainty is accompanied by both a rise in the share mentioning it as a benefit and a risk, to the extent that the two are virtually level (33% benefit; 31% risk). This finding suggests that providing more education will not necessarily equate into an increased likelihood of viewing biotechnology as beneficial. Instead, with more education, there appears to be a greater recognition of the benefits as well as the risks. This is a noteworthy finding, because education is ultimately about producing critically engaged citizens who would be able to appreciate both the inherent promise and risks associated with the emergence and adoption of new technologies.

Reflections on biotechnology, public engagement and policy

Public engagement by the biotechnology sector in South Africa takes place in the context of escalating public familiarity with biotechnology and its related products: familiarity with the concept of biotechnology more than doubled between 2004 and 2015, and awareness of GM foods more than tripled. However, these changes have occurred from a low base, and knowledge about biotechnology is still constrained in South Africa: 73% of the public reported having limited or no knowledge about biotechnology.

This scenario signals an opportunity for engagement between the institutions of biotechnology and the broader public, identifying a space for strategic interventions that would leverage this growing awareness in a constructive manner, in the absence of strongly entrenched or preconceived perceptions. In comparison with Europe, where public knowledge is more developed, and public attitudes more defined, South Africans are more positive about the health implications of GM food, less critical about the environmental impact of GM food, and more positive about the economic consequences of GM food.

Inter-generational dynamics play a central role in these perceptual changes. Knowledge about biotechnology is positively correlated with younger age. Younger generations were more positive about a variety of biotechnology-related issues, including the economic benefits of GM food and the overall risk/benefit assessment of biotechnology. Understanding the causes of these correlations presents an objective for future research. Whatever the causes, the implication is that the future South African public is likely to be more knowledgeable about biotechnology, and have more sharply defined attitudes towards biotechnology.

Privilege, in the form of educational attainment and living standard, is also correlated with greater knowledge and more defined attitudinal positions. This highlights the importance of taking distinct approaches towards engagement with privileged and marginalised groups, which would need to be based on distinct sets of knowledge constructs, and which would encounter different sets of attitudes. For marginalised groups, particularly low-income groups in rural areas and traditional authority areas, engaging on the basis of IKS may prove to be the most effective platform for effective communication.

There are a variety of other dimensions along which engagement strategies and practices could be structured to better respond to public perceptions. The concepts of DNA and genes are reportedly far better understood than those of genetic modification or GM food, and would therefore present a better starting point for engagement and knowledge transfer. Preferences for sources of information differ widely among demographic groups, and communication strategies should be constructed on this basis: for the young and privileged the Internet is central; for the marginalised and rural, radio is central. When it comes to the governance of biotechnology, the public place their highest trust in commercial farmers, university scientists and environmental groups – suggesting that these social actors should have a role to play in public engagement policy and practice.

Together, these considerations point towards new strategic imperatives for public engagement in the South African biotechnology sector. Public policy, and broader sectoral engagement strategies, need to take into account: (1) the highly dynamic nature of public perceptions, (2) the diversity of views held by different demographic groups and (3) the diversity of sources of information utilised and preferred by different demographic groups. These considerations would support a strategically targeted engagement approach that would leverage the rapidly growing public awareness of biotechnology in a constructive manner.

Acknowledgements

We thank the 2940 South Africans who generously gave of their time to participate in the South African Social Attitudes Survey; Prof. Jennifer Thomson for her invaluable technical advice and expertise; and the South African Agency for Science and Technology Advancement (SAASTA) for their support, guidance, advice and input throughout the study.

Authors' contributions

M.G. was responsible for the conceptualisation, methodology and data analysis; for writing the initial and revised drafts; for providing project leadership and project management; and for acquiring the funding. B.R. was responsible for the conceptualisation, methodology, data collection, sample analysis and data analysis and validation; for critical reviewing of the writing; and for providing project management. V.R. was responsible for the conceptualisation and methodology; and for critical reviewing of the writing. S.I. was responsible for the conceptualisation and methodology.

References

1. Reddy V, Gastrow M, Juan A, Roberts B. Public attitudes to science in South Africa. S Afr J Sci. 2013;109(1–2), Art. #1200, 8 pages. https://doi.org/10.1590/sajs.2013/1200
2. Gastrow M, Roberts B, Reddy V, Ismail S. Public perceptions of biotechnology in South Africa. Report for the Public Understanding of Biotechnology Programme. Pretoria: South African Agency for Science and Technology Advancement; 2016. Available from: http://www.pub.ac.za/wp-content/uploads/2016/10/Public-Perceptions-to-Biotechnology.pdf
3. Convention on Biological Diversity [homepage on the Internet]. No date [cited 2017 Oct 16]. Available from: http://www.cbd.int/
4. Bauer MW. Public perception and mass media in the biotechnology controversy. Int J Public Opin Res. 2005;17(1):5–22. https://doi.org/10.1093/ijpor/edh054
5. Gaskell G, Allansdottir A, Allum N, Corchero C, Fischler C, Hampel J, et al. Europeans and biotechnology in 2005: Patterns and trends. Final report on Eurobarometer 64.3 [document on the Internet]. c2006 [cited 2017 Oct 16]. Available from: http://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_244b_en.pdf
6. Macer DR, Azariah J, Srinives P. Attitudes to biotechnology in Asia. Int J Biotechnol. 2000;2(4):313–332. https://doi.org/10.1504/IJBT.2000.000142
7. Aernie P. Attitudes in the public debates on agricultural biotechnology in developing countries. Afr Technol Dev Forum J. 2005;2(1):8–10.
8. Miller JD. Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. Public Underst Sci. 2004;13(3):273–294. https://doi.org/10.1177/0963662504044908
9. Bauer MW, Shukla R, Allum N. The culture of science: How the public relates to science across the globe: New York: Routledge; 2012.
10. Miller J. The measurement of civic scientific literacy. Public Underst Sci. 1998;7:203–223. https://doi.org/10.1088/0963-6625/7/3/001
11. Durant J. Participatory technology assessment and the democratic model of the public understanding of science. Sci Public Policy. 1999;26(5):313–319. https://doi.org/10.3152/147154399781782329
12. Evans G, Durant J. The relationship between knowledge and attitudes in the public understanding of science in Britain. Public Underst Sci. 1995;4(1):57–74. https://doi.org/10.1088/0963-6625/4/1/004
13. Allum N, Sturgis P, Tabourazi D, Brunton-Smith I. Science knowledge and attitudes across cultures: A meta-analysis. Public Underst Sci. 2008;17(1):35–54. https://doi.org/10.1177/0963662506070159
14. Bauer MW, Allum N, Miller S. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. Public Underst Sci. 2007;16(1):79–95. https://doi.org/10.1177/0963662506071287
15. Sturgis P, Allum N. Science in society: Re-evaluating the deficit model of public attitudes. Public Underst Sci. 2004;13:55–74. https://doi.org/10.1177/0963662504042690
16. Bauer M, Petkova K, Boyadjieva P. Public knowledge of and attitudes to science: Alternative measures that may end the "science war". Sci Technol Human Values. 2000;25(1):30–51. https://doi.org/10.1177/016224390002500102
17. Gregory J, Lock S. Evolution of "public understanding of science": Public engagement as a tool of science policy in the UK. Sociol Compass. 2008;2(4):1252–1265. https://doi.org/10.1111/j.1751-9020.2008.00137.x
18. INRA (Europe). The Europeans and biotechnology: Eurobarometer 52.1. Luxembourg: The European Commission; 2000.
19. European Commission, European Parliament. Eurobarometer 73.1: The European Parliament, biotechnology, and science and technology, January-February 2010. Cologne/Ann Arbor, MI: GESIS/Inter-university Consortium for Political and Social Research; 2013. https://doi.org/10.3886/ICPSR31483
20. INRA (Europe). The Europeans and modern biotechnology: European opinions on modern biotechnology. Eurobarometer 46.1. Luxembourg: The European Commission; 1997.
21. Gaskell G, Allum N, Stares S. Europeans and biotechnology in 2002: Eurobarometer 58.0. Brussels: European Commission; 2003.
22. Shukla R. India science report. Delhi: National Council of Applied Economic Research; 2005.
23. Huang J, Qiu H, Bai J, Pray C. Awareness, acceptance of and willingness to buy genetically modified foods in urban China. Appetite. 2006;46(2):144–151. https://doi.org/10.1016/j.appet.2005.11.005
24. Kimenju SC, De Groote H, Karugia J, Mbogoh S, Poland D. Consumer awareness and attitudes toward GM foods in Kenya. Afr J Biotechnol. 2005;4(10):1066–1075.
25. Krishna VV, Qaim M. Consumer attitudes toward GM food and pesticide residues in India. Rev Agric Econ. 2008;30(2):233–251. https://doi.org/10.1111/j.1467-9353.2008.00402.x
26. Quaye W, Yawson I, Yawson RM, Williams IE. Acceptance of biotechnology and social-cultural implications in Ghana. Afr J Biotechnol. 2009;8(9):1997–2003.
27. Mwale PN. Societal deliberation on genetically modified maize in southern Africa: The debateness and publicness of the Zambian national consultation on genetically modified maize food aid in 2002. Public Underst Sci. 2006;15(1):89–102. https://doi.org/10.1177/0963662506058386
28. Mwale PN. The babelisation of debate on GM maize via the media in southern Africa in 2002. Social Dyn. 2010;36(1):112–121. https://doi.org/10.1080/02533950903561346
29. Rule S, Langa Z. HSRC client survey 2004 – Report for the Public Understanding of Biotechnology Programme of the South African Agency for Science and Technology Advancement. Unpublished report 2005.
30. South African Department of Arts, Culture, Science and Technology (DACST). A national biotechnology strategy for South Africa. Pretoria: DACST; 2001. Available from: http://www.dst.gov.za/images/pdfs/dst_biotechnology_strategy.PDF
31. South African Department of Science and Technology (DST). The bio-economy strategy. Pretoria: DST; 2013. Available from: https://www.gov.za/sites/www.gov.za/files/Bioeconomy%20Strategy_a.pdf

