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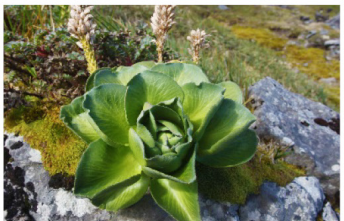

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A 20-year vision for polar research through SANAP

Patterns of blunt force homicide in Cape Town

Proximate and fatty acid composition of Cape snoek

Social norms interventions for public health issues

MeerKAT time and frequency reference optical network design

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Cover caption
The spectacular biodiversity and environment of the Antarctic and sub-Antarctic (photos: Isabelle Ansorge, Sandra Durand, Peter le Roux, Peter Ryan, Bettine van Vuuren). In a Commentary on page 11, Ansorge and colleagues present a 20-year vision for polar research through the South African National Antarctic Programme.

Review Article

Research Article

Research Letter

The geopolitics of global warming: Some thoughts

The Arctic Region is not often in the news headlines and is often considered unimportant. But as a result of the effects of global warming, it is a region of growing importance to the five countries under whose jurisdiction it falls. Canada, Norway, Russia, Denmark and the USA all have territories that fall north of 66°. Under international law, the high seas, including the North Pole and the region of the Arctic Ocean surrounding it, are not owned by any country. The five surrounding Arctic countries are limited to an exclusive economic zone (EEZ) of 200 nautical miles adjacent to their coasts (including the continental shelf below this zone). The waters and seabed beyond the EEZs of the five coastal states are considered to be international waters and the heritage of all people.

While there has long been, and still is, much wrangling and uncertainty over who has jurisdiction over what, and how wide the EEZ should be, two things are certain: the extent of the Arctic ice sheet is decreasing, and the ice at the edge of the sheet is thinning. Since 2012, Russia has been expanding its military presence (building 6 new bases to supplement 18 existing bases) along its Arctic coast and islands, and intensifying research in the seabed, ostensibly to protect shipping in the Barents Sea – but the underlying reason is that the shrinking and weakening of the ice sheet will allow easier access to the extensive gas and oil resources below the seabed. There is little doubt that the other four 'polar' nations will not be entirely happy with these developments. This is a very visible and immediate (if geographically confined) example of the geopolitics of global warming: the primary effects are those that affect the physical world and nature; the inevitable consequences are political.

Mr Trump, the tweeting President of the USA, may wish to believe that global warming is a Chinese hoax, but consequences of the reality, beyond Russian resource opportunism, are approaching. Drought in the Horn of Africa, for instance, has left some 12 million people hungry and several hundred thousand animals dead in the past 18 months. The drought last year was the result of the La Niña phenomenon; this year El Niño is having the same effect.

But climate experts predict that global warming will serve to worsen the situation over time and put even more people at risk of facing famine and death in the years ahead. Oxfam's regional director in the Horn of Africa has, for example, stated that climate change is a real and current problem in East Africa, while research undertaken by The Center for Climate and Life at Columbia University's Lamont-Doherty Earth Observatory found that the region is growing steadily drier – and that it will continue to do so as carbon emissions rise. In an explicitly political move, Mr Trump instructed the US Environmental Protection Agency to remove such data from its website, denying the public access to scientific information – although there is, now, some confusion regarding this order. Meanwhile, in Kenya, the seriousness of the drought has led to violence, with cattle herders attacking lodges, ranches and conservancies in desperate attempts to find fresh pastures for their herds. Tourism in the Laikipia region is threatened by these developments and the Kenyan government has deployed members of the military to the area in an attempt to stop the attacks, but with little effect. In addition to the desperation of the pastoralists, there is a growing concern that local politicians will use the situation to instigate further violence to advance their own interests.

Not unrelated to the problems of famine, death and related violence, is a growing understanding of the effect that climate change has on migration – both locally and internationally. While wars, terror, extreme political oppression, dwindling resources and poverty are clearly major drivers of migration, more and more scientific evidence is emerging, showing that the effects of global warming – whether drought or extreme hurricanes, for instance – play a significant role in intensifying the rate at which migration is increasing. Migration within countries, in the form of displacements, serves to contribute to social unrest as people crowd into already heavily populated but (apparently) safer or better resourced areas. Alternatively, as in the case of severe hurricanes, large numbers of people are left homeless and even poorer than before, facing disease and a lack of food and potable water. Repeated events of this kind often result in people moving away from vulnerable areas to safer (and sometimes urban) areas, which creates major problems for local and national authorities.

The same combination of factors – including drought, flooding and water shortages – are also emerging as part of the growing challenge of international migration. An obvious example of this effect of global warming is the international immigration of people from the Philippines to find work – in the Middle East and the USA in particular. The Philippines is highly vulnerable to increasingly severe storm events, which have the effect of repeatedly damaging both agriculture and building work, leaving many Filipinos with no option but to find employment in other parts of the world.

While drought and extreme weather conditions are directly associated with displacement and migration, rising sea levels are an additional consequence of global warming that will, in the future, present major problems for millions of people. Some will experience displacement (50% of the population of the USA lives in coastal areas), while others will present the world with the serious problem of finding ways of moving, and then accommodating (and possibly finding employment for), people whose home islands have been gradually reduced. NASA estimates that, without serious attention given to reducing human-generated climate change, sea levels will have risen by a metre by the end of this century. The islands most immediately affected are home to almost a million people – while more than a billion people (one sixth of the world's population) live in the most vulnerable parts of the Asian coastline. What is more, the US National Oceanic and Atmospheric Administration points out that higher sea levels result in deadly and destructive storm surges pushing farther inland than they once did, which also means more frequent nuisance flooding. Both disruptive and expensive, nuisance flooding is estimated to be from 300% to 900% more frequent within US coastal communities than it was just 50 years ago.

Professor Peter Kahn of the University of Washington has developed a simple explanation as to why so little is done to face the implications of global warming for the world's geopolitics. He calls it environmental generational amnesia. Let us hope that those marching around the world in support of science, will not only restore belief in science, but also help to eliminate the amnesia.

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Humanities Book Award 2017: Deep scholarship in action

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In 2009, the Academy of Science of South Africa (ASSAf) published a report entitled *Scholarly books: Their production, use and evaluation in South Africa today*[1], which recommended that the publication of scholarly monographs be 'strongly encouraged and supported' in South Africa.

This recommendation was based on a visible need for the 'deep scholarship' enabled by the form of the book to be better recognised in the national research system, particularly when – despite some apparent scepticism towards their real scholarly value, and some of the real difficulties in assessing this scholarship – books 'generated on average three times more citations than the journal article' and enjoy 'a longer active citational life'[1(p.24,25)].

This necessary recognition would register the potential impact of the scholarly monograph on both local and global scholarship, as well as its potential for contributing to, and even changing the terms of, public knowledge and practice.

Within ASSAf, the Standing Committee for the Humanities noted the particular force that the scholarly monograph holds for humanist research and enquiry, for which it is generally believed that the book rather than the journal article is most often the marker for durable impact and international recognition.

Indeed, it is arguable that one of the unintended outcomes of the otherwise successful mode of research support and stimulus through the 'carrot' of government publication subsidy and its favouring of the journal article over the book may well have been a tendency to remove South African scholars from the terms of international visibility and global impact.

The focus on speedier publication of journal articles – and these often in journals with a national rather than international reach and footprint – built into subsidy policy for decades surely acted as a disincentive to the long haul of the book, and its necessarily slower accumulation of deep research and argument. And this despite a global environment in which (in the humanities and social sciences) monograph publication is very often taken as the *sine qua non* for tenure, and the transition from (non-tenured) assistant professor to tenured associate professor, rather than – as it often is in South Africa – for promotion from (already tenured) senior lecturer to associate professor or professor.

As a way of contributing to the greater recognition of the monograph form, and at the same time making more visible the contribution of the humanities to national progress in scholarship and social understanding, the committee resolved to offer an annual prize for a book 'noteworthy' (as the rubric for the prize reads) 'in its contribution to the development of new understanding and insight'. And taking up, in this regard, one of the key recommendations of ASSAf's 2011 *Consensus Study on the State of the Humanities in South Africa*[2], the need to 'enhance the book as a cultural and human asset in both the scholarly and the public minds'.

Such a book is Keith Breckenridge's *Biometric State: The Global Politics of Identification and Surveillance in South Africa, 1850 to the Present*[3], published by Cambridge University Press in 2014 – the first recipient of the ASSAf Humanities Book Award.

Breckenridge argues – and substantiates – that for more than a century,

> *the South African state…served as a laboratory for* [a] *new form of biometric government, and that the technologies that states across the world have been adopting over the last decade find their earliest and fullest development here.*

This study – of the rise of biometrics as 'the automated recognition of human beings…the identification of people by machines' from fingerprinting to iris-scanning – manifests all the virtues of the 'deep scholarship' that the extended form of argument, reference and analysis of the book alone allows.

For it is only through the labour of extended reading and comparative enquiry, and the consequent accumulation of argument and evidence involved in this, that it is possible to shift the weight of received ideas and interpretations that constitute the 'normal science' of any area of humanist or social knowledge.

With *Biometric State*, Breckenridge successfully challenges many of the usual understandings around the politics of identification and surveillance in (but, importantly, not only in) South Africa from 1850 to the present day. In so doing, he consciously moves against a powerful trend in historiography which tends to take the national alone as its boundary, often inhibiting certain forms of global or comparative analysis. At the same time, he demonstrates the value – and indeed the necessity – of understanding some of the most pressing concerns of the present moment through a careful analysis of their often occluded or misunderstood historical roots, and, in so doing, highlighting one of the disciplines of history's most important roles in the promotion of public knowledge.

For – at a moment in which the new US President, Donald Trump, calls for ever more extreme vetting measures, and the volume of migration increases worldwide – there can be no doubt that identification and surveillance are key components of the modern state, and that the mixture of their politically positive and negative roles needs the most careful scrutiny.

In a detailed and painstaking analysis, Breckenridge argues that the colonial world sees the emergence of new modes and methods of biometric identification, and that these methods entail a paradigm-breaking shift away from the older dominant modes of 'documentary identification'.

It is because of the depth and density that the form of the book allows that Breckenridge is able to *correct and enrich* the standard ideas and images of figures in this history such as Francis Galton, the father of scientific fingerprinting, and Edward Henry, usually known for his work in getting Scotland Yard under way in Britain.

In the place of the existing, rather one-dimensional, accounts of such figures available in the literature that present their scientific ideas in isolation from their historical and cultural context, Breckenridge offers powerful new assessments and interpretations. After examining the evidence, he argues, for instance, that 'Galton's nineteenth century ethnography was more important than the existing international scholarship of statistics, eugenics or Darwinism has allowed'[3(p.213)].

Similarly, against the airbrushing of too-celebratory accounts of Gandhi, the book, through its comparative and archival research, is able to situate and throw new light on some of the contradictions and changes in Gandhi's thinking.

Throughout, the book reveals the ways in which the thinking of such figures was importantly modified and even directed by their often neglected experiences in South Africa, and highlights the pressures on 'thinking straight' that decontextualised accounts ignore at their peril.

The force of the book also comes through in the ways in which it is able to *query and contradict* many of the too-casual assumptions at work in modish deployments of concepts such as 'biopower'.

One recipe for the speedy journal article is to take a relatively unfamiliar notion such as 'biopower' and use it as a frame for interpreting a range of texts or events and while this may have some genuine explanatory value, the intellectual problem is that this often leaves unexamined the key term itself. Lending an unquestioned authority to influential figures such as Foucault, Agamben or Negri and Hardt undoes some of the force of the critical thinking associated with what is often referred to as Theory (with a capital T) by proponents and opponents alike. Where the concept as framing device for an argument can work well at article length, the real force of the concept can often only be assessed through the deeper scholarship and critical reflection which the book form allows.

One of the intellectual pleasures of this book, as well as one of its significant contributions to public knowledge, is the ways in which it is able to query, question and challenge many of the received ideas of our own history by locating it in a larger picture (as, for instance, in its correction to the ways in which many have 'taken the state at its own public word and massively overstated its coercive and surveillance abilities'[3(p.161)]).

Throughout, Breckenridge points – with all the authority of the historian's enlarged comparative and temporal perspective – to the paradoxes of the intertwining of progressivism and totalitarianism in the global thinking around identification, noting the 'sweet and perplexing irony that those same coercive systems [of colonial surveillance and identification] are now being championed as the only viable remedy to [our] entrenched forms of poverty'[3(p.214)].

He closes with a warning that is made possible by the scholarly work that made the distinction between the older forms of documentary identification and the newer forms of biometric identification:

> *Biometric registration has always had as its* raison-d-être *the identification of those who cannot write. In the process it has clearly contributed to weakening the political agency of those who can write.*[3(p.218)]

Duly considered, opting for biometric registration in place of documentary identification has played a considerable role in South Africa's 'pitifully weak forms of local government'[3(p.217)].

At a global moment in which the easy access to information and communication made possible by the Internet and social media seems to be working against its critical appropriation in the public spheres of both science and politics, the book's reminder of the liberating potential of literacy is timely indeed.

For this reminder, and especially for its contribution to the development of new understanding and insight into the interaction of local and global forms of governance, *Biometric State: The Global Politics of Identification and Surveillance in South Africa, 1850 to the Present* richly deserves the first ASSAf Humanities Book Award.

Keith Breckenridge (right), the author of *Biometric State: The Global Politics of Identification and Surveillance in South Africa*, *1850 to the Present*, receiving the ASSAf Humanities Book Award from Shireen Hassim (Chair: ASSAf Humanities Standing Committee) on 9 March 2017.

References

1. Academy of Science of South Africa (ASSAf). Scholarly books: Their production, use and evaluation in South Africa today. Pretoria: ASSAf; 2009. Available from: https://www.assaf.org.za/files/2017%20reports/ASSAF%20Scholarly%20Report%20FINAL%20Proof.pdf
2. Academy of Science of South Africa (ASSAf). Consensus study on the state of the humanities in South Africa: Status, prospects and strategies. Pretoria: ASSAf; 2011. Available from: https://www.assaf.org.za/files/2011/09/2011-Humanity-final-proof-11-August-2011.pdf
3. Breckenridge K. Biometric state: The global politics of identification and surveillance in South Africa, 1850 to the present. Cambridge: Cambridge University Press; 2014.

Comments on 'The age of fossil StW573 ('Little Foot'): An alternative interpretation of $^{26}Al/^{10}Be$ burial data'

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StW573, or 'Little Foot', is a nearly complete *Australopithecus* skeleton discovered in 1997[1], in Member 2 of the Sterkfontein Formation – the oldest fossil-bearing member of the cave[2]. The importance of StW573 lies not only in its completeness, which provides comprehensive anatomical and locomotor information on one individual, but also in its age and phylogenetic relationships with other hominid species. The age of StW573 was first suggested to be about 3.5 Ma based on its deep stratigraphic position and the absence of any other hominid fossils which are so abundant in the higher Member 4 deposits.[3] McKee[4] argued on faunal grounds that it should be younger, but Tobias and Clarke[5] countered his arguments. Berger et al.[6] even suggested that StW573 'may be as young as 1.07–1.95 Ma'. Their arguments were comprehensively countered by Clarke[7]. A date of 4.17±0.35 Ma was based on cosmogenic burial dating of the breccia in which the skeleton was found.[8] Dating has also been applied to calcite speleothems found in close proximity to the skeleton[9-12], but careful stratigraphic mapping[13] refined and expanded in Bruxelles et al.[14] shows that the speleothems postdate the skeleton and thus cannot be used to determine more than a minimum age for the specimen.

Granger et al.[15] then used the cosmogenic isochron burial dating method with ^{26}Al and ^{10}Be to determine a depositional age for the breccia containing the skeleton of 3.67±0.16 Ma. The isochron date is based on a suite of 11 different samples taken from a narrow stratigraphic interval encompassing the accessible thickness of M2 above, below and adjacent to the StW573 specimen. Nine of the samples are consistent with a single depositional age and are well-fit by the curve (MSWD=2.12); one sample is older and must have been reworked from an older deposit within the cave, and one sample was an outlier.[15]

The age of StW573

Kramers and Dirks[16] have produced an alternative interpretation of the cosmogenic nuclide data in Granger et al.[15] that they argue is consistent with a younger age for the skeleton. Their re-interpretation, however, hinges on a series of assumptions that are unjustified and based on demonstrably incorrect interpretations of the cave structure and stratigraphy:

1. On Page 1 (paragraph 2), they make an incorrect statement about the dating of Member 4 when they give reference to an article by Clarke as declaring that 'the lower age limit for Member 4 was firmly placed at ca 2 Ma'. In fact, Clarke[7] wrote exactly the opposite, i.e. that the top of Member 4 was slightly older than 2 Ma. Clarke[7] gave references to several researchers who had published even older dates for Member 4.

2. Kramers and Dirks[16] deconstruct the isochron burial date, which is based on the regression of a curve through multiple samples, and instead consider each sample separately. In any statistical regression there will be some samples above the curve (i.e. statistically younger) and some below (i.e. statistically older). They chose the youngest sample, still within the expected statistical uncertainty of the isochron regression, and recalculated its burial age using an assumption that deserves careful explanation. The regression of Granger et al.[15] showed that Member 2 continued to accumulate cosmogenic nuclides after deposition, and that the total amount of ^{26}Al and ^{10}Be produced was 85±13 and 21±3 thousand atoms per gram, respectively. The exact amount of postburial production depends on the age, the burial depth, the density of the overlying rock, and the erosional history of the rock. Postburial production cannot be calculated a priori with high confidence because these multiple parameters are difficult or impossible to determine independently. However, the isochron method solves for postburial production implicitly, without requiring any assumptions regarding the burial history. Kramers and Dirks[16] calculated the postburial component directly, assuming a specific burial depth, overlying rock density, a constant erosion rate at Sterkfontein, and a $^{26}Al/^{10}Be$ production rate ratio of 8.1. They determined a postburial component slightly less than the one that was independently determined by the isochron regression, and then neglected to assign any uncertainty to it. Using this new value, the youngest sample in the regression (and the one that is most sensitive to postburial production) becomes artificially younger, and appears to be younger than 2.8 Ma. Their recalculation assumes that the depth, density, and erosional history of the site are known with certainty (which they are not), and that the production rates of ^{26}Al and ^{10}Be by processes of muon capture and fast muon reactions can be calculated exactly (Balco[17] estimates a 25% uncertainty in calculating muon production rates using a scaling model). They then use this single sample to represent the true age of the deposit and explain that the other samples from the isochron must have all been reworked from a hypothetical upper cave deposit that no longer exists, which leads to additional problems with their interpretation.

   Kramers and Dirks' assumptions are based on several erroneous stratigraphic conclusions which illustrate that they are not familiar with the depositional context of StW573[14]. They also made inaccurate interpretations of our previous work, including points which are not in the papers they cited.

3. Despite our detailed macro- and micro-stratigraphic work, there is no evidence of the collapse they propose anywhere in the exposed Member 2 breccia. If StW573 was deposited with a collapse of older cave fillings, it should represent a discrete and discernible event within the stratigraphy, demonstrated by a facies dominated by poorly organised dolomite clasts and reworked breccia and speleothem pieces. None of these features

is found in the Member 2 deposit. This collapse also cannot be represented by the whole depth of Member 2, which is stratified consistently and conformably – indicative of a long and progressive accumulation.

4. On Page 4, Kramers and Dirks[16] use the Name Chamber as an example of 'such a secondary deposit'. The movement of material into the Name Chamber has been studied in detail[18,19], and the various facies associated with different modes of deposition have been documented. No similar facies are found in the Silberberg Grotto and at no time during the filling of the Name Chamber through collapse or gradual sedimentation would it have been possible for an entire, fully articulated skeleton to be redeposited.