32. Gastrow M. The public understanding of biotechnology in the media. A report for the National Advisory Council on Innovation and the National Biotechnology Advisory Committee. Unpublished report 2010.

33. Gaskell G, Bauer MW, Durant J, Allum NC. Worlds apart? The reception of genetically modified foods in Europe and the US. Science. 1999;285(5426):384–387. https://doi.org/10.1126/science.285.5426.384

34. Ipsos Social Research Institute. Community attitudes towards emerging technology issues – Biotechnology. Report of findings prepared for the Department of Industry, Innovation, Science, Research and Tertiary Education. Unpublished report 2013.

35. Shoemaker PJ, Eichholz M, Skewes EA. Item nonresponse: Distinguishing between don't know and refuse. Int J Public Opin Res. 2002;14:193–201. https://doi.org/10.1093/ijpor/14.2.193

Palaeoecology of giraffe tracks in Late Pleistocene aeolianites on the Cape south coast

AUTHORS:
Charles Helm[1,2]
Hayley Cawthra[2,3]
Richard Cowling[2]
Jan De Vynck[2]
Curtis Marean[2,4]
Richard McCrea[1]
Renee Rust[5]

AFFILIATIONS:
[1]Peace Region Palaeontology Research Centre, Tumbler Ridge, British Columbia, Canada
[2]Centre for Coastal Palaeoscience, Nelson Mandela University, Port Elizabeth, South Africa
[3]Geophysics Competency, Council for Geoscience, Bellville, South Africa
[4]Institute of Human Origins, School of Human Evolution and Social Change, Arizona State University, Tempe, Arizona, USA
[5]Evolutionary Studies Institute, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

CORRESPONDENCE TO:
Charles Helm

EMAIL:
helm.c.w@gmail.com

DATES:
Received: 11 Aug. 2017
Revised: 30 Sep. 2017
Accepted: 18 Oct. 2017

KEYWORDS:
fossil tracks; Still Bay; savanna; South Africa

HOW TO CITE:
Helm C, Cawthra H, Cowling R, De Vynck J, Marean C, McCrea R, et al. Palaeoecology of giraffe tracks in Late Pleistocene aeolianites on the Cape south coast. S Afr J Sci. 2018;114(1/2), Art. #2017-0266, 8 pages. http://dx.doi.org/10.17159/sajs.2018/20170266

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
None

Until now there have been no reliable historical or skeletal fossil records for the giraffe (*Giraffa camelopardalis*) south of the Orange River or northern Namaqualand. The recent discovery of fossil giraffe tracks in coastal aeolianites east of Still Bay, South Africa, significantly increases the geographical range for this species, and has implications for Late Pleistocene climate and vegetation in the southern Cape. Giraffe populations have specialised needs, and require a savanna ecosystem. Marine geophysical and geological evidence suggests that the broad, currently submerged floodplains of the Gouritz and Breede Rivers likely supported a productive savanna of *Vachellia karroo* during Pleistocene glacial conditions, which would have provided a suitable habitat for this species. We show evidence for the hypothesis that the opening of the submerged shelf during glacial periods acted as a pathway for mammals to migrate along the southern coastal plain.

Significance:

- The identification of fossil giraffe tracks on the Cape south coast, far from the area in which giraffe have previously been known to occur, is unexpected; conclusions about prehistoric conditions and vegetation can be drawn from this discovery.

Introduction

Pleistocene aeolianites, the lithified remains of ancient dune systems, extend intermittently along much of the South African coastline, where the conditions were favourable for the deposition and subsequent preservation of these features. They are sensitive barometers of fluctuations in palaeoenvironments, as archived in their orientation, geometry, palaeontology and archaeological content.[1] Exposed bedding planes characterise these sequences, and may contain ichnofossils.[2,3] Aeolianites outcrop along much of the Cape south coast. In this area, a broad continental shelf is currently submerged but various authors have postulated the role of this shelf and its link to submerged landscapes[4-6] – the opening of a landscape over which mammals could migrate without the impact of the Cape Fold Belt[7], supporting populations that were hunted by ancient people and carnivores and fossilised in caves and rock shelters[8,9].

A ground survey by the lead author (C.H.) between 2007 and 2016 of a 275-km stretch of coastline along the Cape south coast, from Witsand in the west to Robberg in the east (Figure 1), identified over a hundred Late Pleistocene trackway sites. These sites provide a rich source of palaeoecological information independent of the fossil remains that traditionally form the main data set for palaeoecological reconstruction. Fossil remains in caves and rock shelters are normally the remains of hunted prey and thus represent a biased sub-set of the animals on the landscape. In contrast, trackways have no such predation selection but rather are a direct reflection of the animals' locomotion and their frequency of walking across ancient land surfaces, although there is often a preservational bias towards larger, heavier trackmakers, which tend to leave deeper tracks. The bones of larger mammals are less likely to be transported to caves and rock shelters, so body fossil sites and track sites provide complementary sources of palaeoecological information. While many such track sites in the southern Cape occur in situ, others have been eroded out and lie as loose blocks at the base of cliffs. Some tracks can be attributed to extinct species or subspecies, while others indicate range differences compared with historical records or the skeletal fossil record. The age of the aeolianites can be obtained with optically stimulated luminescence (OSL) dating, which now allows the trackways to be much more accurately dated and placed on a geological timescale.

The giraffe track site described here occurs east of Still Bay, within a rare zone of concentration of fossil track sites. Some 120 m to the east of the site there is a significant accumulation of elephant tracks, which beyond this point remain evident in profile and as casts in a 300 m laterally persistent, low-angled, cross-laminated facies. Roberts et al.[2] provided an analysis of these elephant and associated tracks, including geochronological control by the application of OSL and amino-acid racemisation dating, confirming their Late Pleistocene age. Some 300 m to the west of the giraffe track site lies a large displaced block, which contains probable tracks of four species of the Late Pleistocene megafauna. Numerous other fossil tracks have been identified between these sites.