5. As evidence for the collapse of a former cave, Kramers and Dirks[16] focus on a massive collapsed dolomite block visible adjacent to the Type Site (Page 4). The position of this block is incorrect in their Figure 2a. This block is located 5–10 m northeast of their documented position (Figure 1), is not above any part of the Silberberg Grotto, and it collapsed onto Member 4 sediments during the accumulation of that deposit. Many other collapsed roof blocks have been found during the excavations of Members 4 and 5[18], but no dolomite blocks can be seen in Member 2 associated with such collapse. Furthermore, this block does not represent a dolomite feature that separated two chambers. It is simply a collapsed dolomite block – a common feature in Sterkfontein Cave (e.g. Milner Hall) and a karstic feature associated with the geomorphological development of the system, as Clarke[18] recognised in Members 4 and 5. Its collapse is not necessarily related to the collapse of the roof as we can see in the present day underground section of the caves.

6. Contrary to Kramers and Dirks[16] (Page 6), we have never proposed that StW573 was deposited in a muddy debris flow. The specimen was embedded in talus cone breccia[14] in dry conditions, as evidenced by the mummification of the body[20] which lies conformably within the talus slope.

7. The cosmogenic analyses showed no evidence of the mixing of two kinds of breccia, as the collapse of a former upper cave should imply. Contrary to what Kramers and Dirks said (Page 4), previous work has not proposed that the layer STM2-light contained chert debris from a higher level in the cave system. Granger et al.[15] state that the angular, unweathered chert clasts 'were probably eroded from the walls of the cave within a few meters of the surface', rather than from the surface where weathering would result in rounding and pedogenic iron-staining. We can only say that that particular sample derives from higher in the same chamber and as such has a different cosmogenic production history. This does not imply that the chert comes from the landscape surface, or from a previous cave filling.

8. Other mistakes were made concerning the use of speleothems as stratigraphic evidence. For example on Page 6, Kramers and Dirks use shelf stones to say that the cave was flooded after deposition of Member 2. But, as one can see today around the lake in Sterkfontein Cave, there are no shelf stones because the phreatic water is not saturated with calcite. These kinds of shelf stones are linked with localised pools, formed in the isolated voids of the talus.[14]

9. On Page 7, Kramers and Dirks suggest that StW573 entered the hypothetical upper cave and 'wandered or fell' from there into the Silberberg Grotto through a 'passageway' that opened suddenly between the two, disturbing and re-depositing 'unconsolidated sediment material that had been lying in the upper cave for hundreds of thousands of years'. The only upper cavern is that containing Member 4 and 5 deposits, which is situated to the north and east of Silberberg Grotto and not directly above it. If such deposits had been re-worked into the Silberberg Grotto, then there would be other fossils of *Australopithecus* in addition to StW573, which there are not.

10. On Page 7, Kramers and Dirks admit that the flowstones formed post-depositionally in voids within the breccia, accepting our previous work (Bruxelles et al.[14]), but then they use those flowstone-derived dates[10-12] as a relevant comparison for their reinterpreted age for the same breccia. We must reiterate that all the flowstones around StW573, including F1, are filling flowstones and formed a long time after its deposition.[14]

11. On Page 7 – just before their conclusion – Kramers and Dirks[16] state that *Cercopithecoides williamsi*, which occurs in the Silberberg Grotto deposits, has not been reported from reliably dated sites older than 2.5 Ma. This statement is misleading, because one can argue about reliability of certain dates, whether from South or East Africa or Chad, but the fact remains that *Cercopithecoides williamsi* occurs in Makapansgat Member 3, which has been dated to about 3 Ma. For discussion see Klein[21] (p.155).

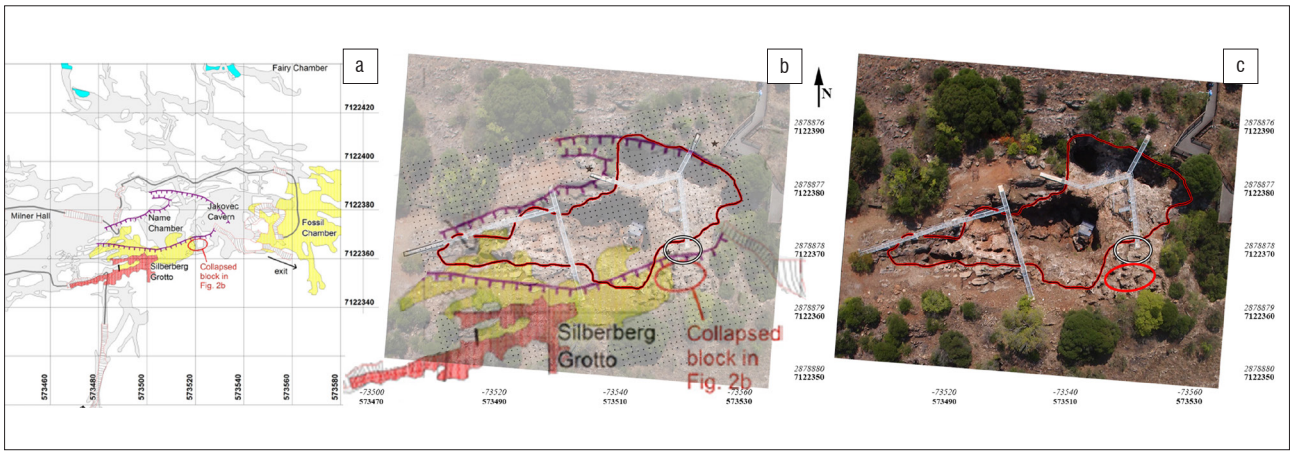

Figure 1: Composite figure illustrating the position of the 'collapsed block' discussed in Kramer and Dirks[16]. (a) Figure 2a from Kramers and Dirks[16] illustrating the position of the 'collapsed block' (red circle) in relation to the chambers mentioned in the text. (b) The same Figure 2a[16] scaled, aligned and superimposed on a georeferenced aerial photograph of the Sterkfontein site. Figure 2a[16] is made transparent to illustrate the position of the 'collapsed block' (red circle from Kramers and Dirks[16]) and position of the Silberberg Grotto in relation to the outline of the excavation (solid red line) and the position of the discussed block (white circle) identified from the photograph. Notice that the block described[16] is north and further from the Silberberg Grotto and Name Chamber than proposed. (c) Georeferenced aerial photograph (photo: D. Stratford) with excavation outline (red line), the suggested position of the 'collapsed block'[16] (red circle), and actual position of the 'collapsed block' discussed in Kramers and Dirks[16]. See supplementary material for enlarged version of Figure 1.

Conclusion

Kramers and Dirks[16] propose a complicated two-stage burial scenario for Sterkfontein Member 2 based primarily on the re-analysis of a single statistically younger sample isolated from the well-fit isochron calculated by Granger et al.[15] Their re-analysis is purely hypothetical and is based on unjustifiable assumptions rather than observations or measurements of the cave or its stratigraphy. After dedicated work on Member 2 over the last 20 years by Clarke[1,13,18,22] and by Bruxelles et al.[14], we find no sedimentological, stratigraphic or geomorphological evidence that supports the two-stage burial scenario. The cosmogenic nuclide data, the cave morphology, and the sediment stratigraphy are all consistent with a single episode of deposition contemporaneous with StW573 at 3.67 ± 0.17 Ma.

References

1. Clarke RJ. First ever discovery of a well-preserved skull and associated skeleton of Australopithecus. S Afr J Sci. 1998;94:460–463.
2. Partridge TC. Re-appraisal of lithostratigraphy of Sterkfontein hominid site. Nature. 1978;275:282–287. https://doi.org/10.1038/275282a0
3. Clarke RJ, Tobias PV. Sterkfontein Member 2 foot bones of the oldest South African hominid. Science. 1995;269:521–524. https://doi.org/10.1126/science.7624772
4. McKee JK. Faunal evidence and Sterkfontein Member 2 foot bones of early hominid. Science. 1996;271:1301. https://doi.org/10.1126/science.271.5253.1301a
5. Tobias PV, Clarke RJ. Faunal evidence and the Sterkfontein Member 2 foot bones of early man: Response to J.K. McKee. Science. 1996;217:1301–1302. https://doi.org/10.1126/science.271.5253.1301b
6. Berger LR, Lacruz R, Ruiter D. Brief communication: Revised age estimates of *Australopithecus*-bearing deposits at Sterkfontein, South Africa. Am J Phys Anthropol. 2002;119:192–197. https://doi.org/10.1002/ajpa.10156
7. Clarke RJ. On the unrealistic 'Revised age estimates' for Sterkfontein. S Afr J Sci. 2002;98:415–419.
8. Partridge TC, Granger DE, Caffee MW, Clarke RJ. Lower Pliocene hominid remains from Sterkfontein. Science. 2003;300:607–612. https://doi.org/10.1126/science.1081651
9. Partridge TC, Shaw J, Heslop D, Clarke RJ. The new hominid skeleton from Sterkfontein, South Africa: Age and preliminary assessment. J Quat Sci. 1999;14:293–298. https://doi.org/10.1002/(SICI)1099-1417(199907)14:4<293::AID-JQS471>3.0.CO;2-X
10. Walker J, Cliff RA, Latham AG. U-Pb isotopic age of the StW573 hominid from Sterkfontein, South Africa. Science. 2006;314:1592–1594. https://doi.org/10.1126/science.1132916
11. Pickering R, Kramers JD. Re-appraisal of the stratigraphy and determination of new U-Pb dates for the Sterkfontein hominin site, South Africa. J Hum Evol. 2010;59:70–86. https://doi.org/10.1016/j.jhevol.2010.03.014
12. Herries A, Shaw J. Palaeomagnetic analysis of the Sterkfontein palaeocave deposits: Implications for the age of the hominin fossils and stone tool industries. J Hum Evol. 2011;60:523–539. https://doi.org/10.1016/j.jhevol.2010.09.001
13. Clarke RJ. Newly revealed information on the Sterkfontein Member 2 *Australopithecus* skeleton. S Afr J Sci. 2002;98:523–526.
14. Bruxelles L, Clarke RJ, Maire R, Ortega R, Stratford DJ. Stratigraphic analysis of the Sterkfontein StW573 *Australopithecus* skeleton and implications for its age. J Hum Evol. 2014;70:36–48. https://doi.org/10.1016/j.jhevol.2014.02.014
15. 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
16. Kramers JD, Dirks HGM. The age of fossil StW573 ('Little foot'): An alternative interpretation of $^{26}Al/^{10}Be$ burial data. S Afr J Sci. 2017;113(3/4), Art. #2016-0085, 8 pages. https://doi.org/10.17159/sajs.2017/20160085
17. Balco G. Production rate calculations for cosmic-ray-muon-produced ^{10}Be and ^{26}Al benchmarked against geological calibration data. Quat Geochronol. 2017;39:150–173. https://doi.org/10.1016/j.quageo.2017.02.001
18. Clarke RJ. On some new interpretations of Sterkfontein stratigraphy. S Afr J Sci. 1994;90:211–214.
19. Stratford DJ, Bruxelles L, Clarke RJ, Kuman K. New stratigraphic interpretations of the fossil and artefact-bearing deposits of the Name Chamber, Sterkfontein. S Afr Archaeol Bull. 2012;67(196):159–167.
20. Clarke RJ. Taphonomy of Sterkfontein *Australopithecus* skeletons. In: Pickering TR, Schick K, Toth N, editors. Breathing life into fossils: Taphonomic studies in honor of CK (Bob) Brain. Bloomington, IN: Stone Age Institute Press; 2007. p. 167–173.
21. Klein RJ. The human career: Human biological and cultural origins. Chicago, IL: University of Chicago Press; 2009. p. 155. https://doi.org/10.7208/chicago/9780226027524.001.0001
22. Clarke RJ. A deeper understanding of the stratigraphy of Sterkfontein fossil hominid site. Trans R Soc S Afr. 2006;61:111–120. https://doi.org/10.1080/00359190609519960

The lost scholarship of changing curricula

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Africanising the curriculum: Indigenous perspectives and theories

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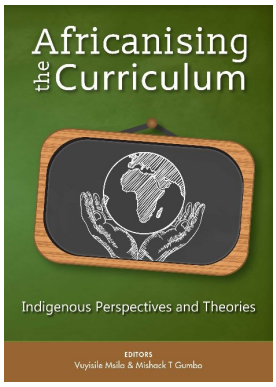

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We know from curriculum history that in times of social crises, there emerges calls for changes to the content of what is taught and learnt in schools and universities. In the days leading up to and following the installation of post-colonial government, that call for curriculum change was heard across continents where Europeans had taken whole countries as possessions. So too in the expectant period that followed Nelson Mandela's release from prison (1990) and the first years of post-apartheid democracy (1994). There are always two principal driving forces behind such calls for curriculum change: the one is symbolic (to signal change intentions – political, in other words) and the other is practical (to change what happens in classrooms – pedagogical, in other words).

The call for 'Africanisation' of curricula is at least as old as the Republic of Ghana, the first African country to gain independence – in 1961. That call could be summarised as follows. The colonial curriculum is Eurocentric and perpetuates Western bias. Students are more likely to learn European history, geography, literature and politics, than anything about those subjects in Africa. In the process, the great social, scientific and literary achievements of Africa in the pre-colonial period are ignored and undermined. When Africa is taught it is through the racist lens of inferior, incompetent, incapable states and individuals who required the colonial power to give the natives civilization through education, religion, governance and infrastructure – like parliament and piped water. Without the 'benevolence' of colonial rule, it follows, Africa would remain backward and barbaric. What is now required, in response, is a recovery of African knowledge and achievements from a distant past and which should be represented at the heart of the curriculum.

The South African university student uprising of 2015–2016 represented one such social crisis, by which I mean a massive disruption in South African society. Unsurprisingly, peaceful protests saw calls for the transformation of the university curriculum followed by more violent protests demanding the decolonisation of the curriculum. In record time, books appeared on these student protests giving academic veneer to the calls for changing the curriculum, both in its symbolic forms (sculptures, paintings, building names) and its practical expression in teaching and learning.

The collection of essays assembled by Vuyisile Msila and Mischack Gumbo comes in the wake of the recent South African student uprising and is therefore a timely collection of writings that speak to the curriculum angst in the student body and, more broadly, among university leaders. This co-edited book of 13 chapters and 10 authors (the editors each wrote four and an additional co-authored chapter) has topics ranging from the African Renaissance and African leadership to indigenous knowledge and the 'revival of the university'. Specific subjects include science education, teacher education and the decolonisation of curricula. In other words, a veritable mixed bag of topics from rather mainstream concerns such as 'mixed methods research' to the ambitious promise of 'a cultural revolution'.

The editors frame their contribution to the curriculum debates as 'Africanisation' rather than 'decolonisation' – despite a nominal reference to the latter in an opening chapter – which raises questions about meaning. Are these the same or similar constructs? Or does one construct subsume the other? We should begin this book review at this point.

In the social sciences, how you answer important curriculum questions depends on whom you ask, where and when. In its earliest forms following European rule, the Africanisation of the curriculum was meant simply as something opposite to, and in contrast with, the Europeanisation of the curriculum, so to speak. Where Europe was at the centre of colonial education in schools and universities, Africa should now occupy the centre as the organising principle around which knowledge, values and skills should be delivered for purposes of teaching and learning: a simple curriculum exchange.

A weaker version of Africanisation called for an additive model rather than a re-centred one. Here African knowledge should simply be added onto what already exists. The curriculum call, in this instance, was for inclusion and extension of African knowledge. Some would call this less radical version a contributionist (or 'us-also') approach to curriculum. And then there was a more radical call for curriculum change after colonial rule which demanded neither re-centring or contributory approaches but replacement – in other words, replace colonial knowledge with African knowledge: us without them. This more radical approach resonates with the more strident calls among students for the decolonisation of the curriculum.

The broad approach, at least from the perspective of the editors of *Africanising the Curriculum*, is one of re-centring – meaning the placement of Africa at the centre of the curriculum enterprise because 'Africans cannot ignore the Western belief systems' (p. iii) for 'humanity shares some knowledge forms and perspectives' (p. iii). While the curriculum position is accommodationist, the plea throughout the book is for an assertive African knowledge and identity at the heart of curriculum theory and practice.

Unfortunately for this book, its moderate Africanist appeal has been overtaken by a much more militant approach to the institutional curriculum to which several of the former white universities have already responded with the inevitable establishment of 'committees' to contain student demands. Not that the core theses of the student activists are irrelevant. It is still true that African thought and ideas are unevenly spread across university disciplines in public universities.

But curriculum transformation did not stand still at South African universities before or since 1994. At the English universities – despite the exaggerated claims of some activists – there has been significant progress in transforming institutional curricula from the impressive African archaeological discoveries at Wits University to the knowledge

recovery project of the University of Cape Town centred on Timbuktu in Mali. At the Afrikaans universities, curriculum transformation informed by Africanisation has been less visible but there are important niche areas such as the influential African Law programme at the University of Pretoria or the powerful research programme in Southern African history at the University of the Free State.

Even so, more could be done to bring a broader Pan-African influence across the university curriculum. In education, for example, some English universities still hold on to a curriculum heavily centred on European theorists like Bernstein and Bourdieu, while teacher preparation in some Afrikaans universities continues to be influenced by fundamental pedagogical thought from the apartheid era. The calls for curriculum transformation, whether in the traditional form of Africanisation or its more radical expression as decolonisation, are not without epistemological and political merit.

But the call for Africanisation (and decolonisation) is not without serious problems. It is hard not to conclude from the chapters in this edited book that Africanisation means black African. There is a racial and ethnic chauvinism at play, which is betrayed through both the limited range of authorship and the deployment of key words like 'pure' forms of the African curriculum. Where is the focus on complex Khoisan histories as in the research of Michael Besten? Or South African Indian symbolic knowledges presented in the writings of Devarakshanam (Betty) Govinden or radical Afrikaans literary explorations in works from Andre Brink to Hein Willemse – and new breakthroughs in creative fiction and poetry of Shirmoney Rhode and Ronelda Kamfer? It is difficult not to conclude that what is being proffered is often an essentialist black African version of Afrikaner nationalist thought.

Which of course raises a critical issue about knowledge, curriculum and identity in the 21st century. To insist on an African versus European curriculum in the age of globalisation is naïve. Our knowledges are integrated both at the level of knowledge as well as in the hands of knowledge workers. Our leading intellectuals stand with their feet in many worlds, travelling across borders and collaborating with their colleagues in Asia, Latin America and the large, very diverse 'West'. The insistence on a 'them vs us' dichotomy this side of colonial rule is anachronistic and unhelpful for those who actually do research and writing across the world; examples of such powerful North–South collaboration (led, incidentally, by black scientists from South Africa) are in the field of health sciences at the University of KwaZulu-Natal (in the area of HIV/AIDS research) and in cardiovascular research at the University of Cape Town. Not only is world knowledge entangled with theory from elsewhere – Southern Theory, for example – but new discoveries are being made in the social and natural sciences through transborder partnerships. Remaining trapped in a discourse of 'the West vs the rest of us' is to ignore changes in knowledge work over the past three decades since dependency theory held us captive. It is also to ignore the changing authority of African scholars and scholarship.

The continued grievance of a hapless African scholarship being dominated by Western 'knowledge and power' betrays an inferiority complex, on the one hand, and a lack of intellectual activism on the other hand. Those who complain loudest about a colonised curriculum often do the least to lead major research projects, produce the influential research books, edit influential African journals and speak truth to global power. The curriculum does not change itself. It changes in collaboration as well as competition with scholars around the world. It requires new bodies of research generated by and with African scholars across the disciplines. It also demands new authorities – new PhD graduates who are research ambitious and can generate theory and research which break new ground from field work on African research questions. Where is this scholarship?

Neither an Africanised curriculum nor a decolonised curriculum adequately come to terms with the reality of entangled knowledges represented in the realities of a 21st-century academy in which the lines are increasingly blurred between the identity, ownership and authority of scholarly transactions. It is time for curriculum theory and practice to move on from becoming stagnant and entrapped in a purist language of another era.