Geological context

The ~800-km Cape south coast represents a tract of relatively low-relief coastal plain bordered at its landward geographic limit by the Cape Fold Belt and at the seaward margin by the Indian Ocean. The basement geology in the area investigated consists of Ordovician to Silurian quartzites of the Table Mountain Group and Devonian age Bokkeveld Group shales with interbedded sandstone packages.[10]

The south coast offshore area is distinguished by its wide, planed continental shelf forming the Agulhas Bank (~270 km wide south of Cape Agulhas) with a shelf break shoaling from a depth of -200 m off Cape Agulhas to -140 m south of Port Elizabeth.[11] In general, the south coast is characterised by a wide, flat outer shelf, a middle shelf rise at a water depth of about 60–80 m, a relatively flat inner shelf and a narrow (~2–14 km), sediment-free rocky nearshore zone.[12] A series of bathymetric nick points and erosional terraces across the shelf at 105–100 m, 80–75 m, 55–50 m and ~40 m water depths are evidence of previous sea level stillstands.[6,11]

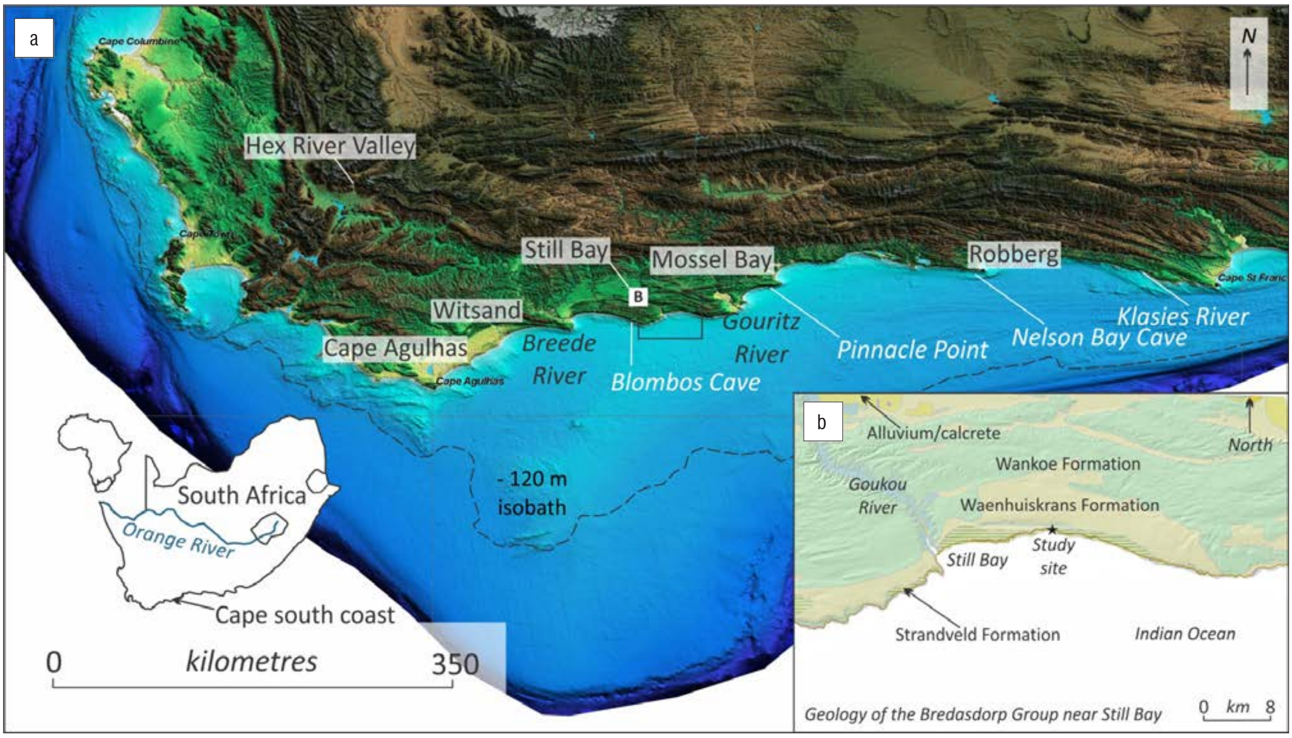


Figure 1: (a) Locality of the study area in the context of the south coast of South Africa. The continental shelf which borders this coastline reaches the broadest extent in South Africa, and the 120-m isobath lies up to 100 km offshore. The relatively shallow and low-gradient Agulhas Bank sweeps from Cape Agulhas in the southwest to Robberg in the east. (b) The dominant geological units at the study site, which are formations of the Bredasdorp Group and were deposited in the Neogene and Pleistocene.

The rapid and globally extensive changes of Quaternary climates resulted in glacio-eustatic sea-level oscillations with maximum regressions exposing the entire Agulhas Bank. The Holocene sediment wedge is a quasi-continuous unconsolidated sediment feature stretching approximately 1500 km from the east to the south coast along the inner to mid-shelf.[11] The major source of terrigenous sediment supply is by fluvial discharge from major rivers, which would have been substantial contributors to the sediments blanketing this ancient plain.

The Late Pleistocene coastal trackways, including the giraffe track site, occur in the Waenhuiskrans Formation of the Bredasdorp Group.[13] Numerous subsequent geochronological investigations have been performed in rocks of the Waenhuiskrans Formation through OSL, thermally transferred OSL and amino-acid racemisation dating.[2,14-16] The great majority of these are from MIS (Marine Isotope Stage) 6 to MIS 5b, with limited MIS 11 deposits dated at ~400 ka.[17] The dating studies performed at the elephant track sites and palaeosols east of the giraffe site yielded an age range from MIS 6 to MIS 5b (140±8.3 ka to 91±4.6 ka).[2]

Track preservation may have been promoted by the favourable substrate constituted by moist sand, swift burial as a result of high sedimentation rates, and the high bioclastic carbonate content of coastal dunes and inter-dune areas.[18] In the region of the giraffe track site, aeolianite rocks form cliffs up to 50 m in height along a rugged 6 km stretch of coastline. Storm surges and high spring tides cause cliff collapse, which results in a high rate of removal of exposed tracks, with the likelihood of new trackways being exposed.

Methods

Nine visits were conducted to the coastline east of Still Bay by the first author (C.H.) between 2007 and 2011. A further visit was conducted in 2016 in order to assess the fate of the main elephant site first described by Roberts et al.[2] During this visit, the giraffe track site was identified. Global Positioning System (GPS) readings were obtained for the track site using a handheld GPS device. Measurements and photographs were taken of the track-bearing surface and the better-preserved tracks. Photogrammetry was performed using a Canon PowerShot D30 camera. Point clouds and digital terrain models were compiled using Agisoft Photoscan Professional (v.1.0.4) and colour topographic profiles were created with CloudCompare (v.2.6.3.beta).

Geological outcrops were investigated in the field by means of correlation to known and documented deposits for which stratigraphic links could be demonstrated. At the site described here, standard field techniques were applied in understanding the context of the ichonofossils. Vertical logs were compiled from the coastal cliffs, the thicknesses of beds and foresets were measured, dip and strike readings were taken on strata to determine palaeowind direction, and geological samples were obtained for thin sections and petrography (Figure 2).

Results

The giraffe track site was not noted during any of the visits between 2007 and 2011, but was readily identified during the 2016 visit. Locality information for this site is reposited at the African Centre for Coastal Palaeoscience. The exposed ichnofossil surface is nestled between a prominent cliff to the north and the Indian Ocean to the south, on a wave-cut platform (Figure 3). The track-bearing surface cannot be extended through excavation.

The tracks are aligned in an approximate north-south, downslope direction on an in-situ surface that measures 3.9 m from north to south and 7.9 m from east to west. They are located in the basal geological unit of the sequence of deposits on the coastal cliffs, which are dominated by calcarenite-composition aeolianite. Variable cementation of the aeolianites has resulted in positive weathering of select surfaces and the layer containing the giraffe ichnofossils is competent. Beds are shallowly dipping (10–15°) and were laid down by southwesterly winds, likely the prevailing conditions at the time. Based on correlations to the reported stratigraphy[2], we suggest that these deposits date to MIS 5e as the published ages[2] for this unit obtained less than 1 km to the east are 126±7.1 ka and 121±6.5 ka. Dating studies above and below the giraffe track horizon would allow this site to be placed with greater certainty within the southern African Pleistocene track record.

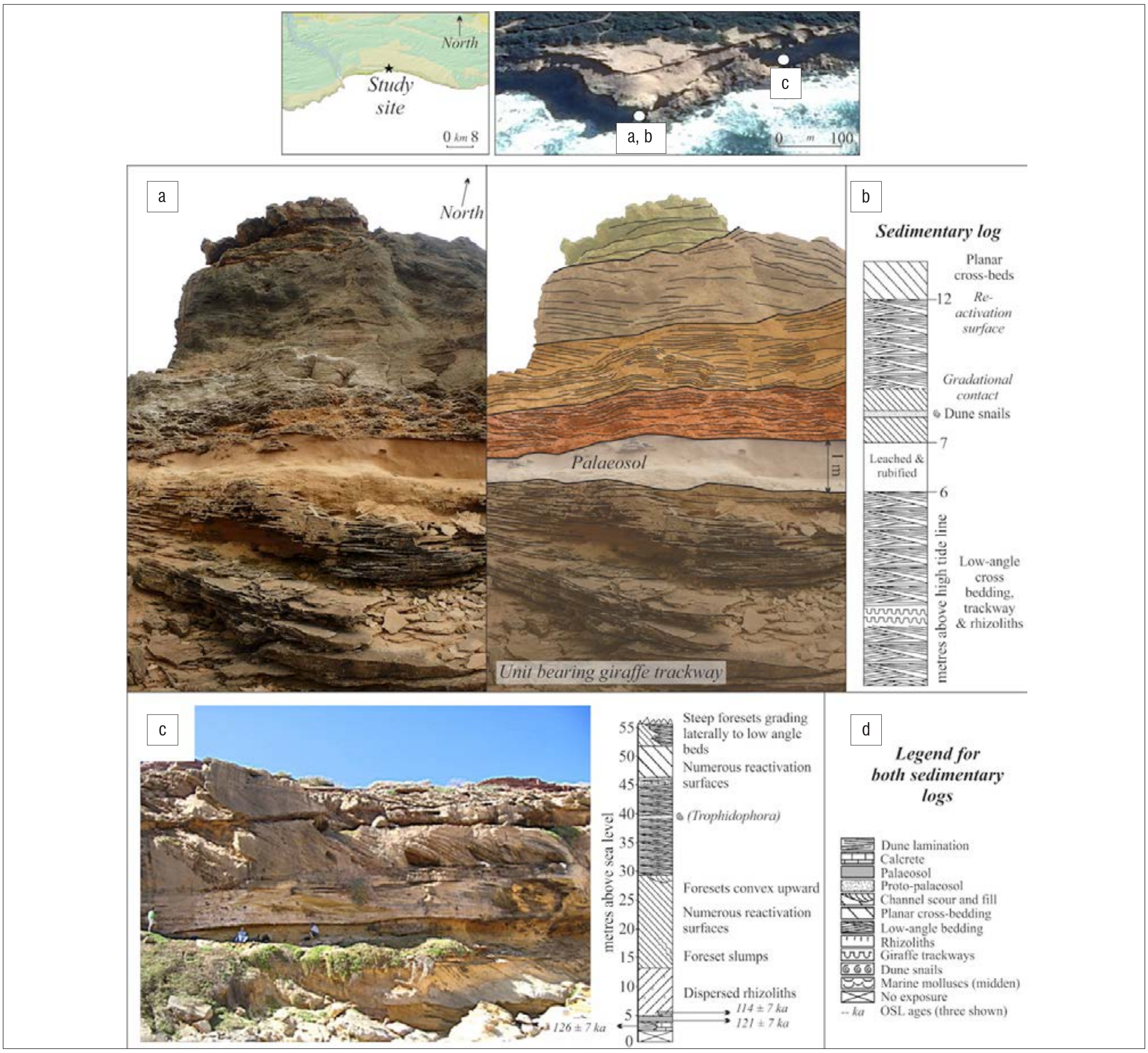


Figure 2: A comparison of the geological section investigated for this work and the known and dated stratigraphy from the region. (a, b) Annotated photograph and logged section for this work. (c) Sedimentary log and photograph of context from Roberts et al.[2] (d) Legend for the symbols and structures shown on both sedimentary logs.

Figure 3: Giraffe tracks on rock surface perched above the Indian Ocean.

There is considerable encrustation and boring of the surface with a modern gastropod species, *Nodilittorina africana knysnaensis,* which inhabits the highest intertidal zone, the littorina.[19] The littorina is partially submerged during high tides and is impacted by ocean wave action. The tracks are subject to degradation both by wave action and the lithophagic effects of the gastropods in establishing their domicile burrows (Domichnia) on the hardgrounds supplied by the consolidated Pleistocene aeolianites.

A total of 12 tracks are currently visible; the best preserved tracks are found at the southern end of the site, where the largest and the smallest tracks occur (Figures 4–6 and Table 1). Although individual trackways are probably present, they cannot be identified with certainty, and pace length and stride length cannot be confidently determined. Two tracks display partial over-printing. Minimal displacement rims are evident.

Identity of the trackmaker

The tracks appear morphologically consistent with those of the giraffe (Artiodactyla, Giraffidae, *Giraffa camelopardalis*). Other than giraffe, there are no extant mammals in southern Africa that leave tracks with these dimensions.[20,21] Many of the coastal Late Pleistocene trackways that have been identified were made by bovids (Bovidae). In most cases these even-toed ungulate tracks cannot be identified to species level, and the terms ‘large bovid’, ‘medium bovid’ and ‘small bovid’ have to suffice. Exceptions include trackmakers with specialised hoof structure, e.g. the klipspringer (*Oreotragus oreotragus*) or adult tracks with distinctive size associated with differences in shape, such as the buffalo species *Syncerus caffer* and *Syncerus antiquus.* However, in comparing adult tracks of extant Giraffidae and Bovidae, the distinction is simpler, as giraffe tracks are uniquely large and long, relatively narrow compared with the largest bovids, and with a distinctive shape to the interdigital sulcus in well-preserved tracks. The better-preserved tracks at this site exhibit these characteristics. The presence of smaller tracks with similar morphology suggests that a family group may have made the tracks.

Sivatheres (short-necked giraffe) need to be excluded as potential trackmakers. We contend that sivatheres are unlikely on two grounds. Firstly, while the extinction date for *Sivatherium maurusium*, the African representative of the giant short-necked giraffes, cannot be determined with precision[22], the most recent documented date of its occurrence in the western or southern Cape is 400 ka at Elandsfontein[23,24]. Possible Late Pleistocene sivathere teeth were recovered at Florisbad (north of Bloemfontein) in 1926, but have been lost.[25]

Secondly, while globally there appear to be no records of sivathere trackways, the massive sivatheres had very robust limb bones, along with substantially longer ossicones than extant giraffe. These factors, considered in the context of Lockley’s observation that ‘hooves follow horns’[26], and Harris’ comparative measurements of sivathere and giraffe[22], suggest that sivathere tracks would not only be larger, but would also be relatively wider than the tracks of *G. camelopardalis*. The fact that the tracks east of Still Bay appear morphologically identical to those of *G. camelopardalis* supports the giraffe as the trackmaker.