From Third World to developing world: The changing face of science in the South

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TWAS: A voice for science in the South

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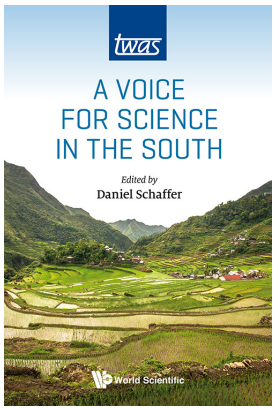

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TWAS: A Voice for Science in the South is a significant contribution to the history of science in the developing world, and a celebration of scientific capacity and excellence achievements that can be attributed to the gap filled by The World Academy of Science (TWAS).

TWAS was established in 1983 as the 'Third World Academy of Science', later known as 'TWAS: the Academy of Sciences for the Developing World', and now 'The World Academy of Science'. These name changes can be seen, literally, as TWAS' response to a changing science world, and, figuratively, as signifying the leaps and bounds that science in the South has experienced – changes to which TWAS' existence has contributed.

Written as a celebration of TWAS' 30 years of existence, the biographical lenses of eminent scientists are used to recollect their interactions with TWAS in its leadership structures, as its members, as leaders in complementary organisations such as the International Centre for Theoretical Physics, and as the next generation of scientists who not only aspire to be members of the academy but also have been recipients of the scientific capacity strengthening that has become congruent with TWAS in all its years of existence.

Through their stories of scientific excellence, the growth of their scientific capacities – including in national, regional and global science leadership mandates, and the passion that has led to their commitment to a thinning of the North–South divide in science, the book not only provides an opportunity to celebrate the contributions of the 11 scholars (representing Latin America, Africa, the Arab Region and Asia) but also weaves their stories with that of the growth of TWAS, and the changes witnessed in the global South on the role of science, technology and innovation (STI) as an engine of development in the last 30 years. These stories are of STI development and individual science career development in the South. They are stories that validate the contribution of the South to global science. Interwoven in their writing is an admirable chronicle of how TWAS' founding father and Nobel Laureate Abdus Salam's dream and vision has found deep resonance with so many others who have taken up the baton, leading with their own convictions but never departing from the original vision: the existence of a global academy of science at the forefront of building scientific capacity and excellence in the South, and in the words of Jacob Palis in the book, 'not just for the sake of science but for the sake of society'.

Academies of science perform a variety of functions: honouring and promoting scientific excellence; harnessing the collective intellectual capacities of their members to contribute to informing science policy; and, in some instances, being managers of research. The Royal Society of London, the French Academy of Science and the United States National Academy of Sciences are amongst the oldest national academies of science in existence. Globally, the advent of TWAS sought to fulfil a crucial need for an institution that would profile scientific excellence in the South; be a leader in contributing to scientific capacity building in the South; and be a voice of developing world science in global engagements and opportunities as that voice had been limited in the years following the Cold War.

For an academy that seeks to represent the voice of science in the South, the book falls short in its examination of the role of the social sciences and humanities, both within the academy and in the future TWAS. This gap is jarringly felt by the concentration of contributing authors in the natural and applied sciences, and the scant introspection given to how the future of TWAS should consider further expansion of the social sciences and humanities in its ranks of membership. This is specifically important in a 21st-century world in which interdisciplinarity, multidisciplinarity and transdisciplinarity are growing outlooks through which interwoven, transboundary and complex global challenges will be solved.

From a developing world (and in fact developed world) perspective, in its contemplation of the future of TWAS, the book provides a blueprint for the continued development of STI in the South – an exercise that seeks to magnify the vision of Abdus Salam. In the spirit of collegiality, increased partnerships and collaboration: (1) the quest towards an inclusive science that considers gender, geographical distribution, age and the North–South divide is an imperative; (2) institutional mechanisms governing science must be innovative with the changing face of science; (3) the role of academies of science in the science–policy nexus must be intensified to support growth of knowledge-based economies and evidence-based policymaking in the developing world; (4) leveraging, raising and optimal use of financial resources for STI should be vigorously and continually pursued; and (5) there must be a consistent re-examination of the growing South–South divide between emerging economies and scientifically lagging countries.

This book is relevant for those interested in the history and sociology of science.

Getting to grips with social media as an academic: Supplementing your scholarly process

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Social media for academics

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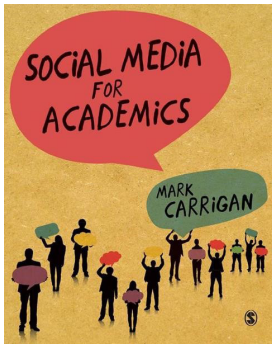

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Social media are all around us. I can say with great certainty that you will have received at least one request from a family member, friend or colleague to join a social media platform. In *Social Media for Academics*, Mark Carrigan suggests that, instead of completely resisting this tidal wave of social media, you should investigate what aspects of it you can make work for you in your professional life.

While other aspects of information technology, such as Internet searches to gather information and emails to communicate with colleagues, have become common practice in academia, the use of social media is less pervasive. This book comes at an opportune time to help academics, researchers and postgraduate students who have been thinking about using social media in their professional lives to get started. The book also provides a useful way for those already engaged on social media to reflect on their goals and purposes and refine their approach.

The book is explicitly not a step-by-step training manual for the multitude of tools available. Rather it takes the view that while the technology may change rapidly, the underlying motivation for using technology remains the same – to become more effective academics. Carrigan focuses on how the technology can feed into academic purposes (e.g. teaching, communicating, sharing). Accordingly, the book is grounded within the discipline of digital scholarship and higher education (Chapter 1), approaching the topic from the perspective of how social media can potentially support and enhance the scholarly activity you already undertake. For those who have been focused on the practice of using social media in their academic endeavours, this book provides a useful introduction to some of the relevant theory and the academic writings on social media use.

The next four chapters are the most helpful for potential or new social media users. These chapters lay the groundwork for why, as an academic or researcher, you should care about social media and help you to come to grips with the suite of possible activities: publicising your work (Chapter 2), building your network (Chapter 3), engaging with the public (Chapter 4) and managing information (Chapter 5).

Although Carrigan does draw on experiences and practices of academics with certain social media tools in their professional lives, these activities – refreshingly – do not focus on a particular set of tools for the most part. Instead each chapter explores some of the possibilities of how you could begin to integrate social media activity into your pre-existing academic work to enhance your practice.

The later chapters explore the challenges that an academic social media user may face: professional identity (Chapter 6), communicating effectively (Chapter 7) and finding time for social media (Chapter 8). I would recommend these chapters specifically for those already using social media spaces as they provide a very useful point of reflection. In the final chapter (Chapter 9), the author explores a few potential scenarios for the future use of social media in higher education. The suggestions for further reading at the end of each chapter act as a useful guide to explore the particular topic further.

The book introduces many important ideas, issues and risks regarding the social media space, such as accessibility of the publications you share, the presence or absence of institutional social media policies and what they can enable and constrain, and the possibility of people engaging with you publically in an unpleasant way. While Carrigan may leave readers wanting to know more, introducing these concepts and challenges does help to flag areas that they may need to investigate further without overwhelming them.

A recurring piece of advice given in the book is to find a balance between what you want to get out of using social media and what you are willing (and able) to put into it in terms of time and energy. The book advises academics to think carefully about their purpose(s) in using social media (visibility, networking, outreach, etc.) and to set goals to help them check on whether they are achieving their original purpose. Finding what works for you, in your context, to achieve your purposes and goals is a key to successfully integrating social media into your working life.

Throughout the book, Carrigan shares the personal story of his move into and experience of the realm of social media as well as key insights from other academics and researchers using such media to communicate and connect professionally. This narrative approach, although sometimes weighted towards the author's experience of certain tools and scenarios, provides good food for thought. The experiences discussed in the book can help the reader to consider whether that approach might work for them in their own academic workflow. They highlight how certain social media tools could be connected to current practice in the research and publishing process, linking older methods of sharing academic work with the possibility of new online tools.

A concern regarding the approaches advocated in the book, especially for those in the Global South, is the general assumption of pervasive availability of (cheap) Internet access and connected personal devices. In contexts in which Internet and electricity are not necessarily widely available, cost-effective or reliable, several of the possibilities suggested in the book would be excluded or, at the very least, narrowed in scope. Yet the awareness of the possibilities as outlined in the book may still aid academics in such scenarios to better select the tools that are most appropriate for their context.

I recommend this book to academics, researchers and postgraduates who are using or thinking about using social media professionally as well as those interested in an introduction to the literature around social media use. It may also be of interest to media and communications departments and those involved in articulating policy around social media at higher education institutions. Even if you are a social media skeptic, you may find that you put down this book with a new perspective and an awareness of approaches that can help with your academic work in our increasingly digital and online world.

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Exploring South Africa's southern frontier: A 20-year vision for polar research through the South African National Antarctic Programme

Antarctica, the sub-Antarctic islands and surrounding Southern Ocean are regarded as one of the planet's last remaining wildernesses, 'insulated from threat by [their] remoteness and protection under the Antarctic Treaty System'[1]. Antarctica encompasses some of the coldest, windiest and driest habitats on earth. Within the Southern Ocean, sub-Antarctic islands are found between the Sub-Antarctic Front to the north and the Polar Front to the south. Lying in a transition zone between warmer subtropical and cooler Antarctic waters, these islands are important sentinels from which to study climate change.[2] A growing body of evidence[3,4] now suggests that climatically driven changes in the latitudinal boundaries of these two fronts define the islands' short- and long-term atmospheric and oceanic circulation patterns. Consequently, sub-Antarctic islands and their associated terrestrial and marine ecosystems offer ideal natural laboratories for studying ecosystem response to change.[5] For example, a recent study[6] indicates that the shift in the geographical position of the oceanic fronts has disrupted inshore marine ecosystems, with a possible impact on top predators. Importantly, biotic responses are variable as indicated by different population trends of these top predators.[7,8] When studied collectively, these variations in species' demographic patterns point to complex spatial and temporal changes within the broader sub-Antarctic ecosystem, and invite further examination of the interplay between extrinsic and intrinsic drivers.

Further south, beyond the Polar Front, the Southern Ocean and Antarctica provide a unique platform from which to investigate questions of past, present and future change. For example, continental ice cores provide a record of earth's climatic history over the last 800 000 years[9,10] and the isotopic composition of the fossil shells of benthic foraminifera provides a proxy measure of past sea temperatures and ice volume[11]. The region's varied pelagic and benthic ecosystems are already showing responses to current environmental change – including declining primary production, changes in circulation and mixed layer depth – as well as impacts on keystone species in Antarctic food webs. Sea ice around the Antarctic Peninsula is rapidly disappearing, potentially driving a decrease in krill biomass as a result of reduced recruitment.[12] By comparison, sea ice extent around the rest of Antarctica is increasing and while West Antarctica is warming, East Antarctica is cooling. Even advanced climate models cannot adequately capture these opposing trends, reducing our ability to predict future changes and impacts in the region. The complex interplay between these positive and negative melting trends has highlighted the vulnerability of Antarctic Bottom Water formation, which may be compromised by increased fresh water input through increased melt run-off in a warming climate.[13] Measures of global sea level rise are currently 3 mm per year, but these levels could increase rapidly if the unstable West Antarctic ice sheet melts, including the ongoing collapse of the Larsen B and C Ice Shelves.

The Southern Ocean is also a crucial sink for anthropogenic CO_2[14], but may become a future source[15]. In addition, this ocean is a major reservoir of unused macronutrients, particularly nitrate and phosphate, primarily because of iron and light limitation of phytoplankton growth.[16] Consequently, this region exports essential nutrients to the lower latitude oceans via intermediate and bottom water circulation. How changes in Antarctic Bottom Water formation will alter such nutrient fluxes remains unexplored. Moreover, changes in macronutrient utilisation by phytoplankton in Southern Ocean surface waters will control the ocean's ability to regulate atmospheric CO_2 in future.[17]

In addition to the importance of the Southern Ocean in oceanographic, climate and ecological research, other opportunities for research exist – notably in space science, exploration and earth's geological history. The dry, stable atmosphere over Antarctica and the convergence of the earth's magnetic field lines provide ideal conditions for studying the near earth space environment, the solar system, and the universe beyond. Related to this, the varied continental ecosystems hold secrets to life in extreme environments. As Antarctica was once part of the supercontinent Gondwana, an understanding of its evolution is key to understanding the broader evolution of the neighbouring continental blocks of Africa, India and Australia.[18]

Taken together, Antarctica and the Southern Ocean form a critical natural laboratory where international scientific investigation can infer the fundamental drivers of the entire earth system and of the near-earth space environment. Advancing our understanding is critical to better comprehend the region's role in global ocean-atmospheric circulation, ecosystem adaptation and its impact on earth's radiation balance. Research emanating from this region already offers conclusive and alarming evidence that the world's climate is changing rapidly. The need to continue monitoring is critical.

A pivotal role for South Africa in the Antarctic and Southern Ocean

South Africa has a strong geographical advantage for conducting and directing research in the Antarctic and Southern Ocean (Figure 1). Logistically, it is the closest African point to the South Pole and is a well-established gateway to Antarctica – acting as a summer springboard for many international expeditions. The distance to Antarctica is the greatest of all southern continents, allowing for a unique configuration of ocean circulation. A transect between Cape Town and Antarctica crosses one of the world's most oceanographically and biologically dynamic regions, encompassing three ocean basins, two major boundary currents and the circumpolar current. The Southern Ocean south of Africa also marks the intersection of deep and bottom water masses (Figure 1), which modulate both heat and CO_2 exchange with the atmosphere.

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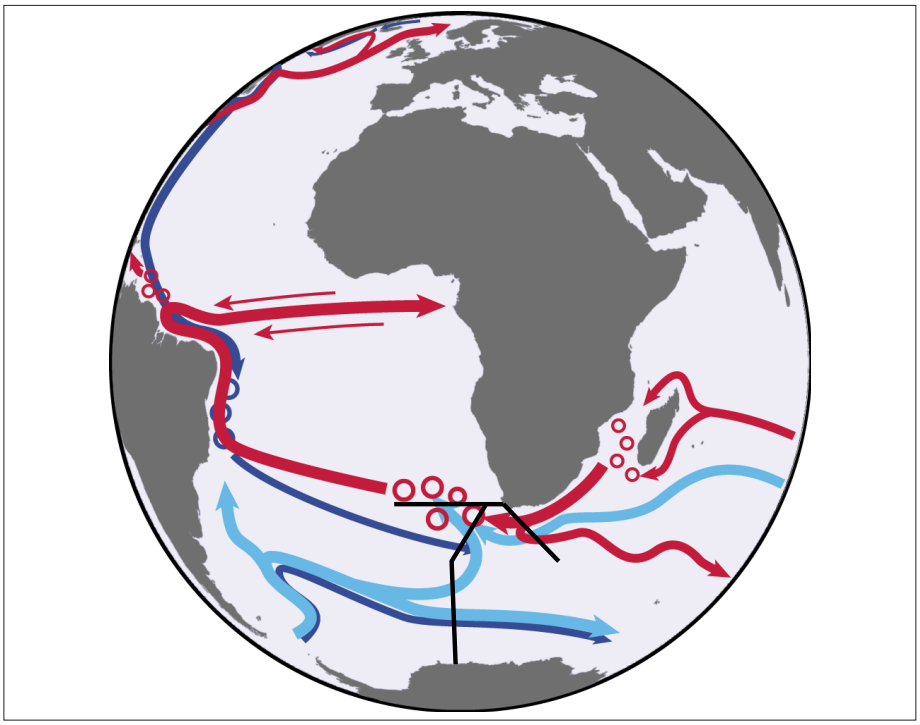

Image courtesy of Jonathan Durgadoo, GEOMAR, Kiel.

Figure 1: Schematic of the ocean circulation south of Africa. Colours indicate surface (0–1000 m, red), intermediate (1000–1500 m, light blue) and deep (1500–4000 m, dark blue) pathways and their interconnectivity. In the South Atlantic, two northward flowing routes exist: the cold-water route which is the direct inflow from the Drake Passage, and the warm-water route southwest of South Africa. The three black lines highlight the main transects occupied by the SA *Agulhas II* during its annual relief voyages to the Prince Edward and Gough Islands and SANAE on the Antarctic continent. Measurement of the ionospheric dynamics by means of the ionospheric scintillation monitor on the SA *Agulhas II* provides a unique data set for studying the impact of the South Atlantic Magnetic Anomaly on ionospheric dynamics.

Indeed, the South African Weather Service already capitalises on this geographical advantage through an established long-term observation programme at its Cape Point Global Atmosphere Watch Station. From a biological perspective, South Africa has had a research presence on the Prince Edward Islands since 1951[19,20], which, together with annual visits to Gough Island in the South Atlantic, has allowed for time-series observations and monitoring at both sites. In contrast, Dronning Maud Land in Antarctica is a distinct biogeographical region that remains poorly studied.[21] The South African National Antarctic Expedition bases (SANAE I–IV) have been located in the region since the 1960s. The current SANAE IV base is ideally situated to address the gaps in terrestrial earth and biological research.

South Africa was a founding member of the Antarctic Treaty System which, over the past 50 years, has proven to be an effective governance regime for Antarctica and the adjacent Southern Ocean. South Africa is currently the only African signatory to this treaty and the only African nation with an Antarctic research programme. The country therefore bears a regional responsibility to serve the broader African community. The Antarctic Treaty System advances a philosophy of peace and security based on principles of mutual cooperation, excellence in scientific research and high standards of environmental protection. As an active participant, South Africa has a long-standing track record and long-term commitment to undertaking research in the region.

South Africa has an interest in ensuring that the Treaty continues to be recognised as the *only* appropriate mechanism for the management, environmental stewardship and governance of the region. To this end, the South African government has indicated its ongoing commitment to continued research through major financial investments in new state-of-the-art platforms – including new and refurbished bases on Marion Island and at SANAE IV; a new polar research and supply vessel, the SA *Agulhas II*; and a new ocean robotics facility at the Council for Scientific and Industrial Research (CSIR). In addition, the establishment of a nationwide South African Environmental Observation Network (SAEON) and DST/NRF Centres of Excellence has further facilitated outstanding academic research, helping to ensure that South African marine and terrestrial science remains at the forefront of international recognition.

Notwithstanding the obvious importance of multidisciplinary and multinational research in this region, there is an increasing fear that these priorities will be neglected in the face of growing economic and human challenges. This fear has been widely recognised in various discussion forums, most notably in the recently released 20 Year Australian Antarctic Strategic Plan which states that 'leadership is fast eroding as logistic and scientific capabilities rapidly stagnate'.

In parallel to national research investments, South Africa remains a party member to various international Southern Ocean and Antarctic initiatives and these continue to guide its research mandate and interests. South Africa is represented on the Scientific Committee on Antarctic Research (SCAR) and within the Council of Managers of National Antarctic Programmes. South African researchers are also leaders and key participants in several SCAR Scientific Research Programmes and Expert/Action Groups across the broad fields of biology, geology and physical sciences.

In the sub-Antarctic belt, the Prince Edward Islands are globally important breeding sites for several marine top predators, including albatrosses and petrels, which South Africa, through its membership of the Agreement on the Conservation of Albatrosses and Petrels, has agreed to conserve. The islands were declared a Special Nature Reserve in 2013 under the *NEMA: Protected Areas Act 57 of 2003* and currently enjoy the highest level of protection of any South African natural area. The large South African exclusive economic zone around these islands exceeds that of mainland South Africa in coverage and likely supports important marine resources.[22] Through the declarations outlined above, South Africa is responsible for all research, monitoring and conservation activities in the region.

Since the inception of the Antarctic Treaty System, South Africa has been at the forefront of a number of major international oceanographic, astrophysical, biological and biophysical projects in which international partnerships are well embedded. These projects seek to develop not only the infrastructure for global research, but also to train and develop human capacity in these scientific fields including, most recently, space research through the establishment of the South African National Space Agency (SANSA).