Amongst the known Pleistocene megafauna in the southern Cape, the giant hartebeest (*Megalotragus*) merits consideration as a trackmaker. Although significantly larger than the extant red hartebeest (*Alcelaphus buselaphus*) and other alcelaphines, and although fossil tracks of this species have not been documented, the track morphology of this species would likely resemble that of other alcelaphines, and a track length of over 20 cm appears implausible (the track length of the red hartebeest has been recorded as 8.5–9 cm by Liebenberg[20] and 8–10 cm by Stuart and Stuart[21]). The giant hartebeest is documented on the south coast in MIS 2 deposits at Nelson Bay Cave and MIS 5 and MIS 4 deposits at Klasies River.[27]

The final possibility is that the trackmaker was a hitherto undescribed member of the Pleistocene megafauna, with tracks that resemble those of the modern giraffe. While such a possibility cannot be completely excluded, it appears to be remote.

Figure 4: Detail of four giraffe tracks. The best preserved adult track is left of centre, and the best preserved purported juvenile track appears below it, above the top right corner of the 10-cm scale bar.

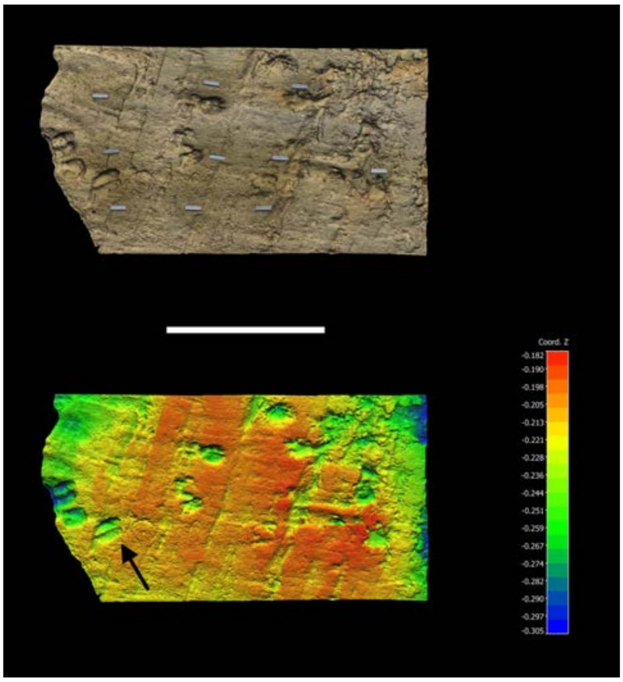


Figure 5: (a) Image capture of a 3D photogrammetry model of the giraffe track site. (b) Photogrammetry colour mesh of the giraffe track site. The arrow indicates the track featured in Figure 6. The 3D model was generated with Agisoft Photoscan Professional (v. 1.0.4) using 592 images from a Canon PowerShot D30 (focal length 5 mm; resolution 4000 x 3000; pixel size 1.5494 μm x 1.5494 μm). Photos were taken an average 0.27 m from the surface. The surface model error is 0.142808 pix. The final images were rendered using CloudCompare (v.2.6.3.beta). White horizontal scale bar (centre) is 1 m. Vertical scale is in metres.

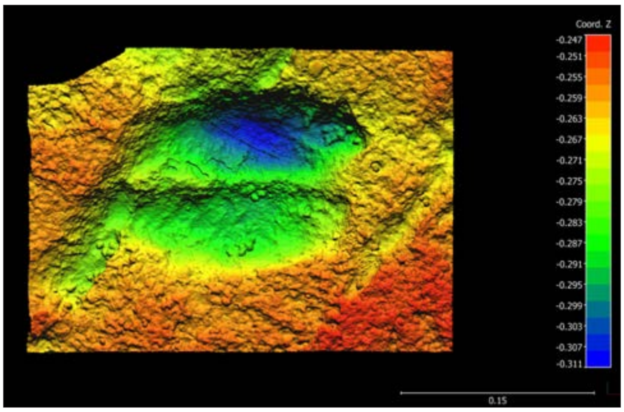


Figure 6: Tight view of a single giraffe track with same photogrammetry metrics as Figure 5. Vertical and horizontal scales are in metres.

Table 1: Selected track dimensions

Track description	Maximum length (cm)	Maximum width (cm)	Maximum depth (cm)
Adult (in Figure 6)	20.5	16.5	4.3
Purported juvenile	7.5	5.0	0.7

Discussion

Pliocene giraffid tracks recorded at Laetoli (3660 ka)[28] had dimensions of 17 cm x 12.5 cm[29]. Holocene giraffe tracks, thought to be hundreds of years old, were recorded from the Kuiseb Delta in Namibia.[30] We contend that the Still Bay trackways are the only Pleistocene giraffe tracks recorded thus far in southern Africa.

Historical records

Historically, giraffe in the Cape Province were mainly confined to 29°S (in the Orange River valley) and further north, associated with riverine woodland and arid savanna, respectively. There is no record of giraffe occurring south of 30°S. The southernmost record was at the Spoeg River, Namaqualand, as noted by Van Meerhoff, 28 November 1663.[31] Here giraffe may have persisted in the *Vachellia karroo* woodlands of the Namaqualand river valleys as well as in isolated patches of *V. erioloba* on deep, sandy soils.[32] Sclater[33] noted that by 1761 'there does not seem to be any evidence of the occurrence of this animal south of the Orange River'. Mitchell and Skinner[34] indicate that 'modem African giraffes were well known to the Khoisan as far south as Graaff Reinet', but provide no reference for this statement.

Skead[35] noted that: '…Namaqualand in the north-west Cape is the most southerly district in which the giraffe has been known in historical times, and probably for long before that'. Skead[35] also noted an 1837 report by Herschel of four giraffe near Cape Town[36]. However, this report appears to refer to giraffe in captivity.

Rock art records

A rock art site from the Hex River Valley includes compelling fine line images of at least two giraffe (Site no. Hx BF 3, slide numbered 13) in Buffelshoekkloof on the farm Kanetvlei, latitude 33°31' S. The images are yellow-orange in colour and were recorded as being 170 mm in height and in poor condition. Beside them antelope-shaped images were recorded, superimposed with finger dots. Figure 7 presents a tracing of these images.[37]

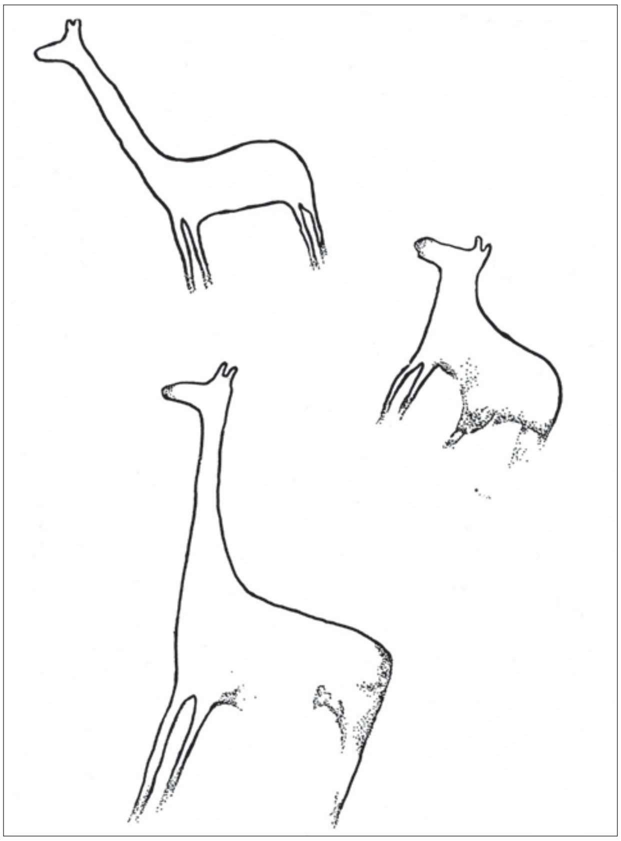


Figure 7: Tracings of giraffe rock art from Buffelshoekkloof, Kanetvlei, Hex River Valley.