Antarctic and Southern Ocean research for South Africa and Africa

In a country such as South Africa – with its complex socio-political history, structures and a large population, many of whose lives are determined by day-to-day necessities of food security, water resources, health and education – it is imperative that the scientific community interrogate the need for continued South African involvement in Antarctica and the Southern Ocean. The recently established national Marine Antarctic Research Strategy (MARS) plan achieves just that.

MARS aims to consolidate Antarctic and Southern Ocean research efforts by the Department of Environmental Affairs (DEA), Department of Agriculture, Forestry and Fisheries (DAFF) and Department of Science and Technology (DST), while remaining central to the expectations and deliverables emerging from the Operation Phakisa Oceans Economy initiative. For South Africa to conduct world-class science, there is a clear need to strengthen Antarctic and Southern Ocean research and its capacity through strong leadership, coordination and consolidation. To achieve these goals, MARS prioritised five thematic areas, which are listed below. It is expected that MARS will soon be implemented through DST and DEA channels and that existing South African National Antarctic Programme (SANAP) activities will be reviewed to align with this multifaceted strategy. Continued financial investment in promoting a broad portfolio of multidisciplinary research under MARS, and its implementation through national research programme calls such as SANAP, are essential if South Africa wishes to remain globally competitive in this key geopolitical region.

Of importance now is aligning ongoing and well-established national and international projects with the MARS themes, while allowing for growth and a re-evaluation of priorities.

MARS Theme 1: Oceans and marine ecosystems under global change

Large-scale ocean circulation and global climate

The Meridional Overturning Circulation (MOC) is a global system of surface and deep ocean currents. It is the primary mechanism for the ventilation, transport and storage of heat, fresh water and carbon throughout the global oceans, and connects the ocean surface and atmosphere with the deep oceanic reservoir of heat, nutrients and carbon. Central to the MOC is the Southern Ocean, which provides a link between the upper and lower ocean layers, and across all ocean basins. The most dynamic region of the Southern Ocean–MOC circuit lies south of Africa. To identify the potential drivers of climate change in this region, we need to improve understanding of the interplay between the Southern Ocean and the Greater Agulhas Current systems.

Southern Ocean in the coupled ocean-atmosphere-biosphere system

The Southern Ocean is an important component in the global carbon cycle and is responsible for 40–50% of the ocean's anthropogenic CO_2 uptake.[14,23] Understanding the links between ocean-atmospheric physics, light and iron availability, macronutrient and trace element biogeochemistry, ocean ecosystem functioning and productivity are crucial to reliable modelling of carbon–climate feedbacks. Extensive multiscale and seasonal investigations into the sensitivity of large-scale trends in the Southern Ocean are necessary. Through combined observations and empirical models, we can derive low-uncertainty CO_2 exchange fluxes and help assess the risks associated with a changing oceanic carbon cycle.

Antarctic sea ice and its role in the environment

The seasonal growth and decay of the Antarctic's 15 million square kilometres of sea ice is a phenomenon that remains under-appreciated, particularly during winter when access is limited. The use of remote-sensing observations allows capture of the large-scale and longer-term variations, but this information needs to be ground-truthed by appropriate observations. Sea ice also acts as a habitat for microorganisms and a buffer for nutrients, CO_2 and trace elements. Earth system models have a coarse parameterisation of sea ice processes, mostly designed to modulate the transfer of heat and CO_2 fluxes across the sea surface. There is a clear need for further research to better understand how these processes influence the Antarctic cryosphere.

MARS Theme 2: Earth systems

A window into geospace

Fundamental questions for space physics include the mechanisms of energy transfer between the different layers in the upper atmosphere and the impact of space weather on the middle atmosphere and modern electrical technologies (e.g. radio communications) on the ground. We have a limited understanding of the generation and impacts of space weather; important questions include how helio-climate variability may impact long-term terrestrial climate, or how best to forecast the severity of impacts on our atmosphere and technologies from sporadic solar storms.

SANSA operates an extensive array of ground-based instruments to monitor space weather from southern Africa, Gough and Marion Islands, SANAE IV and the SA *Agulhas II*. For example, space weather observations within the South Atlantic Magnetic Anomaly where the earth's magnetic field is weakest, are critical for understanding the impact of particle precipitation on ionospheric scintillation and its impact on satellite navigation.

A window into earth's history

By driving the global carbon cycle, the Southern Ocean has played a key role in earth's climate over millennia. To understand both the magnitude and rate of current change, the scientific community needs to delve into the past. Some of the best-known proxies for past climate are derived from isotope ratios recorded in microfossils such as foraminifera and diatoms, which serve as a palaeo-thermometer and record of ice volume[11], as well as an archive of past nutrient utilisation[24]. Similarly, gases trapped in continental ice-cores provide a CO_2 and temperature record exceeding 800 000 years.[9,10] Combining multiple proxies in sediment or ice cores and cosmogenic nuclide dating of eroded surfaces and deposits allows reconstruction of past climate evolution, sea ice extent and environmental consequences.

Although the configuration of Gondwana is fairly well constrained prior to its fragmentation, the geological processes and distribution of the continental blocks which led to its amalgamation are still poorly understood and are the focus of continuing research. This research is focusing on obtaining better data and an improved understanding from the recent magnetic and gravity aerial surveys of the sub-glacial rock basement and will contribute to the recognition and definition of sub-glacial continental blocks, which comprised pre-Gondwana supercontinents like Rodinia. In this context, Dronning Maud Land lies in the broad area of the intersection of two orogenic mountain belts of similar age – the East African and Kuunga Orogenies – both of which also transect southern Africa and northern Mozambique.

In the shorter term, the terrestrial landscape of continental Antarctica, most visible in the areas of exposed ground called nunataks, is key to understanding the earth system's responses to global change. Ground temperature measurements in the region show that the active layer and permafrost temperatures continue to increase. Such information has important implications for understanding Antarctic geomorphology, permafrost, the active layer and water availability in soils, as well as how these are changing in a warming climate.

MARS Theme 3: Living systems

Ecosystem functioning and the response to global change

How resilient are Antarctic and Southern Ocean ecosystems to global change? The terrestrial ecosystems in the sub-Antarctic provide valuable opportunities to study ecosystem responses to global change. The Prince Edward Islands, in particular, have experienced warming at double the global average rate and a decrease in precipitation of 30% since the 1960s. Some biotic (e.g. rapid upslope expansion of flora) and abiotic (e.g. loss of ice plateau) consequences of these climatic changes have already been documented, with severe impacts on ecosystem functioning predicted.[25,26] Furthermore, the study of seabirds and seals at their terrestrial breeding grounds can also provide valuable information on the state of the surrounding marine environment.

About 85% of all ocean productivity is supported by nutrients derived from the Southern Ocean. These nutrients are seldom limiting south of 50°S, yet phytoplankton biomass remains low as a result of iron and light limitation.[27] Tight interactions across the food web also impact a wide range of trophic levels, from bacteria and viruses to apex marine predators. Global warming is likely to drive important changes in biological interactions between the components of the pelagic food webs. Currently, abilities to reproduce the seasonal cycle of primary producers with numerical models are limited, which impacts the reliability of projected responses to changes. At the same time, the microbial community and predators (from krill to killer whales) have complex, little-understood feedbacks that affect phytoplankton productivity and therefore biogeochemical cycles that are of global importance.

Sub-Antarctic islands typically have simple ecosystems, which have been affected by the variable histories of these islands (continental or volcanic origin, glaciation, volcanism) linked to global change. For Marion Island, genetic diversity is unexpectedly high and notably structured across the island[28-30], while at local scales, dispersal is influenced by prevailing winds and local topography[31]. Understanding the exact drivers of such high diversity and spatial complexity, as well as the role of local adaptations, will be important in ensuring the long-term conservation of biota.

Given their extreme isolation, both Antarctica and the sub-Antarctic islands also form an ideal system for understanding invasion trajectories and for examining the impacts of species introductions (and subsequent eradication; e.g. feral cats) on ecosystem functioning.[32] Invasive species on Marion and Gough Islands are of growing concern as a consequence of the changes which they effect on native species (with documented impacts on seabirds, invertebrates and plants) and the resulting impacts on primary productivity, nutrient dynamics and community composition. In contrast to several new species becoming established on sub-Antarctic islands, few alien species have to date established themselves on continental Antarctica, although the potential for the establishment of human-transported species (and the associated environmental impacts) may increase strongly under warming conditions. As a result, these ecosystems are also particularly well suited for studying the interplay between climate change and biological invasions.

Biodiscovery and biotechnology

Recent advances in metagenomics have focused attention on mining genomes for enzymes, biocatalytic pathways and bioactive secondary metabolites with industrial and pharmaceutical potential, as well as on the potential for gene discovery in the largely unexplored novel marine viral genomes. While the sub-Antarctic and Antarctic regions, including the Southern Ocean and the sea ice, are thought to be regions of relatively low species diversity, high levels of endemism reflect adaptation to these extreme environments. There is scope and capacity within South Africa to explore the potential of this field. Modern metagenomic bioprospecting methods have the advantage that they have almost zero environmental impact – just a few grams of soil or water can generate gigabases of nucleic acid sequences.

MARS Theme 4: Innovation and technology

Technology and engineering

The infrastructure and logistics supporting research are constantly in need of re-design, maintenance and improvement. The harsh conditions of the Antarctic provide an opportunity to evaluate the most recent designs and adaptation of technologies and construction materials. Over and above being infrastructure platforms, research vessels act as high-resolution measurement probes which contribute to the validation of satellite data and climate models. This research area offers unique opportunities for innovative and leading engineering studies; within the South African context this field is largely unexplored. Furthermore, the challenging field conditions for biological research also promote creativity and ingenuity in the use and development of novel technologies[33] that can be applied more broadly[34].

Robotics

Modern technologies are delivering significant advances in automation and unmanned platforms that can address our lack of scientific ability or continued presence through year-round observations.[35] Such vested activities in engineering and robotics have multiple auxiliary benefits to society by spurring scarce skills in engineering and innovation that provide positive spin-offs for the greater South African economy. It is important that South Africa remains a global leader in the rapidly growing area of specialised marine technology and robotics.

MARS Theme 5: Human enterprise

Geopolitics and legal aspects

South Africa has enacted a number of statutes that are directly or indirectly relevant to this region. It is therefore essential to monitor and ensure that the South African domestic legislative and regulatory framework remains in line with developments in international law.

Human history and archaeology

Although relatively recent, there is a rich history of human enterprise in the Antarctic and Southern Ocean. The Antarctic Legacy of South Africa archival database is an online, open-access tool for supporting historical, archaeological, sociological and other research. This research sub-theme intends to encourage usage of the resource and to develop and refine this important asset.

Arts, architecture and literature

South African activities within the humanities in Antarctica and the Southern Ocean remain insignificant and the few that have been undertaken remain poorly recorded. The challenge is to engage with non-scientists, creating opportunities for artists (such as writers, poets

and musicians) and social scientists to partake in SANAP voyages to see for themselves the region and to be involved with South Africa's activities within it. This area has been addressed successfully by other programmes, for example by Australian researchers through an initiative called 'Antarctica: A new musical'.

Social adaptation and human impact

The Antarctic and Southern Ocean is a harsh inhospitable region in which any human activity can be extremely stressful and unforgiving. As such, the region provides a natural laboratory for studying the human condition under stress. Also, tourism to the polar region is increasing and already makes use of South African infrastructure. The effects of tourism in these highly sensitive regions of the world need to be closely studied.

Taking South African Southern Ocean and Antarctic Science forward

Are we able to align with the SCAR Antarctic and Southern Ocean Horizon Scan priorities? In October 2016, South Africa's leading polar researchers convened a 2-day workshop in Cape Town. The aim of this workshop was to build on past policy efforts under the MARS and Operation Phakisa Ocean Economy Initiatives and to review the 2014 National Research Plan for South Africa in Antarctica and the Southern Ocean.[36] The workshop aimed to formulate a renewed vision at retaining world-class research, technology and innovation within the SANAP framework. The workshop created a forum to debate identified priorities and challenges for research and to discuss how best to align these priorities to the societal needs outlined by MARS. This Commentary summarises the outcome of the workshop; it presents specific priorities for research investment while identifying challenges and infrastructural needs critical to ensure that South Africa retains its international edge in polar research. Furthermore, we identify steps that both academic researchers and government departments must follow if (1) this vision is to become a reality, (2) South Africa is to retain its geographical and historical advantage in the region, and (3) the country's polar research programme is to remain a proud and sustainable national contributor to Antarctic research in the future.

The need for development of a comprehensive research theme for South African science in Antarctica and the Southern Ocean has been the concern of the scientific community for over a decade. Following the transfer of the research management role of SANAP from the then Department of Environmental Affairs and Tourism (DEAT) to the DST in 2003, DST produced an Antarctic Research Strategy for South Africa (ARESSA) to guide SANAP research. The ARESSA vision was to establish a national research programme that will (1) develop human capital innovation and economic growth, (2) increase the programme's international profile and influence, and (3) create a coordinated interactive effort towards public visibility. The implementation of the national research effort unfortunately remains to this day fragmented, with strategic priorities defined across several key stakeholders in a largely uncoordinated manner.

The recent National Research Plan for South Africa in Antarctica and the Southern Ocean and MARS reports both plan to seek a clearer vision by aligning extensive and targeted research within the Antarctic and oceanic domains while meeting key challenges identified by the 2014 SCAR Horizon Scan.[37]

How can SANAP make a global impact?

While the themes above clearly identify with those of the international community, the question unique to South Africa is what approach should be taken to achieve the success of this vision against the context of South Africa's increasing societal needs? The ongoing societal challenges that South Africa faces are in stark contrast to the escalating costs and logistics of accessing such remote regions. Yet the past few decades have seen a growing appreciation by government of the major importance of Antarctica and the Southern Ocean in governing global climate. With climate change predicted to severely impact on resources and future agricultural productivity in South Africa, understanding the mechanisms that drive change is of fundamental importance. What is critical is for South African polar science to move away from single researcher or institution projects to multidisciplinary (multinational) and integrated projects, with collaborators from a number of fields who address broad and internationally relevant questions. To do so, increased research time across all disciplines is critical to allow more comprehensive and in-depth research questions to be addressed.

The bulk of oceanographic research continues to be restricted to the three logistic relief operations, with only an additional 30 dedicated sea days available each year. For land-based research, the relief voyages provide a major limitation by their time-constrained access to Antarctica and the islands (logistical requirements dictate research access). Although there is comparable long-term data series, seasonal data are lacking and are crucial to understand biotic responses to changes in climate. The number of participants per voyage is also limited by space; large numbers of berths are reserved for logistical and maintenance personnel.

There is an increasing trend to link pure or basic research with applied research. One such opportunity can come from closer ties between SANAP-orientated research and commercial enterprises, notably fisheries. From a fisheries perspective, there is a growing world food security concern and the need to increase fisheries yields in this region is well recognised. As fishing technology continues to improve, large-scale krill fishing will become economically viable, and within a decade South Africa could find itself well placed geographically to benefit in terms of economics and job development from a krill fishery. This will require concurrent advances in single and multispecies models to provide the basis to maintain and regulate a sustainable fishery; this field is one in which South Africa continues to make valuable contributions.[38,39]

Bridging together operations with often competing interests is critical for the success of any polar research programme.[40] It is now critical that these activities be facilitated through a single polar research entity, which provides a platform for multinational and multidisciplinary collaborations. In doing so, the scientific community is able to obtain a critical mass and direct its efforts and limited resources towards key research goals – a strategy adopted by many international partners.

A clear message from the recent workshop for the long-term visibility and sustainability of SANAP is to ensure research outcomes are of global relevance. Such excellence can be attained through high-impact publications, continued leadership in Antarctic and Southern Ocean affairs and high-level and close coordination between science and logistical activities. Most importantly, South Africa's role as both a regional and international leader is linked to the development of high-quality human capital in sciences and numeracy. Furthermore, the associated study fields have to be competitive in terms of bursaries and travel grants, to attract the most talented people within the country. A blueprint outlining future opportunities for early career researchers working in this region is critical for the interaction and strengthening of both international and national networks. The Antarctic and Southern Ocean region provides excellent opportunities for raising public awareness and engaging with the future generation of polar scientists. Not only are the conditions and environment spectacular, but the scope of science from space research to deep sea exploration is extreme. South Africa's ability to enthuse the next generation of scientists can be enhanced by the use of modern day social media and more conventional channels – the recent success of SEAmester, South Africa's Class Afloat programme[41], is an example.

It is critical that, in future years, SANAP continues to remain well positioned to respond to new breakthroughs and new environmental challenges and, at the same time, remains effective in its ability to foster innovation and discovery. Workshops such as the one reported on here are essential to allow scientists to align Antarctic research priorities to national priorities, thereby ensuring a cohesive vision for future research priorities. At a time of tightening budgets and unforeseen cuts in research and logistical support and limited access outside of logistical voyages, the need to prioritise the scientific and societal demands of South Africa remains our greatest challenge. Notwithstanding, Antarctic and Southern Ocean research has made, and will continue to make, pivotal contributions to South Africa's international research standing and our global research footprint.