The rock art of the Hex River Valley includes entoptic images, finger dots and handprints, and the depiction of sheep (which are not known in the archaeological record of southern Africa before approximately 2.0–1.6 ka). It was probably executed in the final phase of the rock art tradition in the southwestern Cape by peoples who occupied the area within the last 2 ka. Evidence suggests that handprints, finger dots and strokes in the Western Cape are later in the dating sequence than fine line paintings.[38] Paintings of handprints and finger dots are superimposed on antelope in the same shelter as the images of giraffe, suggesting that the inanimate images were executed later in the chronological sequence.

However, rock art images of giraffe cannot be regarded as a proxy for the historical distribution of the species, as they may simply reflect awareness by the artists that these distinctive mammals occurred further north. The Hex River Valley does provide access to areas further north from which historical records are known.

The only other possible San rock art of giraffe in the Cape has been recorded from the Eastern Cape near the Swart Kei River and near Whittlesea in the Queenstown District.[39] It is also contended that these images may represent mountain reedbuck. This species, although relatively long-necked in comparison to most other ungulates, has forward-pointing horns which are distinct from the ossicones of the giraffe. The Hex River images appear consistent with the depiction of giraffe ossicones rather than reedbuck horns.

Fossil records

Skead[35] noted 'signs that in prehistoric times a giraffe or giraffe-like animal lived as far south as Darling' (~33.3°S), mentioning a report by Cooke[40] of fossil specimens from this area in the South African Museum in Cape Town. However, Skead[35] noted further that Hendey, the palaeontologist at the museum, knew of no other fossils having been found at that site, and had cast doubt on the locality. Harris in his description of Giraffoidea attributed mid-Pleistocene age to this possible site.[41] Harris described a sivathere species and a giraffine species in Pliocene deposits at Langebaanweg (~33.0°S).[42]

The Cape south coast has a diversity of fossil palaeoarchives that have samples of fossil animal remains dating from the Pleistocene and Holocene. These represent the predation and collection activities of primarily modern humans, hyenas, jackals, leopards and porcupines. Giraffe are regularly predated by humans with advanced projectile weapons and/or poison technologies, e.g. the Hadza.[43] Giraffe are not regularly predated by hyenas, leopards and jackals, although hyenas and jackals will scavenge them when possible. It is important to note that the bones of very large mammals like giraffe are not as readily transported by predators as the bones of smaller prey, so there is a taphonomic filter that biases their presence in palaeoarchives such as caves and rock shelters.[44]

Giraffe fossils are not reported from palaeoarchives on the south coast, despite there being some very large samples collected by a diversity of bone-collecting agents. Several sites have sediments that date to the likely time of the giraffe track site. Pinnacle Point (PP) 13B and PP30 have MIS 6 sediments and giraffe are not reported.[45] Blombos, PP13B and Klasies River have MIS 5 sediments and no reported giraffe remains.[46,47] There is a large sample of fauna dating from MIS 2–1 at Nelson Bay Cave, and giraffe are not reported.[48] It would seem that the giraffe track site provides a unique record, perhaps because giraffe were not predated or their remains were not regularly transported to these caves. This finding highlights the fact that ichnofossils can provide an independent record of past animal occurrences that expands on the records provided by traditional fossil archives.

Past distribution of giraffe in KwaZulu-Natal

Cramer and Mazel[49] found no reliable historical records of giraffe in KwaZulu-Natal, nor any rock art of giraffe. However, they noted reports of giraffe bones at three archaeological sites, the southernmost of which was Sibudu Cave, latitude 29°31'S. The most recent of these sites was dated at 1 ka.

Implications of the palaeoecology of the Palaeo-Agulhas Plain

Recent reviews of the palaeoecology of the Palaeo-Agulhas Plain can be found in Marean et al.[8] and Copeland et al.[9] The faunal composition of the Palaeo-Agulhas Plain was first revealed by publications on the fossil faunal remains from Nelson Bay Cave and Klasies River.[46,48] More recent publications of faunal assemblages from Blombos[47] and Pinnacle Point[45] have added to this body of data. It is important to note that these assemblages were accumulated primarily by humans, and modern hunter–gatherers sample with a ~10 km daily foraging radius[50], so the assemblages represent both interior and Palaeo-Agulhas Plain faunas. The Pleistocene samples all include both browsing and grazing species, with the grazers being more abundant, and the browsing species being typical of the Cape fauna today such as grysbok, grey duiker and bushbuck. The species absent from the Cape today and present in these Pleistocene assemblages include large-bodied grazers typical of African savanna ecosystems. The large-bodied grazing faunal suite includes many extinct species. Marean[51] hypothesised that when sea levels retreated, this exposed plain was the location of a seasonal migration ecosystem with animals wintering in the west to exploit green forage in the winter rainfall regime, and then moving east in the summer to forage the green summer rainfall grasses. A strontium isotope analysis showed that these grazing species lived almost exclusively on the Palaeo-Agulhas plain and did not venture inland in any significant manner.[9] An analysis of age at death data of fossil blue antelope is consistent with a seasonal migratory movement.[52]

The emergence of the Palaeo-Agulhas Plain is strictly controlled by sea level and the position of resultant shorelines.[5,53] Interpretation of marine geophysical data in the Mossel Bay area suggests a low-relief 'plains' landscape offshore of the southern coastal plain[16,6], and this region was dominated by shallowly incised rivers with vast floodplains and wetlands. Cemented seafloor deposits, as well as a mobile wedge of unconsolidated sediment available for dune construction through times of sea-level regression, provide evidence that the aeolianite deposits on the present day coastal plain are the fringing remnants of a dominance of comparable deposits on the adjacent shelf.[16]

Contemporary giraffe populations in southern Africa are invariably associated with subtropical savanna, mostly dominated by deciduous acacias (*Vachellia* spp.) with a field layer of summer-growing, C4 grasses.[35] Their presence in the southern Cape fossil record, far south of their current range, has important implications for the Late Pleistocene climate and vegetation of the region. Most noteworthy is the requirement for extensive subtropical savanna, a habitat that is rare in the present landscape, being confined to the alluvial soils of the incised valleys of the Gouritz, Breede, Great Brak and Little Brak Rivers. This is the 'doringveld' of Vlok et al.[54], comprising an open and species-poor stratum of relatively low (3–5 m) trees, dominated by deciduous *V. karroo*, and a field layer of largely ephemeral grasses and karroid shrubs. Although several introductions of this species to this habitat have occurred in the recent past, it appears unlikely that this habitat can sustainably support populations of giraffe. However, when complemented with evergreen thicket, a habitat that would likely have been widespread on the calcareous substrata that dominated the Palaeo-Agulhas Plain, the sustenance of a giraffe population appears more realistic.

The giraffe populations of the Late Pleistocene southern Cape likely occurred on the wide, alluvial valleys of the aforementioned rivers, which meandered across the low-gradient Palaeo-Agulhas Plain[6], when it was exposed during glacial conditions[52]. While appropriate edaphic conditions, namely fertile alluvial soils[55], certainly existed to support giraffe habitat at this time, there is less certainty regarding the climate. Isotopic evidence derived from speleothems from Pinnacle Point shows shifts from C3 vegetation and winter rain to C4 grasses and summer rain at several times during the Middle and Late Pleistocene, notably at the transition between MIS 5 and MIS 4 (about 74 ka).[56,57] The invasion of the usually temperate Southern Cape by subtropical biomes (C4 grassland and savanna) during these transitional intervals would have provided habitat suitable for giraffe and many other ungulate species observed in the Pleistocene fossil record, including several species now extinct or occurring many hundreds of kilometres to the east and north.

Conservation

The likelihood is that the track surface became exposed at some point since 2011, as it would likely have been noted during searches for track sites during visits between 2007 and 2011. Visits in 2017 revealed interim partial degradation of the track surface caused by erosion. Given its precarious perch, the likelihood of it falling into the ocean is high. The slab is probably too heavy for helicopter retrieval to be considered. Preserving it with a substance such as Paraloid™ would help prevent erosion by weather and gastropods on the surface, but would not prevent its collapse into the Indian Ocean. The photogrammetry that has been performed allows for the reproduction of the track surface. Alternatively, the creation of a replica using latex or silicone would be feasible. The nearby museum in Still Bay would potentially form a suitable repository for such specimens, and for their interpretation. The richness of the ichnofauna along the coastline east of Still Bay, and the ephemeral nature of exposed track sites, makes the need for regular ichnological surveys desirable.