References

1. Shaw JD, Terauds A, Riddle MJ, Possingham HP, Chown SL. Antarctica's protected areas are inadequate, unrepresentative, and at risk. PLoS Biol. 2014;12, e1001888, 5 pages. http://dx.doi.org/10.1371/journal.pbio.1001888
2. Ansorge IJ, Durgadoo JV, Treasure AM. Sentinels to climate change. The need for monitoring at South Africa's Subantarctic laboratory. S Afr J Sci. 2014;110, Art. #0044, 4 pages. https://doi.org/10.1590/sajs.2014/a0044
3. Graham RM, De Boer AM, Heywood KJ, Chapman MR, Stevens DP. Southern Ocean fronts: Controlled by wind or topography? J Geophys Res. 2012;117, C08018. https://doi.org/10.1029/2012JC007887
4. Constable AJ, Melbourne-Thomas J, Corney SP, Arrigo KR, Barbraud C, Barnes DKA, et al. Climate change and Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. Glob Change Biol. 2014;20:3004–3025. https://doi.org/10.1111/gcb.12623
5. Bergstrom DM, Chown SL. Life at the front: History, ecology and change on Southern Ocean islands. Trends Ecol Evol. 1999;14:472–477. https://doi.org/10.1016/S0169-5347(99)01688-2
6. Allan EL, Froneman PW, Dugadoo JV, McQuaid CD, Ansorge IJ, Richoux NB. Critical indirect effects of climate change on sub-Antarctic ecosystem functioning. Ecol Evol. 2013;3:2994–3004. https://doi.org/10.1002/ece3.678
7. Pistorius PA, De Bruyn PJN, Bester MN. Population dynamics of southern elephant seals: A synthesis of three decades of demographic research at Marion Island. Afr J Mar Sci. 2011;33:523–534. https://doi.org/10.2989/1814232X.2011.637357
8. Wege M, Etienne M-P, Oosthuizen WC, Reisinger RR, Bester MN, De Bruyn PJN. Trend changes in sympatric Subantarctic and Antarctic fur seal pup populations at Marion Island, Southern Ocean. Mar Mammal Sci. 2016;32:960–982. https://doi.org/10.1111/mms.12306
9. Jouzel J, Masson-Delmotte V, Cattani O, Dreyfus G, Falourd S, et al. Orbital and millennial Antarctic climate variability over the past 800,000 years. Science. 2007;317:793–796. https://doi.org/10.1126/science.1141038
10. Lüthi D, Le Floch M, Bereiter B, Blunier T, Barnola J-M, Siegenthaler U, et al. High-resolution carbon dioxide concentration record 650,000–800,000 years before present. Nature. 2008;453:379–382. https://doi.org/10.1038/nature06949
11. Lisiecki LE, Raymo MEA. Pliocene-Pleistocene stack of 57 globally distributed benthic $d^{18}O$ records. Paleoceanography. 2005;20, PA1003. https://doi.org/10.1029/2004PA001071
12. Trivelpiece WZ, Hinke JT, Miller AK, Reiss CS, Trivelpiece SG, Watters GM. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. Proc Natl Acad Sci USA. 2011;108:7625–7628. https://doi.org/10.1073/pnas.1016560108
13. Williams GD, Herraiz-Borreguero L, Roquet F, Tamura T, Ohshima KI, Fukamachi Y, et al. The suppression of Antarctic bottom water formation by melting ice shelves in Prydz Bay. Nat Commun. 2016;7:12577. https://doi.org/10.1038/ncomms12577
14. DeVries T. The oceanic anthropogenic CO_2 sink: Storage, air-sea fluxes, and transport over the industrial era. Global Biogeochem Cycles. 2014;28:631–647. https://doi.org/10.1002/2013GB004739
15. Tollefson J. How much longer can Antarctica's hostile ocean delay global warming? Nature. 2016;539:346–348. https://doi.org/10.1038/539346a
16. Tagliabue A, Mtshali T, Aumont O, Bowie AR, Klunder MB, Roychoudhury AN, et al. A global compilation of dissolved iron measurements: Focus on distributions and processes in the Southern Ocean. Biogeosciences. 2012;9:2333–2349. https://doi.org/10.5194/bg-9-2333-2012
17. Sarmiento JL, Toggweiler JR. A new model for the role of the oceans in determining atmospheric pCO_2. Nature. 1984;308:621–624. https://doi.org/10.1038/308621a0
18. Grantham GH, Macey PH, Ingram BA, Roberts MP, Armstrong RA, Hokada T, et al. Terrane correlation between Antarctica, Mozambique & Sri Lanka: Comparisons of geochronology, lithology, structure and metamorphism and possible implications for the geology of southern Africa and Antarctica. In: Satish-Kumar M, Motoyoshi Y, Osanai Y, Hiroi Y, Shiraishi K, editors. Geodynamic evolution of East Antarctica: A key to the east–west Gondwana connection. Geological Society of London Special Publications. 2008;308(1):91–119. https://doi.org/10.1144/SP308.4
19. Rand RW. Notes on the Marion Island fur seal. Proc Zool Soc Lond. 1956;126:65–82.
20. Van Zinderen Bakker EM, Winterbottom JM, Dyer RA. Marion and Prince Edward Islands. Report on the South African biological and geological expedition 1965-1966. Cape Town: A.A. Balkema; 1971.
21. Terauds A, Chown SL, Morgan F, Peat HJ, Watts DJ, Keys H, et al. Conservation biogeography of the Antarctic. Divers Distrib. 2012;18:726–741. https://doi.org/10.1111/j.1472-4642.2012.00925.x
22. Lombard AT, Reyers B, Schonegevel LY, Coopers J, Smith-Adao LB, Nel DC, et al. Conserving pattern and process in the Southern Ocean: Designing a marine protected area for the Prince Edward Islands. Antarct Sci. 2007;19:39–54. https://doi.org/10.1017/S0954102007000077
23. Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL, et al. The oceanic sink for anthropogenic CO_2. Science. 2004;305:367–371. https://doi.org/10.1126/science.1097403
24. Martínez-García A, Sigman DM, Ren H, Anderson RF, Straub M, Hodell DA, et al. Iron fertilization of the Subantarctic Ocean during the Last Ice Age. Science. 2014;343:1347–1350. https://doi.org/10.1126/science.1246848
25. Smith VR. Climate change in the sub-Antarctic: An illustration from Marion Island. Clim Change. 2002;52:345–357. https://doi.org/10.1023/A:1013718617277
26. Le Roux PC, McGeoch MA. Rapid range expansion and community reorganization in response to warming. Glob Change Biol. 2008;14:2950–2962. https://doi.org/10.1111/j.1365-2486.2008.01687.x
27. Martin JH. Glacial-interglacial CO_2 change: The iron hypothesis. Paleoceanography. 1990;5:1–13. https://doi.org/10.1029/PA005i001p00001
28. Mortimer E, Jansen van Vuuren B. Phylogeography of *Eupodes minutus* (Acari: Prostigmata) on sub-Antarctic Marion Island reflects the impact of historical events. Polar Biol. 2007;30:471–476. https://doi.org/10.1007/s00300-006-0205-7
29. Mortimer E, Jansen van Vuuren B, Meiklejohn KI, Chown SL. Phylogeography of a mite, *Halozetes fulvus*, reflects the landscape history of a young volcanic island in the sub-Antarctic. Biol J Linn Soc. 2012;105:131–145. https://doi.org/10.1111/j.1095-8312.2011.01770.x
30. Myburgh M, Chown SL, Daniels SR, Jansen van Vuuren B. Population structure, propagule pressure, and conservation biogeography in the sub-Antarctic: Lessons from indigenous and invasive springtails: Biodiversity research. Divers Distrib. 2007;13:143–154. https://doi.org/10.1111/j.1472-4642.2007.00319.x
31. Born C, Le Roux PC, Spohr C, McGeoch MA, Jansen van Vuuren B. Plant dispersal in the sub-Antarctic inferred from anisotropic genetic structure. Mol Ecol. 2012;21:184–194. https://doi.org/10.1111/j.1365-294X.2011.05372.x
32. Hughes KA, Convey P. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: A review of current systems and practices. Glob Environ Change. 2010;20:96–112. https://doi.org/10.1016/j.gloenvcha.2009.09.005
33. De Bruyn PJN, Bester MN, Carlini AR, Oosthuizen WC. How to weigh an elephant seal with one finger: A simple three-dimensional photogrammetric field application. Aquat Biol. 2009;5:31–39. https://doi.org/10.3354/ab00135
34. Postma M, Tordiffe ASW, Hofmeyr MS, Reisinger RR, Bester LC, Buss PE, et al. Terrestrial mammal three-dimensional photogrammetry: Multi-species mass estimation. Ecosphere. 2015;6, Art. #293, 16 pages. http://dx.doi.org/10.1890/ES15-00368.1
35. Monteiro PMS, Gregor L, Lévy M, Maenner S, Sabine CL, Swart S. Intraseasonal variability linked to sampling alias in air-sea CO_2 fluxes in the Southern Ocean. Geophys Res Lett. 2015;42:8507–8514. https://doi.org/10.1002/2015GL066009

36. Skelton PH. The South African Antarctica and Southern Ocean research plan 2014–2024 [document on the Internet]. c2014 [cited 2017 May 15]. Available from: http://saimi.co.za/downloads/Antarctic%20and%20SOuthern%20Ocean%20Research%20Plan.pdf

37. Kennicutt MC, Chown SL, Cassano JJ, Liggett D, Massom R, Peck LS, et al. Polar research: Six priorities for Antarctic science. Nature. 2014;512:23–25. https://doi.org/10.1038/512023a

38. Butterworth DS, Gluckman GR, Thomson RB, Chalis S, Hiramatsu K, Agnew DJ. Further computations on the consequences of setting the annual krill catch limit to a fixed fraction of the estimate of krill biomass from a survey. CCAMLR Sci. 1996;1:81–106.

39. Plagányi ÉE, Butterworth DS. The Scotia Sea krill fishery and its possible impacts on dependent predators: Modelling localized depletion of prey. Ecol Applic. 2012;22(3):748–761. https://doi.org/10.1890/11-0441.1

40. Treasure AM, Moloney CL, Bester MN, McQuaid CD, Findlay KP, Best PB, et al. South African research in the Southern Ocean: New opportunities but serious challenges. S Afr J Sci. 2013;109, Art. #a009, 4 pages. http://dx.doi.org/10.1590/sajs.2013/a009

41. Ansorge IJ, Brundrit G, Brundrit J, Dorrington R, Fawcett S, Gammon D, et al. SEAmester – South Africa's first class afloat. S Afr J Sci. 2016;112, Art. #a0171, 4 pages. http://dx.doi.org/10.17159/sajs.2016/a0171

The function of a university in South Africa: Part 1

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South African universities are under pressure to alter their institutional cultures and policies in order to provide compensation for the neglect of black academic staff and students during our apartheid past. This redress is interpreted by pressure groups and policymakers to entail giving priority to rectification goals within existing universities. What is ignored is the question of whether the first-order functions of every South African university – which are research and teaching – will be compromised. Elevating a second-order function like redress above what have historically been the defining features of a university for more than a thousand years, has probable destructive consequences overlooked by academic and administrative insiders and policymakers. But when viewed historically, educational compensation is a recent phenomenon, arising within the last century. Because of the large scale involved in the South African case, these pressures on local universities are an extreme version of what is locally called 'a concern with redress or social justice'. As such, these institutions are being pushed into a major historical experiment. Most important, it is a process without the needed research backing. So this lack of precedence and research must be accorded much greater recognition within South African universities themselves than is evident so far. If our institutions are facing an existential crisis, it must be acknowledged openly. If such an outcome remains an afterthought, recognised only once it is here, then the damage in many spheres of our national life will be extremely high.

'It's a poor sort of memory that only works backwards' the Queen remarked.
Lewis Carroll, *Through the Looking Glass*

Introduction

A number of misconceptions shape thinking about South Africa's universities in the post-apartheid era. Such misconceived ideas may be understandable in politicians but one wonders why these ideas appear also in the reform programmes urged by education policymakers, their advisers, and even by certain professional educationists.

The argument of this essay is straightforward. The core or first-order functions of a university system are more important than its second-order functions, like the pursuit of equality or redress. If the first-order functions are not fulfilled then there is nothing to re-distribute to a wider segment of the population in a given country and a given higher education system. Thus, secondary functions cannot be conceived as continuous with the core functions, but rather as *subsequent and dependent*. This conceptual distinction is not appreciated in a great deal of South African discussion about university reform in the post-apartheid period.

The title of this essay anticipates some definite and complete answer, which is more than can be provided. The subject matter is complex and widely ramifying so it cannot be wholly accounted for in a short treatment. But the urgency of the questions it raises makes an attempt necessary even if partial in its nature.

In the long run, if it should turn out that South Africa's universities make the transition successfully to the new set of functions demanded by government and by many others, that outcome will be gratifying but also surprising. No one wants South African higher education to fail because new and unique burdens are being placed on the existing institutions. But equally no one can tell whether the universities will endure the imposed changes without failing to meet as well their *first-order* or *systemic functions* in society, polity and economy.

Because terminology is important it needs stating that the labels chosen for these two kinds of university functions, *core and supplementary*, are potentially divisive. The concern with inequality in many, perhaps most, countries at the present time has heightened the expectation that a key institution like a university needs to counter this deepening trend. *That idea is not questioned in this essay*. Yet it is mistaken to presume that the pursuit of equality in individual universities pre-dates the 20th century and is therefore an inherent and defining function. During their thousand-year evolution out of the Middle Ages, universities have served the stability needs of empires and nation states in spheres like law, administration, politics, religion, the economy and culture. This was so for most of their history, but it is erroneous to pretend that combating inequality was also a function they purposely performed in the centuries before the last 100 years.

Here I concentrate on what is pertinent to our South African universities in their struggle to meet so many demands, certain of which appear mutually contradictory. To do that it is necessary to examine universities as institutions that function in specific ways in the world and, in particular, the relationship in which universities stand to the larger society as unique institutions.

First, all the universities in the world that merit the label are *elitist* in their culture and practice. A more neutral term might be *selective* but, in general, universities admit only students who are judged to have the intellectual abilities needed for academic success. Of course it is the case that many, probably most, universities have programmes of inclusion for high-school graduates from poor families and unpromising cultural backgrounds in recognition of the abilities of such potential students.

A sub-group are *research universities* by name because the internal allocation of activities within them places a higher priority on research compared to the average tertiary institution that exists within their national education

systems. Courting potential confusion, in the USA these are also known as 'public research universities', despite many being privately founded and partially funded. They are public because they receive a portion of their financing from federal, state and local appropriations.

Research is accorded much more attention at present than in the past for historical reasons. This was the case in particular before the rise to international prominence of organised research in German universities in the 19th century. Other universities, the majority in the world today, attempt to mix teaching and research activities in ways judged best to meet their national priorities as they interpret, or sometimes are set, for post-school education. They recognise that teaching and learning at this level are for the most part the assimilation of what is already known.

This mixture of institutional types is the case in South Africa, as in numerous other countries and most notably in Latin America and Africa. Such differentiation or diversity can complicate fulfilment of the functions adopted by the institutions themselves on the one hand, and those functions imposed on them by government or founding donors on the other.

The first modern university, Bologna, was founded in 1088 to train theologians, administrators, lawyers, literary scholars and scientists, mainly mathematicians and astronomers. Today theologians are not prominent, but scientists and applied scientists as well as engineers and humanities scholars are categories of intellectual skill produced uniformly in almost every recognised university in the world.

The thorny question all such institutions face is whether excellence is complemented or is challenged by the pursuit of equity? It is not possible to generalise, so the question is best left open and *not*, as in South African policy discussion, simply presumed to be the joint goals of every university and that are never in conflict.

It is important not to confuse the exclusivity argued here to be intrinsic and essential for every university as a historically evolved institution, with the elitism of enrolment that can be contrived by particular universities for their own motives. These motives are usually financial. For example, Ivy League universities in the USA keep their undergraduate numbers down because this raises the value of, and therefore the price to be paid for, a place at Harvard, Yale or Princeton or at the other institutions with similar goals within that exclusive grouping. So their first degree enrolments are limited to 5000–6000. Postgraduate totals are more flexible because they determine research output, institutional research status, and the ultimate pull on research funding.

Thus a place at Harvard is what in economic terms is called a *positional* good. It is prized highly *because* it is unique and scarce. A larger supply would bring the value down. A useful metaphor for understanding this concept is that of a crowd attending a popular event. If one person stands on tip-toe then he or she sees more and further than everyone else; but if every person in the crowd stands on tip-toe then no one sees anything.[1] Access to such a good is contrived and controlled by the suppliers. At a university it leads to a deliberate form of individual elitism that is neither discussed nor advocated in this essay.

Second, academics see themselves as members of an *international* community. This is true of all national universities but is strongest in traditional English-language institutions because of the worldwide predominance of English in science and many other kinds of scholarship. Research and teaching objectives drive academic staff backwards and forwards between countries. For example, at present 41% of academic staff at Oxford University in the United Kingdom are non-British nationals.

One of the telling criteria of membership in this worldwide academic community is the consciousness of *standards* that come from abroad, and the necessity of measuring up to these standards. Seldom written down, but a powerful criterion of success, is the presumption by many South African universities that their best graduates at honours level, after 4 years, are usually accepted for postgraduate study by the major universities of the world. If this should stop being the case, then local academic staff will detect a serious decline in the academic standing of their institutions.

Third, changing the *culture* of universities is difficult and time-consuming for legislation and dedicated policies to achieve when judged necessary. A simple definition will meet the present purpose:

> *In speaking of culture here* [in higher education]*, I have in mind the whole complex of knowledge, tastes and attitudes relating to the principal human achievements in the arts and sciences.*[2(p.395)]

Fourth, *autonomy* is essential for open-ended and freely chosen research and teaching activities. This means self-recruitment,[3] independent admissions policies, the complete absence of ideological influence, whether religious or political, and above all no direction from the organs of the state. The 20th century included a number of clear examples of the destructive effect of state domination of universities, like the Lysenko aberration in plant genetics research in the USSR under Stalin, and the nationalist infection of German physics and chemistry under Hitler. Ironically, this isolation probably set back progress on German development of atomic weaponry. More generally, state domination of once autonomous institutions like universities was completely orthodox policy under the Leninist interpretation of socialism that came to be called Communism between 1918 and 1989.[4] Contemporary Venezuela appears to be another example of destructive state meddling in the governance of universities, given the news of a large-scale exodus by academics under Hugo Chavez's policies that have led to curricular interference, reduced university funding, inadequate salaries and a high crime rate.[5]

First-order and second-order functions

The functions just listed are the characteristics that define a good university wherever it may be. Numerous other requirements exist, but for a perspective on South African universities at the present time, these four characteristics are the important determinants of their functioning that have to be preserved in any process of reform.

Why are these specific features considered essential for the roles that a university plays in a constitutional democracy? Because on the basis of historical experience they make up the only inherent source for the sets of attitudes, skills and aptitudes required to provide stability in a nation state. When institutionalised these practices comprise democratic government, the sustaining of a cultural life satisfying to all classes, and the emergence and promotion of a self-sustaining economy. More broadly conceived, the material welfare levels of a national population are stabilised most effectively under such economic arrangements.

The group providing these skills and abilities sometimes is called a *meritocracy*, and this label should be a matter of taste rather than of polemic when we try to understand what is dispensable and what is not in the functioning of a university. Our present South African dilemma in policy formulation is how far universities' demand for intellectual talent to meet their defining obligations should be compromised in the pursuit of redress for past apartheid practices. During the time of what has been called 'high apartheid' in particular, the state's discrimination against and neglect of tertiary education provided for black citizens is not at all in dispute in this Commentary but, in fact, supports its arguments.

Viewed in this way, the present contention is that we cannot *presume* on grounds of political expediency that institutional policies aimed at the remedial admission of large numbers of underprepared students, and the preferential employment of staff self-identified as black, will not hinder the maintenance of a meritocracy. A higher education system performing in accordance with international standards, whether characterised as meritocratic or not, is essential to counter the emergence of a South African fragile state in the future.

To *assume* there is no conflict between the defining features of a university, and the imposition on it of second-order goals is certainly risky. That is, as already stated, in the South African case, to pursue redress through the imposition of redistributive and 'developmental' tasks, is not prudent in the absence of much more policy research. At present such actions fly in the face of the risks of failure and the unknown probability that governs negative consequences for universities. The simple point is that nobody knows.

Yet this assumption of no conflict between a university's functions appears to be dominant in the minds of South African politicians, civil servants, certain educationists, and, not surprisingly, student groups. The latter in particular have not considered seriously the possibility of threats to the integrity of their institutions. One purpose of this essay is to bring into the open the possible costs which, in the broad sense of socially created obstacles, will have to be paid for institutional failure.

To be clear, there is no doubt that what is being pursued and what has been achieved by individual South African universities under the heading of 'overcoming the secondary-tertiary [level] articulation gap' is commendable and must be supported by any protagonist in the policy arena of tertiary education.[6] Such policies of redress are certainly not being questioned in this paper. But what should be examined are the assumptions underlying these programmes. For instance, are there or will there be a sufficient number of individual lecturers interested in pursuing careers in the way of 'professional development of academic staff [engaged in these programmes]…and the growing support for the scholarship of teaching and learning' of students underprepared by academic criteria, as some observers contend is already the case in a number of South African universities?[7(p.112)]

It must also be recognised that student success in these special programmes is mixed. This is partly because different disciplines, different remedial strategies, and different universities make generalisation a problem in assessing the accuracy of any encompassing statement. Their problematic performance goes much deeper of course. The following is one recently published example of disappointment with a well-designed set of remedial courses:

> *The key finding of the current study is that the educational interventions included in the first-year courses in the AD* [academic development] *programmes in commerce, engineering and science* [faculties] *did not have a statistically significant effect on the graduation rate achieved by AD students for the period under investigation. These findings carry weight as each of the three programmes was configured differently at the time and the econometric results are consistent with each other. The findings are disappointing given the substantial effort and resources into improving AD students' academic performance during the years covered in the study* [at UCT].[8(p.635)]

As our universities are now constituted, and to the extent to which certain of them aspire to be research institutions on the international model, such a presumption, about greater numbers of academic staff building their careers on higher education *development*, is questionable. This presumption remains to be researched with the necessary thoroughness.

Yet this field should be seen as comprising work that is pioneering on an international scale. Its success or failure will convey forceful lessons for universities elsewhere in the world that are attempting, more resolutely than at any time in the past, to pursue both the goals of efficiency and equity at the same time. Awareness of inequality in wider society is on the increase, as is the recognition that wider access to all forms of tertiary education is an essential component of the needed remedy.

Historical precedents

A look at history clarifies the functions that universities play today. After the first founding at Bologna, late medieval universities appeared throughout Europe and were driven by the renewed interest in Roman Law, in particular the Code of Justinian dating from 529 and formulated first in Constantinople. Both the church and the emerging states or principalities making up the units of government came to value the sophistication of Roman Law in the promotion and regulation of contracts and in administering the evolving market economy.

The renewed emphasis on the concepts of social order and justice, and their operational interpretation in daily life when viewed through the lens of Roman legal thinking, led to state administration and commercial relationships becoming systematised and institutionalised. These innovations had multiple goals in the early modern states. They aimed to place limitations on the power of political rulers; to establish the authority of law in its capacity to constrain and control the behaviour of public officials and private authority figures; to make rights to private property more secure; and to provide 'mechanisms for contract enforcement, and facilitated coordination among powers', in the political as well as economic spheres of the political units destined to become the nations of Europe.[9] Most of these states emerged 'out of the German lands of the Holy Roman Empire'[9].

Driven by the emerging demand, university training in law and state administration took their places as taught disciplines alongside theology, philosophy and science, mainly in the shape of mathematics and astronomy. Universities and their students were granted privileges because of their role in stabilising the new states. They provided unique supporting institutions, recognised in time as such by rulers and administrators who held political power.

These inherited functions exist today in most if not all the world's universities worthy of the name. They exist in particular in research universities, whether these universities are mature or aspiring to that function and status. As already explained, all universities aim to produce the skills and aptitudes essential for providing administrative, cultural and economic services without which a state would fail or at least become fragile, threatening failure as recent examples show.[10] In the economic sphere, these skills are those without which the use of sophisticated technology in production is not possible.

What is disturbing in South Africa is that certain politicians and bureaucrats, as well as educationists, are determined to 'transform' existing universities by making their racial profiles of staff and students 'demographically representative'. It is disturbing because the wider and deeper potential consequences have not been investigated in the discussion arena.

So the existing policy interpretation of this reform is not backed by thorough and objective research. Evidence in support of this judgement is provided by the recent actions of the Minister of Higher Education and Training, Dr Blade Nzimande. In 2013, he set up an oversight committee on university transformation headed by Prof. Makgoba, Vice-Chancellor of the University of KwaZulu-Natal. In their turn, Prof. Makgoba and a colleague, Dr Govinder, in 2015 devised an 'Equity Index' to measure so-called 'transformation' when it is applied as a standard to individual universities. Not surprisingly, this index has been severely criticised, not only on ethical and political grounds but for its technical failings as a measuring device. The debate about its purpose and acceptability can be followed in recent issues of the *South African Journal of Science*.[11-15]

Individual benefits and external effects

As stated, the present Commentary aims to provide an historical as well as an international perspective on this set of issues. In this way it should inform the local discussion that appears increasingly fixated on a single issue, namely that South African universities are trying to compensate by policies of remediation for their apartheid past as best they can, with little analytical guidance. For instance, prominent research universities in Western Europe and America, like the Ivy League, Oxbridge, the Sorbonne and numerous others, have been heavily criticised as unsuitable models by certain South African educationists. Their sets of values and ideas are judged unwelcome as precedents to be followed by the universities of developing countries including South Africa. This case is argued in particular when tertiary education redress is in question, and it tends to be approached as the overriding objective of South African university reform. Representative instances of this negative viewpoint on elitism are not hard to find.[16]

This criticism is questionable on a number of grounds. First, elitism, interpreted as the recruitment of the best intellectual talent in a country, as already explained, is a defining feature of the vast majority of contemporary universities in the world that aim to fulfil their intended functions. Second, the pursuit of equity and social justice as second-

order goals can be persuasively argued as *not* possible *without* the effective performance of those first-order functions already described. So, to achieve the re-distributive or social justice objectives demanded of South African universities in the political arena *depends* on the prior recruitment of a national elite within a democracy. This elite has to be deployed in every supporting institution of government, civil society and the mixed economy as discussed below. Third, it is a confusing source of bias to criticise and reject only the universities in older developed countries, as in Europe and America, to refer principally to those using mainly the English language, for being models that are judged too elitist for developing countries. This criticism is far from an accurate characterisation of the world's universities.

For instance, the major universities in Asian countries, such as Japan, Korea and Singapore, exhibit a degree of competitiveness in job appointments, selectivity of student enrolments, and the mobilisation of academic resources that is at least as high as that found in research universities elsewhere.

Yet it is important to be aware that causation is likely to run both ways. The recruited elite make for nationwide political stability, for a rewarding culture and society, and for steady economic growth. Yet success in these spheres, marked by the high status and monetary rewards paid to these elite graduates, in turn encourages and makes possible the university production of the talents and skills that are considered essential ingredients in such national elites.

In addition, it is vital to recognise the *external effects*, which are benefits for the wider society that do not accrue only to the successful individual graduate, but which emerge freely available from well-functioning universities. The most important categories of these external benefits can be characterised as *philosophical understanding, generalised trust* towards others and *moral imagination*.

Of course it is perfectly possible to acquire skills in philosophy and the other dimensions, and to use these skills in multiple ways outside a formal institutional environment like a university. But in the contemporary world all serious study of these subjects takes place in universities. It is there that disciplined thinking is taught deliberately, both for applied purposes like reforming the law, formulating state policies in every domain, and enriching the forms of culture, and yet also for the wider perspective on human life that makes philosophical understanding so vitally important. Bertrand Russell was admirably clear:

> *Uncertainty, in the presence of vivid hopes and fears, is painful, but it must be endured if we wish to live without the support of comforting fairy tales. It is not good either to forget the questions that philosophy asks, or to persuade ourselves that we have found indubitable answers to them. To teach how to live without certainty, and yet without being paralysed by hesitation, is perhaps the chief thing that philosophy, in our age, can still do for those who study it.*[17(p.14)]

The further tasks of universities, best classified as cultural, are to build the institutions that foster *generalised trust* in all individuals towards others, as well as their moral imagination. Within every society, the absence of such trust is a major source of arrested social and economic development. Credibility, or the capacity of being believed by others, for instance, is the precondition for retaining trust and legitimacy.

There is no easily understood causal model that links universities with the existence of generalised trust and moral imagination in society. The intermediary institutions tend to be diffuse. So the evidence is indicative more than definitive. Here too there is the likelihood of reverse causation: the presence of trust and moral imagination within a population, brought into being by other causes, fosters the foundation of institutions like universities.

Sometimes such trust at a collective scale is measured by what is called *social capital*, the term coined by Putnam and currently growing in use although not universally popular. It means valuable knowledge and skills that are bestowed by a set of institutions that have come and some that have gone in the course of history. An example is the guilds which dominated economic life in the Middle Ages, comprising the pre-capitalist system then conceived and known as a moral economy. Its principal linkages between individuals were moral obligation not social relations mediated through market processes. The concept underlying such social capital is simple enough even when identification and measurement is not so in practice: 'Those persistent and shared beliefs and values that help a group overcome the free rider problem in the pursuit of socially valuable activities.'[18(p.6)]

How do universities produce and sustain generalised trust? They do so through the construction and maintained stability of institutions without which trust cannot exist. Clear instances are the supportive underpinning of contract law essential for collaboration between individuals and groups; an efficient law enforcement system that evokes legitimacy; political institutions that encapsulate democracy, and thus engender active support and not rejection of the underlying moral values; constitutions that provide clear and unambiguous guidance to state policymakers, the political elite, and to the citizenry; civil society organisations that harness collective interests and efforts; formal institutions of education at all levels; and the regulation and control of the largest economic units, like corporations that generate profit for individual owners, as well as trade unions or federations that pursue the partisan interests of their members.

These are an illustration and not a complete listing. They suffice to demonstrate which institutions in society would not function or at best function imperfectly without the instruction, training and research activities of universities.

Trust is not recognised often enough, when insufficient, to be a major constraint on social cohesion, cultural deepening, and the economic development process. When attained, trust is thought of in practical terms as providing contractual assurance between people in the conduct of social and economic life. Thereby it governs the efficiency essential for economic progress. Yet this view can be too limited and potentially distorts a functional perspective necessary for universities. The differential development of nation states is a good example.

> *I have remarked on the responsibility for truthfulness in economic life, but the issue goes even further. Virtually every commercial transaction has within itself an element of trust, certainly any transaction conducted over a period of time. It can be plausibly argued that much of the economic backwardness in the world can be explained by the lack of mutual confidence.*[19(p.356-357)]

One final illustration of a university function concerns moral imagination. This is the quality in an individual which makes human life not only endurable for that person but enriches the lives of others, who together make up the collective entities or groups that constitute any given society. When this moral dimension of the individual personality is weak at the aggregate level – that is, the entire population that is living together – we suffer the consequences of a fragile state or, in the extreme, a failed state. The current migration crisis experienced not only in South Africa but also in Europe is a clear consequence of the numerous failed states to our north and further south and east of Europe.

The Treaty of Westphalia in 1648 marked the end of Europe's Thirty Years War. By so doing, it also inaugurated the nation state as the basic unit of political order that has survived much conflict between states in the succeeding three and a half centuries.

> *From the mass of overlapping rulers – emperors, kings, dukes, popes, archbishops, guilds, cities, etc. – the Peace of Westphalia produced a solution of dazzling simplicity and longevity. The governing unit henceforth would be the state. Borders would be clearly defined and what went on inside those borders (especially the choice of religion) would be decided by its ruler and a matter of no one*

> *else's business. In modern terms, the delegates invented and codified state sovereignty, a single authority governing each territory and representing it outside its borders, no authority above states, and no outside interference in states' domestic affairs…* [Yet today the growing] *limits on global resources, porous borders, a globalizing culture… cannot be seen only as a matter of the distribution of state power…The Westphalian order is not going away, but it is no longer what it once was. It's too soon to see what that system and the new* [non-state] *forces will produce as they co-exist; but it's safe to say it won't look anything like the familiar past.*[20(p.5)]

So at the present time there is speculation and concern that certain existing states show vulnerability due to the incompleteness as well as recent decay of their democratic institutions. It is too early to say whether the rise of religion in the post-colonial era, associated with 'authoritarian resurgence or democratic backsliding', will destroy states. Though the prospect remains troubling.[21-25]

To foster the moral imagination of individuals is a social task performed by institutions, many created essentially through university teaching and research practice. This claim is not that universities pursue and achieve this directly; and such a process of moral imagining is not exclusive to universities of course, but they are prime movers.

Without such a contribution by education at the tertiary level, it is difficult to imagine such institutions coming into being to sustain a tolerant and humane order. Historically, this order has come about by natural evolution as well as by purposive administrative practice devised for its achievement. It is accepted by scholars that such a trend characterised the history of the contemporary university, commencing immediately after its European foundation in Bologna.[3,26,27]

The institutions required to avoid social conflict range from the mundane to the essential. Clear examples are the political and administrative complexes of a modern state that demand high levels of collective order absent before the emergence of such states; effective political processes that reflect the majority values and views of citizens; institutions that foster tolerance and respect for those who are different; taxing authorities that are considered legitimate and support voluntary compliance without which they would not work; and thus steady revenue and expenditure flows at nationwide level that are governed by appropriately skilled and honest officials.

In addition, there is the administration of the stabilising activities that only the state can undertake nationwide (or, ironically, destroy) with its monopoly of authority, power and the pressure it can apply for compliance by individuals. Again, simple instances are the required immunisation of children against selected and specified diseases; their compulsory early education; and the complete education of all citizens up to some level decided to be individually and socially desirable by the political process.

At their widest, these are examples of the institutions which govern the ever-changing character of attitude, aptitude and the formation of skills in all human beings. This is so from the chosen perspective in this essay, specifically at the post-school level that comprises *all* the forms of education and training taking place in a given state.

Moral imagination does not yet constitute a set of issues amenable to research at the aggregate or society-wide level. Although in the perspective given in this paper, it is certainly plausible that tertiary education is a key influence in the emergence of the kind of imagination that generates social morality. This is essential for cooperation amongst a large number of individuals in groups who share interaction as well as resources but do not relate inter-personally. That is, one can infer confidently that these are aggregations of people sufficiently large to produce and support institutions that create cooperation and stability.

Whether when viewed this way, universities should be accorded status as the culminating institutions in the chain of human development phases that begin with the role of the family remains an open question. A recent strand of research work has emphasised this perception of inter-connected stages *because* it has far-reaching implications for the strategic direction and sequencing of national education, training and all other policies aimed at enhancing human ability. This is clearly of considerable pertinence in current South Africa. Prominent researchers in this field describe the underlying hypothesis in the following terms:

> *The recent literature is based on multiple generation models with multiple periods of childhood and adulthood. It emphasises the dynamics of skill formation. Central to the literature are the concepts of complementarity, dynamic complementarity, multiplicity of skills and critical and sensitive periods for different skills. These concepts account for a variety of empirical regularities that describe the process of human development. Family environments during the early years and parenting are critical determinants of human development because they shape the lifetime skill base. Through dynamic complementarity they enhance the productivity of downstream investments* [in skill and aptitude acquisition]*….Later stage remedial interventions are generally less effective…*[28(p.57)]

More simply put, such acquisition in its widest conception is *cumulative*. Success at the early stages of life, soon after birth, makes success at subsequent levels easier and more probable. Further, it has proved to be cheaper than later remediation in time and resource use. Catching up the skills missed in early life is possible but frequently inefficient and costly to the individual and to society. But this is not to say it is a set of actions that can be judged dispensable or avoidable in the real world. In certain situations brought about by historical circumstances, such policies are essential, as in current South African universities.

In the past, as well as in more recent times, the social role played by the moral imagination can be seen most clearly in the institutions of the welfare state. These evolved during the 20th century, gathering momentum after each major war.[29-32]

Part 2 of this Commentary will appear in a forthcoming issue.

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References

1. Hirsch F. Social limits to growth. London: Routledge/Kegan Paul; 1977. https://doi.org/10.1016/S0313-5926(77)50008-2
2. Olafson F. Democracy, 'high culture', and the universities. Philos Public Aff. 1973;2(4):385–406.
3. Collini S. What are universities for? London: Penguin Books; 2012.
4. Appelbaum A. The Leninist roots of civil society repression. J Democr. 2015;26(4):21–27. https://doi.org/10.1353/jod.2015.0068
5. Carmona A. Poor conditions blamed for Venezuelan scientist exodus. University World News [serial on the Internet]. 2014 July 18 [cited 2016 Dec 15]. Available from: http://www.universityworldnews.com/article.php?story=20140717180605819
6. Council on Higher Education (CHE). A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure Pretoria: CHE; 2013. Available from: http://www.che.ac.za/sites/default/files/publications/Full_Report.pdf

7. Lewin T, Mawoyo M. Student access and success: Issues and interventions in South African universities. Cape Town: Inyathelo: The South African Institute for Advancement; 2014. Available from: http://kresge.org/library/student-access-and-success-issues-and-interventions-south-african-universities

8. Smith L, Case J, Van Walbeek C. Assessing the effectiveness of academic development programmes: A statistical analysis of graduation rates across three programmes. S Afr J High Educ. 2014;28(2):624–638.

9. Cantoni D, Yuchtman N. The political economy of educational content and development: Lessons from history. J Develop Econ. 2013;104:233–244. https://doi.org/10.1016/j.jdeveco.2013.04.004

10. Collier P. Fragile African states: What should donors do? FERDI Working Paper 95 [document on the Internet]. c2014 [cited 2016 Dec 15]. Available from: http://www.ferdi.fr/sites/www.ferdi.fr/files/publication/fichiers/wp95_collier_web.pdf

11. Borden VH. Anything but simple: Inappropriate use of Euclidean distance in Govinder et al. (2013). S Afr J Sci. 2014;110(5/6), Art. #a0065, 4 pages. https://doi.org/10.1590/sajs.2014/a0065

12. Cloete N. A new look at demographic transformation: Comments on Govinder et al. (2013). S Afr J Sci. 2014;110(1/2), Art. #a0048, 4 pages. https://doi.org/10.1590/sajs.2014/a0048

13. Dunne T. Mathematical errors, smoke and mirrors in pursuit of an illusion: Comments on Govinder et al. (2013). S Afr J Sci. 2014;110(1/2), Art. #a0047, 6 pages. https://doi.org/10.1590/sajs.2014/a0047

14. Govinder KS, Zondo NP, Makgoba MW. Taking the transformation discourse forward: A response to Cloete, Dunne and Moultrie and Dorrington. S Afr J Sci. 2014;110(3/4), Art. #a0060, 8 pages. https://doi.org/10.1590/sajs.2014/a0060

15. Moultrie T, Dorrington R. Flaws in the approach and application of the Equity Index: Comments on Govinder et al. (2013). S Afr J Sci. 2014;110(1/2), Art. #a0049, 5 pages. https://doi.org/10.1590/sajs.2014/a0049

16. Jansen JD. Wrest power from English tyranny. Mail and Guardian [serial on the Internet]. 2013 Oct 04 [cited 2016 Dec 15]. Available from: http://mg.co.za/article/2013-10-04-wrest-power-from-english-tyranny

17. Russell B. History of Western philosophy. London: Allen & Unwin; 1946.

18. Alesina A, Giuliano P. Culture and institutions. NBER Working Paper 19750 Cambridge, MA: National Bureau of Economic Research; 2013. https://doi.org/10.3386/w19750

19. Arrow K. Gifts and exchanges. Philos Public Aff. 1972;1(4):343–362.

20. Mathews JT. The road from Westphalia. New York Review of Books [document on the Internet]. 2015 March 19 [cited 2016 Dec 15]. Available from: http://www.nybooks.com/articles/2015/03/19/road-from-westphalia/

21. Bermeo N. On democratic backsliding. J Democr. 2016;27(1):5–19. https://doi.org/10.1353/jod.2016.0012

22. Fukuyama F. Why is democracy performing so poorly? J Democr. 2015;26(1):11–20. https://doi.org/10.1353/jod.2015.0017

23. Krastev I. Liberalism's failure to deliver. J Democr. 2016;27(1):35–38. https://doi.org/10.1353/jod.2016.0001

24. Plattner M. Is democracy in decline? J Democr. 2015;26(1):5–10. https://doi.org/10.1353/jod.2015.0014

25. Walker C. The authoritarian resurgence. J Democr. 2015;26(2):21. https://doi.org/10.1353/jod.2015.0025

26. Kagan D. Ave atque vale [Hail and farewell]. New Criterion. 2013;31(10):4. Latin.

27. Ogilvie S, Carus A. Institutions and economic growth in historical perspective: Part 2. CESifo Working Paper 4862 [document on the Internet]. c2014 [cited 2016 Dec 15]. Available from: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2463601

28. Heckman JJ, Mosso S. The economics of human development and social mobility. NBER Working Paper 19925. Cambridge, MA: National Bureau of Economic Research; 2014. https://doi.org/10.3386/w19925

29. Archer S. The basic homework on basic income grants in South Africa [document on the Internet]. CSSR Working Paper 122. Cape Town: Centre for Social Science Research, University of Cape Town; 2007. Available from: http://www.cssr.uct.ac.za/sites/cssr.uct.ac.za/files/pubs/WP122.pdf

30. Castles F, Leibfried S, Lewis J, Obinger H, Pierson C, editors. The Oxford handbook of the welfare state. Oxford: Oxford University Press; 2010. https://doi.org/10.1093/oxfordhb/9780199579396.001.0001

31. Goodin R, Headey B, Muffels R, Dirken H-J. The real worlds of welfare capitalism. Cambridge: Cambridge University Press; 1999. https://doi.org/10.1017/CBO9780511490927

32. Greve B. The Routledge handbook of the welfare state. Abingdon: Routledge; 2013.

A probabilistic definition of a species, fuzzy boundaries and 'sigma taxonomy'

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Morphometric and genetic analyses of a variety of living and fossil taxa[1-7] support the use of a probabilistic definition of a species in the context of 'sigma taxonomy' (where sigma represents 'S' for spectrum[6,7]), in contrast to alpha taxonomy[8], for which boundaries discriminating species are presumed to be distinct, thus accommodating only rigid, 'either-or' classification schemes.