Conclusions

The discovery of a Pleistocene giraffe track site on the Cape south coast is unexpected, given the lack of known skeletal material in the region and the recorded historical distribution of the species. Our description of the earliest known evidence for giraffes in this region has significant palaeoecological implications because of the specialised feeding niche of giraffes which require a savanna ecosystem. The likely location for this ecosystem is on the broad floodplain of the southern Cape river valleys which could have supported a savanna of *Vachellia karroo* and C4 grasses. The presence of giraffe tracks at the margin of this submerged plain is likely evidence for such vegetation.

Acknowledgements

The assistance and support of Stephen Townley Bassett, Chris Heese, Linda Helm and Thalassa Matthews are acknowledged. Guy Gardner, and Peter Todd and family, generously provided access across their land to the coastline. We thank Dr John Rowan and Dr Jan Venter for their helpful review and comments, and Izak Venter and Tertius Haak for field assistance. Dr David Roberts made the initial elephant trackway discoveries; his mentorship and presence are sorely missed.

Authors' contributions

C.H. is the senior and corresponding author and co-discoverer of the site; he was responsible for the conceptualisation, site analysis, data collection, data analysis, write-up of the manuscript and project leadership. H.C. was responsible for the data analysis and field stratigraphy, contributed regarding the geological context, and reviewed drafts and revisions. R.C. was responsible for the palaeobotany contributions; contributed to the conceptualisation and data analysis, and reviewed drafts and revisions. J.D.V. is the co-discoverer of the site and was responsible for site analysis, data collection and photography for photogrammetry, and reviewed drafts and revisions. C.M. was responsible for the palaeoecology, contributed to the methodology, and reviewed drafts and revisions. R.M. contributed to the data analysis and photogrammetry, and reviewed drafts and revisions. R.R. was responsible for the rock art contributions and reviewed drafts and revisions.

References

1. Roberts DL, Cawthra HC, Musekiwa C. Dynamics of Late Cenozoic aeolian deposition along the South African coast: A record of evolving climate and ecosystems. In: Martini IP, Wanless HR, editors. Sedimentary coastal zones from high to low latitudes: Similarities and differences. Special Publication 388. London: Geological Society of London; 2014. p. 353–387. http://dx.doi.org/10.1144/SP388.11
2. Roberts DL, Bateman MD, Murray-Wallace CV, Carr AS, Holmes PJ. Last interglacial fossil elephant trackways dated by OSL/AAR in coastal aeolianites, Still Bay, South Africa. Palaeogeogr Palaeoclimatol Palaeoecol. 2008;257(3):261–279. http://dx.doi.org/10.1016/j.palaeo.2007.08.005
3. Helm C, McCrea R, Helm D. A South African Pleistocene avian and mammal track site with purported prints of a shod hominid. The Digging Stick. 2012;29(3):17–20.
4. Dingle RV, Rogers J. Pleistocene palaeogeography of the Agulhas Bank. T Roy Soc S Afr.1972;40:155–465. http://dx.doi.org/10.1080/00359197209519415
5. Van Andel TH. Late Pleistocene sea levels and human exploitation of the shore and shelf of southern South Africa. J Field Archaeol. 1989;16:133–155. http://dx.doi.org/10.1179/jfa.1989.16.2.133
6. Cawthra HC, Compton JS, Fisher EC, MacHutchon MR, Marean CW. Submerged terrestrial landscape features off the South African south coast. In: Harff J, Bailey G, Lüth F, editors. Geology and archaeology: Submerged landscapes of the continental shelf. Special Publication 411. London: Geological Society of London; 2015. p. 219–233. http://dx.doi.org/10.1144/SP411.11
7. Compton JS. Pleistocene sea level fluctuations and human evolution on the southern coastal plain of South Africa. Quat Sci Rev. 2011;30(5-6):506–527. http://dx.doi.org/10.1016/j.quascirev.2010.12.012
8. Marean CW, Cawthra HC, Cowling RM, Esler KJ, Fisher E., Milewski A, et al. Stone Age people in a changing South African Greater Cape Floristic Region. In: Allsopp N, Colville JF, Verboom GA, editors. Fynbos: Ecology, evolution, and conservation of a megadiverse region. Oxford: Oxford University Press; 2014. p. 164–199. http://dx.doi.org/10.1093/acprof:oso/9780199679584.001.0001
9. Copeland SR, Cawthra HC, Fisher EC, Lee-Thorp JA, Cowling RM, Le Roux PJ, et al. Strontium isotope investigation of ungulate movement patterns on the Pleistocene Paleo-Agulhas Plain of the Greater Cape Floristic Region, South Africa. Quat Sci Rev. 2016;141:65–84. http://dx.doi.org/10.1016/j.quascirev.2016.04.002
10. Newton AR, Shone RW, Booth PWK. The Cape Fold Belt. In: Johnson MR, Annhauser CR, Thomas RJ, editors. The geology of South Africa. Johannesburg: Geological Society of South Africa/Council for Geoscience; 2006. p. 521–531.
11. Martin AK, Flemming BW. The Holocene shelf sediment wedge off the south and east coast of South Africa. In: Knight RJ, McLean JR, editors. Shelf sands and sandstones. Memoir II. Calgary: Canadian Society of Petroleum Geologists; 1986. p. 27–44.
12. Birch GF. Nearshore Quaternary sedimentation off the south coast of South Africa: (Cape Town to Port Elizabeth) – Geological Survey Bulletin 67. Pretoria: Government Printing Works; 1980.
13. Malan JA. Lithostratigraphy of the Waenhuiskrans Formation (Bredasdorp Group) – South African Committee for Stratigraphy Lithostratigraphic Series 8. Pretoria: Department of Mineral and Energy Affairs;1989.
14. Bateman MD, Carr AS, Dunajko AC, Holmes PJ, Roberts DL, McLaren SJ, et al. The evolution of coastal barrier systems: A case study of the Middle-Late Pleistocene Wilderness barriers, South Africa. Quat Sci Rev. 2011;30:63–81. http://dx.doi.org/10.1016/j.quascirev.2010.10.003
15. Jacobs Z, Roberts RG, Lachlan TJ, Karkanas P, Marean CW, Roberts DL. Development of the SAR TT-OSL procedure for dating Middle Pleistocene dune and shallow marine deposits along the southern Cape coast of South Africa. Quat Geochronol. 2011;5(5):491–513. http://dx.doi.org/10.1016/j.quageo.2011.04.003
16. Cawthra HC, Bateman MD, Carr AS, Compton JS, Holmes PJ. Understanding Late Quaternary change at the land-ocean interface: A synthesis of the evolution of the Wilderness coastline, South Africa. Quat Sci Rev. 2014;99(1):210–223. https://doi.org/10.1016/j.quascirev.2014.06.029
17. Roberts DL, Karkanas P, Jacobs Z, Marean CW, Roberts RG. Melting ice sheets 400,000 yr ago raised sea level by 13 m: Past analogue for future trends. Earth Planet Sci Lett. 2012;357–358:226–237. http://dx.doi.org/10.1016/j.epsl.2012.09.006
18. Roberts DL. Last Interglacial hominid and associated vertebrate fossil trackways in coastal eolianites, South Africa. Ichnos. 2008;15(3):190–207. http://dx.doi.org/10.1080/10420940802470482
19. Branch GM, Griffiths CL, Branch ML, Beckley IE. Two oceans: A guide to the marine life of southern Africa. Cape Town: David Philip; 1994.
20. Liebenberg L. A photographic guide to tracks and tracking in southern Africa. Cape Town; Struik Publishers; 2000.

21. Stuart C, Stuart T. A field guide to the tracks and signs of southern and east African wildlife. Cape Town: Struik Nature; 2000.

22. Harris JM. Family Giraffidae. In: Harris JM, editor. Koobi Fora research project: Volume 3. The fossil ungulates: Geology, fossil artiodactyls, and palaeoenvironments. Oxford: Clarendon Press; 1991. p. 93–138.

23. 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. http://dx.doi.org/10.1016/j.jhevol.2006.08.006

24. Kingdon J, Happold D, Butynski T, Hoffmann M, Happold M, Kalina J. Mammals of Africa. vol. VI. London: A & C Black Publishers Ltd; 2013.

25. Singer R, Boné EL. Modern giraffes and the fossil giraffids of Africa. Ann S Afr Mus.1960;45:375–603.

26. Lockley M. The eternal trail – A tracker looks at evolution. New York: Perseus Publishing; 1999.

27. Klein RG. Palaeoenvironmental implications of Quaternary large mammals in the Fynbos Region. In: Deacon HJ, Hendey QB, Lambrechts JJN, editors. Fynbos palaeoecology: A preliminary synthesis. Pretoria: Cooperative Scientific Programmes; 1983. p. 116–138.

28. Lockley M, Roberts G, Kim JY. In the footprints of our ancestors: An overview of the hominid track record. Ichnos. 2008;15(3–4):106–125. http://dx.doi.org/10.1080/10420940802467835

29. Masao FT, Ichumbaki EB, Cherin M, Barili A, Boschian G, Iurino DA, et al. New footprints from Laetoli (Tanzania) provide evidence for marked body size variation in early hominins. eLife. 2016;5, e19568, 29 pages. http://dx.doi.org/10.7554/eLife.19568

30. Bennett MR, Liutkus CM, Thackeray F, Morse SA, McClymont J, Stratford D. Footprints of the Kuiseb Delta, Namibia. The Digging Stick. 2010;27:3.

31. Godée Molsbergen IE. Reizen in Zuid-Afrika in de Hollandse tijd. Deel 1.Tochten naar het Noorden, 1652–1686's [Travels in South Africa during the Dutch period. Part 1. Excursions to the North, 1652–1686]. Gravenhage: Martinus Nijhoff for Lichthoten Society; 1916 [Dutch]. In: Skead CJ. Historical incidence of the larger land mammals in the broader Western and Northern Cape. In: Boshoff AF, Kerley GIH, Lloyd PH, editors. Port Elizabeth: Centre for African Conservation Ecology, Nelson Mandela Metropolitan University; 2011. p. 288.

32. Cowling RM, Pierce SM. Namaqualand, a succulent desert. Cape Town: Fernwood Press; 1999.

33. Sclater WL. The mammals of South Africa. Volume I. London: Porter; 1900.

34. Mitchell G, Skinner JD. On the origin, evolution and phylogeny of giraffes *Giraffa camelopardalis*. Trans R Soc S Afr. 2003;58(10):51–73. http://dx.doi.org/10.1080/00359190309519935

35. Skead CJ. Historical mammal incidence in the Cape Province. Vol. 1: The Western and Northern Cape. Cape Town: Department of Nature and Environmental Conservation of the Provincial Administration of the Cape of Good Hope; 1980.

36. Evans DS, Deeming TJ, Evans BH, Goldfarb S. Herschel at the Cape: Diaries and correspondence of Sir John Herschel, 1834–1838. Austin, TX: University of Texas Press; 1969.

37. Rust R. A micro-regional survey of rock art in the Hex River Valley, Western Cape, South Africa [BA honours thesis]. Stellenbosch: Stellenbosch University; 1995.

38. Yates RJ, Manhire AH, Parkington JE. Rock painting and history in the south-western Cape. In: Dowson TA, Lewis-Williams JD, editors. Contested images: Diversity in southern African rock art research. Johannesburg: Witwatersrand University Press; 1994. p. 29–60.

39. Stow GW. The native races of South Africa. A history of the intrusion of the Hottentots and Bantu into the hunting grounds of the Bushmen, the Aborigines of the country. London: Swan Sonnenschein & Co. Limited; 1905.

40. Cooke HBS. Some fossil mammals in the South African Museum collections. Ann S Afr Mus. 1955;42:161–168.

41. Harris JM, Solounias N, Geraads D. Giraffoidea. In: Werdelin L, Sanders WJ, editors. Cenozoic mammals of Africa. Berkeley, CA: University of California Press; 2010. p. 797–811. http://dx.doi.org/10.1525/california/9780520257214.003.0039

42. Harris JM. Pliocene Giraffoidea (Mammalia, Artiodactyla) from the Cape Province. Ann S Afr Mus. 1976:69;325-353.

43. Marlowe F. The Hadza: hunter-gatherers of Tanzania. Berkeley: University of California Press; 2010.

44. Monahan CM. The Hadza carcass transport debate revisited and its archaeological implications. J Archaeol Sci. 1998;25:405–424. https://doi.org/10.1006/jasc.1997.0241

45. Rector AL, Reed KE. Middle and Late Pleistocene faunas of Pinnacle Point and their paleoecological implications. J Hum Evol. 2010;59(3–4):340–357. https://doi.org/10.1016/j.jhevol.2010.07.002

46. Klein RG. The mammalian fauna of the Klasies River Mouth sites, southern Cape Province, South Africa. S Afr Archaeol Bull. 1976;31:75–98. https://doi.org/10.2307/3887730

47. Henshilwood CS, Sealy JC, Yates RJ, Cruz-Uribe K, Goldberg P, Grine FE, et al. Blombos Cave, southern Cape, South Africa: Preliminary report on the 1992–1999 excavations of the Middle Stone Age levels. J Archaeol Sci. 2001;28:421–448. https://doi.org/10.1006/jasc.2000.0638

48. Klein RG. The Late Quaternary mammalian fauna of Nelson Bay Cave (Cape Province, South Africa): Its implications for megafaunal extinctions and environmental and cultural change. Quatern Res. 1972;2:135–142. https://doi.org/10.1016/0033-5894(72)90034-8

49. Cramer MD, Mazel AD. The past distribution of giraffe in Kwazulu-Natal. S Afr J Wildl Res. 2007;37:198–201.

50. Marlowe FW. Hunter-gatherers and human evolution. Evol Anthropol. 2005;14(2):54-67. https://doi.org/10.1002/evan.20046

51. Marean CW. Pinnacle Point Cave 13B (Western Cape Province, South Africa) in context: The Cape Floral Kingdom, shellfish, and modern human origins. J Hum Evol. 2010;59:425–443. https://.org/10.1016/j.jhevol.2010.07.011

52. Faith TJ, Thompson JC. Fossil evidence for seasonal calving and migration of extinct blue antelope (*Hippotragus leucophaeus*) in southern Africa. J Biogeogr. 2013;40(11):2108–2118. https://doi.org/10.1111/jbi.12154

53. Fisher EC, Bar-Matthews M, Jerardino A, Marean CW. Middle and Late Pleistocene paleoscape modeling along the southern coast of South Africa. Quat Sci Rev. 2010;29:1382–1398. http://dx.doi.org/10.1016/j.quascirev.2010.01.015

54. Vlok JHJ, Euston-Brown DIW, Cowling RM. Acocks' Valley Bushveld 50 years on: New perspectives on the delimitation, characterisation and origin of thicket vegetation. S Afr J Bot. 2003;69:27–51. http://dx.doi.org/10.1016/S0254-6299(15)30358-6

55. Cawthra HC. The marine geology of Mossel Bay [PhD thesis]. Cape Town: University of Cape Town; 2014.

56. Bar-Matthews M, Marean CW, Jacobs Z, Karkanas P, Fisher EC, Herries AI, et al. A high resolution and continuous isotopic speleothem record of paleoclimate and paleoenvironment from 90 to 53 ka from Pinnacle Point on the south coast of South Africa. Quat Sci Rev. 2010;29(17):2131–2145. http://dx.doi.org/10.1016/j.quascirev.2010.05.009

57. Braun K. Influence of the Agulhas Current on the terrestrial climate of South Africa as derived from speleothems [PhD thesis]. Jerusalem: Hebrew University of Jerusalem; 2014.