Recently, integrated taxonomic approaches, involving morphology and genetics, have demonstrated that traditional definitions of species boundaries may require re-evaluation and revision. Integrated analyses of gibbons[9] and giraffes[10], for example, have narrowed boundaries and led researchers to recognise more species than were previously identified. Species identification is complicated in part by the potential for some populations to hybridise and, in the case of living wolf populations[11], genetic analyses have widened boundaries and revealed that there are fewer species – or more hybrids – than previously thought. Analyses of ancient DNA have also exposed hybrids of the past: there is now evidence that populations of elephants and mammoths likely interbred[12] and, of course, Neanderthal DNA is known to be part of the modern human genome to this day, as a result of introgression of Neanderthals and early modern *Homo sapiens* – a relationship hinted at by morphology[13], now confirmed genetically[14].

De Manuel et al.[4] have recently provided genetic evidence of interbreeding between chimpanzees (*Pan troglodytes*) and bonobos (*Pan paniscus*) within the last million years. The two groups diverged sometime between 1 and 2 million years ago[5], and most likely interbred during episodic contraction of forests during relatively dry and cool intervals within the Plio-Pleistocene[15]. This finding is consistent with morphometric analyses of homologous pairs of cranial measurements of specimens of *P. troglodytes* and *P. paniscus* showing there is not a clear boundary between the taxa.[6,16,]

In morphometric analyses of hominoid crania[6], homologous cranial measurements of specimens A and B are compared by least squares linear regression analysis. Two 'log sem' statistics are obtained when specimen A is on the *x*-axis and B is on the *y*-axis, and vice versa, where 'log sem' is the log transformed standard error of the *m*-coefficient in equations of the form $y=mx+c$.[6,17] The mean of these two log sem statistics is called M-log sem, where M relates to the difference between log sem values, termed delta log sem.[6] Delta log sem values are small (circa 0.03) when the two specimens are known conspecifics (e.g. two individuals from the same population), and large ($>>0.03$) when they are of different species of different size and shape. Delta log sem data are assessed in relation to M-log sem values obtained from pairwise comparisons of cranial measurements in regression analyses. Mean log sem values for modern conspecifics tend to show central tendency around a value of -1.61, which Thackeray[18] hypothesised to be an approximation of a biological species constant ($T=-1.61\pm0.2$) through geographical space and evolutionary time, associated with a probabilistic definition of a species.

Using homologous pairs of cranial measurements of *P. troglodytes* and *P. paniscus*, Gordon and Wood[16] confirmed that the mean of two log sem values for conspecific specimens tends to approximate an average M-log sem value of -1.61. Remarkably, this applies to specimens of both *P. troglodytes* and *P. paniscus* (based on adult male and female specimens, $n>1000$ regression analyses).[16] There is no clear boundary between *P. paniscus* and *P. troglodytes* on the basis of log sem values[6,16], which can now be explained in terms of genetic evidence indicating hybridisation within the Plio-Pleistocene[4].

A recent study by Roux et al.[3] sheds light on 'the grey zone of speciation' in living taxa, from a genomics perspective; based on genetic analyses of more than 61 animals, the authors found that the '"grey zone" of speciation, in which taxonomy is often controversial, spans from 0.5% to 2% of net synonymous divergence…'[3]. This range of values is compatible with an approximation of a biological species constant (T) of -1.61 ± 0.2 and lends support to the concept of 'sigma taxonomy'.[7]

In a recent review article, Llamas et al.[1] stated that 'Admixture…blurs the species limits for extinct groups, especially since the morphological identification of hybrids is difficult'. This 'blurring' of species limits, or 'fuzzy boundaries' as A.R. Wallace put it in 1870[19], reflects the concept of 'palaeo-spectroscopy' in hominin evolution, advocated by Thackeray and Odes[20] who conducted a morphometric analysis of early Pleistocene African hominin crania in the context of a statistical (probabilistic) definition of a species.

We propose that a probabilistic definition of a species may be obtained by recognising the 'grey zone' concept, or 'sigma taxonomy'[7], as opposed to 'alpha taxonomy'[8]. We strongly recommend the adoption of a probabilistic definition of a species which has the potential to be applied to fossil hominins[15,20,21] and other taxa.

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References

1. Llamas B, Willerslev E, Orlando L. Human evolution: A tale from ancient genomes. Philos Trans R Soc B. 2017;372(1713), Art. #20150484. https://doi.org/10.1098/rstb.2015.0484
2. Jónsson H, Schubert M, Seguin-Orlando A, Ginolhac A, Petersen L, Fumagalli M, et al. Speciation with gene flow in equids despite extensive chromosomal plasticity. Proc Natl Acad Sci USA. 2014;111(52):18655–18660. https://doi.org/10.1073/pnas.1412627111
3. Roux C, Fraïsse C, Romiguier J, Anciaux Y, Galtier N, Bierne N. Shedding light on the grey zone of speciation along a continuum of genomic divergence. PLoS Biol. 2016;14(12), e2000234, 22 pages. https://doi.org/10.1371/journal.pbio.2000234
4. De Manuel M, Kuhlwilm M, Frandsen P, Sousa VC, Desai T, Prado-Martinez J, et al. Chimpanzee genomic diversity reveals ancient admixture with bonobos. Science. 2016;354(6311):477–481. https://doi.org/10.1126/science.aag2602
5. Prüfer K, Munch K, Hellmann I, Akagi K, Miller JR, Walenz B, et al. The bonobo genome compared with the chimpanzee and human genomes. Nature. 2012;486:527–531. https://doi.org/10.1038/nature11128
6. Thackeray JF, Dykes S. Morphometric analyses of hominoid crania, probabilities of conspecificity and an approximation of a biological species constant. HOMO J Comp Hum Biol. 2016;67(1):1–10. http://dx.doi.org/10.1016/j.jchb.2015.09.003
7. Thackeray JF. Sigma taxonomy in relation to palaeoanthropology and the lack of clear boundaries between species. Proc Eur Soc Study Hum Evol. 2015;4:220.
8. Mayr E, Linsley EG, Usinger RL. Methods and principles of systematic zoology. New York: McGraw-Hill; 1953.
9. Fan P-F, He K, Chen X, Ortiz A, Zhang B, Zhao C, et al. Description of new species of *Hoolock* gibbon (Primates: Hylobatidae) based on integrative taxonomy. Am J Primatol. 2017;9999, e222631, 15 pages. https://doi.org/10.1002/ajp.22631
10. Fennessey J, Bidon T, Reuss F, Kumar V, Elkan P, Nilsson MA, et al. Multi-locus analyses reveal four giraffe species instead of one. Curr Biol. 2016;26(18):2543–2549. http://dx.doi.org/10.1016/j.cub.2016.07.036
11. VonHoldt BM, Cahill JA, Fan Z, Gronau I, Robinson J, Pollinger JP, et al. Whole-genome sequence analysis shows that two endemic species of North American wolf are admixtures of the coyote and gray wolf. Sci Adv. 2016;2(7), e1501714, 13 pages. http://dx.doi.org/10.1126/sciadv.1501714
12. Callaway E. Elephant history rewritten by ancient genomes. Nature News. 2016 September 16. http://dx.doi.org/10.1038/nature.2016.20622
13. Thackeray JF, Maureille B, Vandermeersch B, Braga J, Chaix R. Morphometric comparisons between Neanderthals and 'anatomically modern' *Homo sapiens* from Europe and the Near East. Ann Transv Mus. 2005;42:47–51.
14. Green RE, Krause J, Briggs AW, Maricic T, Stenzel, U, Kirchner M, et al. A draft sequence of the Neandertal genome. Science. 2010;328(5979):710–722. https://doi.org/10.1126/science.1188021
15. Thackeray JF. *Homo habilis* and *Australopithecus africanus*, in the context of a chronospecies and climatic change. Palaeoecol Afr. 2016;33:53–58.
16. Gordon AD, Wood BA. Evaluating the use of pairwise dissimilarity metrics in paleoanthropology. J Hum Evol. 2013;65465–477. https://doi.org/10.1016/j.jhevol.2013.08.002
17. Dykes SJ, Dykes R. 'Professor regressor': A computer programme for rapid processing of large sets of pairwise regression analyses in palaeontological contexts. Palaeontol Afr. 2015;49:53–59.
18. Thackeray JF. Approximation of a biological species constant? S Afr J Sci. 2007;103:489.
19. Wallace AR. Contributions to the theory of natural selection. London: Macmillan; 1870. p. 161. https://doi.org/10.5962/bhl.title.1254
20. Thackeray JF, Odes E. Morphometric analysis of early Pleistocene African hominin crania in the context of a statistical (probabilistic) definition of a species. Antiquity. 2013;87:1–2. http://antiquity.ac.uk/projgall/thackeray335/
21. Thackeray JF. Probabilities of conspecificity. Nature. 1997;390:30–31. https://doi.org/10.1038/36240

Issues of water quality in stormwater harvesting: Comments on Fisher-Jeffes et al. (2017)

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Stormwater harvesting (SWH) has long been considered a potential solution to water insecurity in water-scarce areas, especially in urban settings with a high proportion of impermeable surfaces.[1-3] The recent paper in this journal by Fisher-Jeffes et al.[4] provides a summary of the potential benefits of SWH in South Africa, grouped under three themes: water security, flood prevention and additional benefits through enhancing natural assets. Some specific examples of SWH reuse and management were provided from the Western Cape region to illustrate their points. Whilst it is absolutely the case that, on a national scale, SWH is an under-exploited resource in South Africa, there are many problems with stormwater use that are not discussed in the article but which may significantly limit the extent to which this greywater is beneficial to the environment and communities. In this commentary I highlight additional factors not considered by Fisher-Jeffes et al.[4], but which are significant in a South African context, including (1) climate and precipitation variability, (2) water quality, (3) management of urban water systems, and (4) infrastructural and community adaptive capacity. I then identify some future research directions.

Firstly, ensemble climate models for southern Africa are consistent in their predictions of an overall future drying trend across the region, but all models suggest significant spatial variations in precipitation trends, changes in seasonality and a shift towards heavier single-event rainfall.[5,6] Fisher-Jeffes et al.[4] mention increased evapotranspiration as a climate change impact but this has minimal effect on individual storm events. A more significant effect of heavier rainfall is increased overland flow, flooding and impacts, including loss of life and property. SWH of such events is problematic because of high water volumes, which can overwhelm sewer transport and storage capacity[7], and the sudden onset and unpredictable timing of individual storm events[8]. Such climate variability has implications for the development and sustainability of infrastructure for managing stormwater, and how this management imperative is built into any future plans for wider water resource management systems (e.g. management of potable water, existing greywater, sewage/sanitation).[9]

Secondly, water quality is a very significant issue with respect to the reuse of stormwater or other greywater, but was not mentioned by Fisher-Jeffes et al.[4] who assumed that all stormwater is potentially available for use. In the urban environment, however, stormwater flow over roads washes sediment, trash and many chemicals into sewage systems. The latter components include oil, spilt fuel, heavy metals (e.g. lead, copper, zinc, chromium, manganese), polycyclic aromatic hydrocarbons and non-volatile organic compounds derived from fuel, tyre wear etc.[10,11] Airborne chemical pollutants and particulate matter can experience wet or dry deposition on to the land surface or vegetation, and can also get washed into the sewer system.[12] Collectively, these pollutants result in lowered water quality and significant potential human health effects, including from *E. coli* and novovirus.[13,14] Biofiltration through urban wetlands, discussed below, is a key method for cleaning contaminated water and improving water quality.

Thirdly, management of urban water systems, including stormwater, requires an understanding of future patterns of climate and urbanisation[15], and potentially conflicting water management issues of aquifer recharge, maintaining urban rivers and water quality, equity of service provision, and economic sustainability[16,17]. Studies are now looking at the functioning of urban water systems from the viewpoint of integrated systems management, and flux and water budget modelling.[8,18] These methodological approaches are better able to incorporate greywater as part of the active water management system rather than as an unquantified part of the precipitation input to the system.[18,19] Fisher-Jeffes et al.[4] take the position that SWH can reduce flood risk when water is stored in retention dams on rivers, or when pumped into aquifers. More integrated and sustainable 'systems' approaches to water management are not discussed.

Lastly, for SWH to become a reality in urban settings, significant changes in water management thinking are needed. These changes may involve devolution of water management decision-making to the community level, to build community resilience and water security.[20,21] The social and institutional barriers to widespread stormwater use identified by Fisher-Jeffes et al.[4], including regulatory frameworks for potable water supply, can be better tackled through bottom-up community initiatives, including use of domestic water butts, urban food gardens and urban greening of waste ground. These initiatives have been shown to have positive community benefits as well as reducing run-off and improving wastewater quality.[22] Such ideas of sustainable and integrated water systems represent an emerging research field in sub-Saharan Africa.[23]

In summary, the article by Fisher-Jeffes et al.[4] highlights many of the advantages of SWH but does not expand upon their limitations or the interconnections between stormwater, natural hydrological (river) systems in urban areas, and the built infrastructure of urban water management. Many studies show that stormwater can be naturally cleaned by biofiltration through urban wetlands[24], and this method has the advantage of providing green spaces within the urban environment, cooling local climate and increasing biodiversity and human well-being. An alternative option for urban areas is to develop soakways alongside roads and pavements, which has not yet been explored. Water from green roofs or from roof catchment systems may be of better quality than stormwater run-off from roads, and thus can be used for different purposes within integrated water systems. Thus, not all stormwater exhibits the same properties or has the same filtration needs. In South Africa, SWH has greatest potential in urbanised areas with impermeable surfaces, not in rural areas where land surface run-off following storms results in significant negative impacts such as soil erosion, and contamination by sewage or agricultural run-off. In South Africa, future changes in climate, urban planning and infrastructure must be considered in the design and management of water systems, which are needed for sustainable development and climate resilience.

References

1. Mitchell VG, Deletic A, Fletcher TD, Hatt BE, McCarthy DT. Achieving multiple benefits from stormwater harvesting. Water Sci Technol. 2007;55(4):135–144. http://dx.doi.org/10.2166/wst.2007.103
2. Fletcher TD, Deletic A, Mitchell VG, Hatt BE. Reuse of urban runoff in Australia: A review of recent advances and remaining challenges. J Environ Qual. 2008;37(5):S116–S127. http://dx.doi.org/10.2134/jeq2007.0411
3. Hamdan SM. A literature based study of stormwater harvesting as a new water resource. Water Sci Technol. 2009;60(5):1327–1339. http://dx.doi.org/10.2166/wst.2009.396
4. Fisher-Jeffes L, Carden K, Armitage NP, Winter K. Stormwater harvesting: Improving water security in South Africa's urban areas. S Afr J Sci. 2017;113(1/2), Art. #2016-0153, 4 pages. http://dx.doi.org/10.17159/sajs.2017/20160153
5. Bellprat O, Lott FC, Gulizia C, Parker HR, Pampuch LA, Pinto I, et al. Unusual past dry and wet rainy seasons over southern Africa and South America from a climate perspective. Weather Clim Extremes. 2015;9:36–46. http://dx.doi.org/10.1016/j.wace.2015.07.001
6. Li L, Diallo I, Xu C-Y, Stordal F. Hydrological projections under climate change in the near future by RegCM4 in southern Africa using a large-scale hydrological model. J Hydrol. 2015;528:1–16. http://dx.doi.org/10.1016/j.jhydrol.2015.05.028
7. Haque MdM, Rahman A, Samali B. Evaluation of climate change impacts on rainwater harvesting. J Cleaner Prod. 2016;137:60–69. http://dx.doi.org/10.1016/j.jclepro.2016.07.038
8. Huang C-L, Hsu N-S, Wei C-C, Luo W-J. Optimal spatial design of capacity and quantity of rainwater harvesting systems for urban flood mitigation. Water. 2015;7(9):5173–5202. http://dx.doi.org/10.3390/w7095173
9. Tavakol-Davani H, Goharian E, Hansen CH, Tavokol-Davani H, Apul D, Burian SJ. How does climate change affect combined sewer overflow in a system benefiting from rainwater harvesting systems? Sustain Cities Society. 2016;27:430–438. http://dx.doi.org/10.1016/j.scs.2016.07.003
10. Brown JN, Peake BM. Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. Sci Total Environ. 2006;359(1–3):145–155. http://dx.doi.org/10.1016/j.scitotenv.2005.05.016
11. Hwang H-M, Fiala MJ, Park D, Wade TL. Review of pollutants in urban road dust and stormwater runoff: Part 1. Heavy metals released from vehicles. Int J Urban Sci. 2016;20(3):334–360. http://dx.doi.org/10.1080/12265934.2016.1193041
12. Murphy LU, O'Sullivan A, Cochrane TA. Quantifying the spatial variability of airborne pollutants to stormwater runoff in different land-use catchments. Water Air Soil Poll. 2014;225(7):2016. http://dx.doi.org/10.1007/s11270-014-2016-8
13. Jiang SC, Lim K-Y, Huang X. Human and environmental health risks and benefits associated with use of urban stormwater. WIREs Water. 2015;2(6):683–699. http://dx.doi.org/10.1002/wat2.1107
14. Ma Y, Egodawatta P, McGree J, Goonetilleke A. Human health risk assessment of heavy metals in urban stormwater. Sci Total Environ. 2016;557:764–772. http://dx.doi.org/10.1016/j.scitotenv.2016.03.067
15. Saraswat C, Kumar P, Mishra BK. Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. Environ Sci Pol. 2016;64:101–117. http://dx.doi.org/10.1016/j.envsci.2016.06.018
16. Burns MJ, Fletcher TD, Walsh CJ, Ladson AR, Hatt BE. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landsc Urb Plann. 2012;105(3):230–240. http://dx.doi.org/10.1016/j.landurbplan.2011.12.012
17. Upadhyaya JK, Biswas N, Tam E. A review of infrastructure challenges: Assessing stormwater system sustainability. Can J Civil Eng. 2014;41(6):483–492. http://dx.doi.org/10.1139/cjce-2013-0430
18. Malinowski PA, Stillwell AS, Wu JS, Schwarz PM. Energy-water nexus: Potential energy savings and implications for sustainable integrated water management in urban areas from rainwater harvesting and gray-water reuse. J Water Res Planning Manag. 2015;141(12):A4015003. http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000528
19. Walsh CJ, Fletcher TD, Burns MJ. Urban stormwater runoff: A new class of environmental flow problem. PLoS One. 2012;7(9), e45814, 10 pages. http://dx.doi.org/10.1371/journal.pone.0045814
20. Adegun OB. Coping with stormwater in a Johannesburg, South Africa informal settlement. Proc Inst Civil Eng. 2014;167(ME2):89–98. http://dx.doi.org/10.1680/muen.13.00030
21. Adegun OB. State-led versus community-initiated: Stormwater drainage and informal settlement intervention in Johannesburg, South Africa. Environ Urbanization. 2015;27(2):407–420. http://dx.doi.org/10.1177/0956247815569700
22. Ward EW, Winter K. Missing the link: Urban stormwater quality and resident behaviour. Water SA. 2016;42(4):571–576. http://dx.doi.org/10.4314/wsa.v42i4.07
23. Mguni P, Herslund L, Jensen MB. Sustainable urban drainage systems: Examining the potential for green infrastructure-based stormwater management for sub-Saharan cities. Nat Hazards. 2016;82:S241–S257. http://dx.doi.org/10.1007/s11069-016-2309-x
24. Rousseau DPL, Lesage E, Story A, Vanrolleghem PA, De Pauw N. Constructed wetlands for water reclamation. Desalination. 2008;218(1–3):181–189. http://dx.doi.org/10.1016/j.desal.2006.09.034

Applying behavioural science to issues of public health in South Africa: The case for social norms intervention

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In the effort to address behavioural risk factors – which contribute significantly to the global burden of disease – there is a growing movement in public health towards the use of interventions informed by behavioural science. These interventions have the benefit of being amenable to testing in randomised controlled trials, are cost-effective and, when scaled up, can have significant public health benefits. A subset of these interventions attempts to change behaviour by shifting social norms perception (what I *think* everyone else does and thinks). We surveyed the work on social norms intervention and considered its applicability to issues of public health in South Africa. Social norms interventions have widespread and significant potential to address issues of public health in South Africa; policymakers should look to these interventions as cost-effective tools to address key issues. More broadly, we advocate for an expansion of the use of behavioural science in developing public policy in South Africa.

Significance:

- The application of behavioural science to issues of public health will contribute to evidence-based policy efforts in South Africa.

Introduction

South Africa faces a number of significant public health crises. While much has been done over the past decades to address the quadruple disease burden, we have, nonetheless, witnessed a rise in non-communicable diseases (responsible for 39% of deaths in 2010) and a failure to curb HIV/AIDS infection rates (35% of deaths in 2010).[1-3] Given that behavioural risk factors contribute significantly to the global disease burden, there is a growing movement towards the application of evidence-based behavioural science interventions to issues of public health; public health in South Africa would greatly benefit from joining this movement.[4,5] These interventions have the benefit of being amenable to testing in randomised controlled trials, are relatively cheap and cost-effective, and even when they yield only small effects they can have significant positive impacts on public health when scaled up.[4,6] A subset of these interventions focuses on changing behaviour through shifting social norms perception. In this paper, we focus on social norms as an important site for behavioural change interventions, and consider its applicability to issues of public health in South Africa.

Social norms

Social norms are 'shared beliefs within a social unit about the appropriate ways to think, feel, and behave in a given context'[7(p.240)]. By 'social unit' we mean an 'in-group' – a group of people who identify with one another within relevant contexts, for instance, South Africans at the Rugby World Cup, members of the ANC at a party rally, Kaizer Chiefs supporters at a soccer match.

It is important to distinguish two different types of norms: descriptive and injunctive.[8-10] A descriptive norm refers to the prevalence of a behaviour in a social in-group (for example, the percentage of people in a workplace who get a flu vaccine) while an injunctive norm refers to what behaviours in-group members think others within a social in-group ought to do (for example, the percentage of people in a workplace who think others ought to get flu vaccines).[9] A further distinction is made between actual and perceived norms. Actual norms refer to the accurate rates of prevalence (descriptive) or approval/disapproval (injunctive) of a particular behaviour. Perceived norms are the common (mis)perceptions of the prevalence (what I think other in-group members do) and approval/disapproval (what I think other in-group members approve/disapprove of) rates held by in-group members. The norms that drive behaviour are often the *misperceived* descriptive and injunctive norms, which may overestimate the prevalence and approval of risk behaviours and underestimate that of protective behaviours within social in-groups.[8,11,12] The misperception of norms is common because we are often unable to base our understandings of phenomena on accurate data – rather, we look to our own behaviour or employ mental shortcuts (for example, by looking at what salient members of our in-group appear to be doing) to determine norms.[12,13]

Social norms perception interventions

Norms perceptions can be an important site for shifting behaviour – unlike attitudes, norms perception has been shown to govern behaviour significantly and to be dynamic and malleable.[12] The cost-effectiveness of norms perception interventions means that they can function as a practicable tool to help policymakers and practitioners shift behaviour in a more healthful direction.[14]

Sources of norms information

Three primary sources of norms perception information, which can be targeted by interventions, have been identified[12]:

1. Individual group members' behaviours act as an important source of norms information within a social in-group. This influence is not spread equally among group members; rather, some group members who are widely known or seen as 'clique leaders' in particular contexts (referred to in the literature as 'social referents') hold an exaggerated influence. Social referents are seen by their fellow in-group members as prototypical and, in turn, they are looked to for in-group appropriate behaviour.[12] Interventions which attempt to shift norms perception by addressing this source of norms information do so by shifting the views and behaviours of key social referents. One such intervention was run as a randomised controlled trial in 56 schools to reduce bullying behaviour. Social referents were identified through a social network analysis and asked to take part in school-wide anti-bullying campaigns. Compared with control schools in which no intervention was administered, intervention schools saw a 30% reduction in bullying.[15]
2. Summaries of actual norms are a common source of norms information. This information usually comes in the form of accurate statistics on the prevalence and support rates for a particular behaviour within a social in-group. Once collected and disseminated, this information is used to highlight the actual descriptive and injunctive norms which are present in a social in-group – thereby, in theory, correcting misperceptions and shifting behaviour. In the UK, the efficacy of disseminating actual norms summaries to decrease unnecessary prescription of antibiotics among general practitioners was tested in a randomised controlled trial. The top 20% of prescribers within a geographical area were randomly assigned to two groups. One group was sent letters notifying them that they were prescribing antibiotics at a higher rate than 80% of other practitioners in the area (i.e. that they were deviating from the social norm), while the other group received no communication. The intervention led to a significant reduction in antibiotic prescriptions in the intervention group (3.3%) when compared with the control group.[16]
3. Institutional signals are a source of norms information. These signals come from organisational, educational or governmental institutions which influence a reference group and their social activities.[12] When considered legitimate, these institutions act as a source of normative information both directly (e.g. through laws which proscribe and prescribe behaviours) and indirectly (e.g. when individuals observe normative changes as a result of institutional signals and in turn adapt their behaviour). However, there is at present too little empirical evidence to conclude that changes to institutional signals can cause significant shifts in behaviour.[12]

Social norms misperception approach

A great deal of research has examined how norms perception (source 2 above) can be applied to a variety of risk and protective behaviours,[11,17,18] with a particular focus on one approach, herein termed the 'social norms misperception approach' (SNMA). The assumptions of this approach are simple: overestimations of anti-social/risky descriptive and injunctive norms and underestimations of pro-social/protective descriptive and injunctive norms will increase and decrease such behaviours, respectively.[11] Because of cognitive biases and mental shortcuts, we have a tendency to make these over- and underestimations (misperceptions) of group members' behaviours and attitudes. In theory, interventions which aim to disseminate accurate descriptive and injunctive norms (through a variety of strategies such as social norms marketing and computerised feedback) will have the effect of correcting such misperceptions and in turn effect important behavioural change.[18]

These theoretical assumptions have found some support in a number of empirical studies which have applied different permutations of the simple intervention formula to an array of behaviours. For instance, small-scale research has found the SNMA to be efficacious in reducing gender-based and sexual violence[19-21], lowering bullying behaviour[22], and decreasing rates of driving under the influence of alcohol[23]. Larger scale studies have found the SNMA approach to be effective in encouraging energy conservation and other pro-environmental behaviour[8,24,25], increasing voter turnout[26], and increasing tax compliance rates[27]. Moreover, several studies have also found the SNMA to be successful in lowering alcohol and substance use among school and university students[18,28-30], although some suggest that the effect of social norms interventions may be only small[31].

The field, of course, is not uniformly replete with success stories. Norms interventions must be constructed carefully, and those that have failed may have done so because they used only descriptive norms.[8] One study, for instance, disseminated individual norms and compared them to the neighbourhood norm. The study found that while the dissemination of *actual* descriptive norms of average neighbourhood household energy consumption compared to individual norms had the positive effect of reducing the energy consumption of those who exceeded the norm, it also was associated with an increase in the energy consumption of those who were below the norm (the so-called 'boomerang effect').[8] In other words, neither the high nor the low usage consumers wanted to deviate from the norm. However, by adding an injunctive norm to their descriptive norm feedback, they were able to ameliorate the boomerang effect.[8] A corollary of this finding is the insight that social campaigns which stress the prevalence of the negative behaviours they wish to alter (e.g. 'This is a high crime zone') have the potential to unintentionally drive up these behaviours. Cialdini and colleagues found park signs which indicate that '[m]any past visitors have removed the petrified wood from the park, changing the state of the Petrified Forest' resulted in more theft over signs which stated that most people do not steal or asked visitors to please refrain from stealing.[32(p.8)] This provides an important guideline for future research and also has practical implications for public campaigns which stress the prevalence of negative behaviours.[12]

Another important consideration is that of the salience of an in-group. Social identity theorising predicts that our behaviour is significantly influenced by the social identity which is presently salient and meaningful to us.[33,34] The level of social identification moderates the association between descriptive and injunctive norms and behaviour – that is to say norms of more proximal and salient groups have a greater influence on behaviour than those of distal groups.[30,35-37] It is therefore critical to determine the relevant social identity and members' level of identification with that identity when conducting social norms research and developing interventions.[7,12]

A further consideration for using the SNMA pertains to the baseline actual prevalence or approval rates for a particular behaviour. Because the approach relies on correcting the misperceptions of behaviours that are perceived as more or less prevalent and approved than they actually are, interventions are limited to behaviours which already fit these patterns. For example, if a majority of people within a social in-group do not use condoms and disapprove of others using condoms, then disseminating the actual descriptive or injunctive norms – even if misperceptions exists – would not be an effective way of promoting condom use. In that sense, the SNMA is limited to promoting behaviour change only in instances in which the actual prevalence and approval rates are in line with desired behavioural outcomes. Tankard and Paluck[12] suggest that one way around this limitation would be to emphasise the positive direction in which a norm is shifting (for example, 'more and more South Africans are using condoms').

Social norms in the South African context

In South Africa, academics, non-governmental organisations and government ministers often evoke the idea of shifting social norms to tackle persistent social issues. These recommendations are made in relation to a variety of societal issues ranging from reducing rates of smoking[38] and dangerous driving[39], to HIV-risk behaviour among low-income communities[40] and violence against women and children[41,42]. While these suggestions abound, relatively little thought has been given to the means

of achieving the prescribed norms change. Moreover, there is a dearth of rigorously evaluated evidence-based attempts to shift norms in the South African context. Therefore there is immense potential for social norms research to test its applicability to key social issues in South Africa.

Some of these potential applications, and their limitations, will be considered below. To quantify the most important behaviours which require focused intervention, we looked to the risk factors which are associated with the highest percentage of disability-adjusted life years. We looked at three of the top five risk factors – unsafe sex, interpersonal violence and tobacco smoking – which collectively are risk factors for 43.9% of the total disability-adjusted life years in South Africa (the other two risk factors are high body mass index and alcohol harm).[43] We deal with each of these in turn, focusing on previous social norms research, as well as local data which could be useful for future interventions.

Suggestions for social norms interventions in South Africa

Unsafe sex

We examined three risky sexual behaviours and their amenability to social norms intervention: multiple sexual partners, lack of HIV-testing and non-use of condoms. A study conducted in two low-income areas in South Africa found that people who had been tested for HIV were more likely to agree or strongly agree with the statement 'Most people have been tested for HIV'[44(p.621)] than those who had not been tested. Moreover, a study conducted in Gugulethu township found that men significantly overestimate the prevalence of and support for multiple sexual partners and underestimate that of condom use in their community. The authors concluded that these findings 'provide support for greater attention to perceived norms and their potential for influencing behaviour in the development of individual and social-structural interventions to prevent HIV transmission'[45(p.38)]. Results from the South African National HIV Prevalence, Incidence and Behaviour Study[46] also lend support to potential social norms interventions. The study found that most (87.4%) South Africans (aged 15 and over) do not report having multiple sexual partners in the past 12 month and that a majority (65.6%) have been tested for HIV.[46] A potential norms intervention would focus on disseminating the message – through norms marketing campaigns – that a significant majority of South Africans do not engage in this risky sexual practice and that most South Africans do get tested. These data are disaggregated by province (and could be further disaggregated by enumeration area), locality type, sex and age group – which could be used in future interventions by tapping into salient social identities and disseminating the actual norms of this type of risky sexual behaviour (for example, a billboard campaign: 'Most men in Polokwane have been tested for HIV and know their status. #MostOfUs'). Injunctive norms data of these risky sexual behaviours would enhance future campaigns, and should be explored in future studies.

However, on the basis of present data, condom use would not be directly amenable to a SNMA intervention – a minority of sexually active South Africans report using condoms at last sex with their most recent sexual partner.[46] Future surveys should include measures of injunctive norms of condom use among South Africans to assess whether it might be a suitable focus of SNMA intervention. Another avenue for intervention would be to use the social network approach to determine social referents in particularly at-risk communities to encourage new norms around condom use. Nonetheless, this finding points to the abovementioned practical limitations of the SNMA – that is, these interventions are restricted to risky behaviours which are not pervasive and protective behaviours which are pervasive.

Interpersonal violence

Bullying behaviour

One form of interpersonal violence which has seen significant reduction through norms intervention is school bullying. Research suggests that when it comes to problem-solving strategies, students often overestimate the normative support for aggression and underestimate normative support for non-violence.[47] As mentioned above, a randomised controlled trial conducted in 56 schools in the USA used a social network analysis to identify social referents and then asked them to join an anti-bullying campaign. The intervention reduced bullying behaviour by 30% over a year, compared with control schools.[12]

Bullying is a serious problem in South Africa – with 19.7% of 15–17 year olds reporting having been bullied in a nationally representative study.[48] Moreover, school bullying may be linked to negative academic outcomes[49], internalising symptoms and conduct problems in victims[50]. Given the success of the US intervention in reducing rates of bullying, future research could modify the intervention to suit a South African context. Once contextualised, the intervention could be tested through a randomised controlled trial in South African schools. If positive results are found, there would be a strong case for scaling up the intervention. Such a process would contribute significantly to evidence-based policy efforts in South Africa.

Corporal punishment

Parental corporal punishment is a form of disciplinary behaviour which is an important issue to address for the protection of child rights, and also because it may be a risk factor for harsher forms of abuse.[51,52] While a nationally representative survey found that 57% of South African parents report using corporal punishment on their children[53] (descriptive norm), 72% of parents agreed with the statement '[w]hen children do wrong, it is always better to talk to them about it than give them a smack' (p. 18; injunctive norm). This finding is potentially useful for future interventions. We are currently working on a research project in two Early Childhood Development Centres in historically disadvantaged communities in the Western Cape to examine the social norms of parenting disciplinary practices. If significant misperceptions exist, we will be in a good position to trial the SNMA to parenting intervention.

Tobacco smoking

Tobacco smoking is a risk factor accounting for 4% of the total disability-adjusted life years and 8.5% of mortality in South Africa.[43] While relatively few studies have examined the efficacy of the SNMA on tobacco smoking, there are promising signs: the few studies that have been conducted in the USA have shown significant reductions in smoking among university students and youth smoking initiation.[54,55] Results from the South African National Health and Nutrition Examination Survey are clear: most South Africans do not smoke.[56] This nationally representative survey found that only 16.8% of South Africans (over 15 years old) smoke cigarettes.[56] A potential anti-smoking campaign could therefore stress that the vast majority (83.2%) of South Africans do not smoke. Moreover, the survey data are disaggregated by province (and potentially enumeration area), age and sex, so – again – it is possible to tailor the messages to particularly salient social identities (e.g. 'Most Durbanites don't smoke'). Future research should test the efficacy of such a campaign in the South African context, and future surveys should also include measures of injunctive norms of smoking to enhance potential interventions.

Insights from past research

We need to emphasise here that the SNMA, and social norms interventions in general, are not a silver bullet or cure-all – public health issues are complex and dealing with them requires multipronged and multisectoral efforts. Social norms approaches are but one way in which behavioural science can contribute to these efforts – we have collected some of the insights from recent research on norms interventions to guide future practice. First, as described above, SNMA interventions are most appropriate for behaviours for which misperception exists but the baseline actual prevalence or approval rates are not already high. Second, a strong sense of identification with the reference group used and the source of the norms information will increase the likelihood of a successful intervention.[12] Third, descriptive and injunctive norms are most effective in changing behaviour when they appeal to a collective self (e.g. 'Most of us don't smoke cigarettes', 'Let's reduce lung cancer together').[57] Finally, because of the many problems South Africa faces – from disease burden to water scarcity – that may be amenable to an SNMA approach, it is a fruitful arena in which to study these approaches.

Using South Africa as a study site might also provide opportunities to develop SNMA theory. For instance, questions regarding the level of social identification which is necessary to affect behaviour change could be tested in resource-poor settings. Moreover, and perhaps more importantly, SNMA research in South Africa could help answer important, and topical, questions about the replicability of SNMA findings from the developed world.

Summary

Evidence-based behavioural science interventions are increasingly becoming an important tool to address public health issues in developed countries. Given the scarcity of resources and large-scale social issues, this cost-effective form of behavioural change has perhaps even more utility in developing countries such as South Africa. Social norms interventions are one such tool which could affect important health-related behavioural change. We have argued that there is indeed significant potential for such an approach to be tested and adopted locally. To begin harnessing this potential, piloting of social norms interventions which address a variety of unhealthy and dangerous behaviours should commence, and nationally representative surveys should start including measures of injunctive norms. More broadly, here we attempt to advocate for an expansion of the use of behavioural science in developing public policy in South Africa. Future behavioural science research should be policy-minded and apply its methods to societal issues with a focus on scalability, as well as make use of the unique aspects of South African society to develop and build SNMA theory.

Authors' contributions

All authors contributed to the writing of the manuscript.

References

1. Msemburi W, Pillay-van Wyk V, Dorrington RE, Neethling I, Nannan N, Groenewald P, et al. Second national burden of disease study for South Africa: Cause-of-death profile for South Africa, 1997–2010. Cape Town: South African Medical Research Council; 2014. p. 1–23.
2. Nojilana B, Bradshaw D, Pillay-van Wyk V, Msemburi W, Laubscher R, Somdyala NIM, et al. Emerging trends in non-communicable disease mortality in South Africa, 1997–2010. S Afr Med J. 2016;106(5):477–484. http://dx.doi.org/10.7196/samj.2016.v106i5.10674
3. Mayosi BM, Lawn JE, Van Niekerk A, Bradshaw D, Abdool Karim SS, Coovadia HM, et al. Health in South Africa: Changes and challenges since 2009. Lancet. 2012;380(9858):2029–2043. http://dx.doi.org/10.1016/s0140-6736(12)61814-5.
4. Roberto CA, Kawachi I. Behavioral economics and public health. Oxford: Oxford University Press; 2015. https://doi.org/10.1093/med/9780199398331.001.0001
5. Glanz K, Bishop DB. The role of behavioral science theory in development and implementation of public health interventions. Annu Rev Public Health. 2010;31:399–418. http://dx.doi.org/10.1146/annurev.publhealth.012809.103604
6. Behavioural Insights Team. Applying behavioural insights to organ donation: Preliminary results from a randomised controlled trial. London: Behavioural Insights Team; 2013. Available from: https://www.gov.uk/government/publications/organ-donor-registrations-trialling-different-approaches
7. Neville FG. Preventing violence through changing social norms. In: Donnelly PD, Ward CL, editors. Oxford textbook of violence prevention: Epidemiology, evidence, and policy. Oxford: Oxford University Press; 2014. p. 239–244. https://doi.org/10.1093/med/9780199678723.003.0033
8. Schultz PW, Nolan JM, Cialdini RB, Goldstein NJ, Griskevicius V. The constructive, destructive, and reconstructive power of social norms. Psychol Sci. 2007;18(5):429–434. http://dx.doi.org/10.1111/j.1467-9280.2007.01917.x
9. Cialdini RB, Kallgren CA, Reno RR. A focus theory of normative conduct: A theoretical refinement and reevaluation of the role of norms in human behaviour. Adv Exp Soc Psychol. 1990;24(20):201–234. http://dx.doi.org/10.1016/s0065-2601(08)60330-5
10. Deutsch M, Gerard HB. A study of normative and informational social influences upon individual judgment. J Abnorm Psychol. 1955;51(3):629–636. http://dx.doi.org/10.1037/h0046408
11. Berkowitz AD. The social norms approach: Theory, research, and annotated bibliography [document on the Internet]. c2004 [cited 2015 Nov 01]. Available from: http://www.alanberkowitz.com/articles/social_norms.pdf
12. Tankard ME, Paluck EL. Norm perception as a vehicle for social change. Soc Issues Policy Rev. 2016;10(1):181–211. http://dx.doi.org/10.1111/sipr.12022
13. Kahneman D. Thinking, fast and slow. New York: Farrar, Straus and Giroux; 2013.
14. Thaler RH, Sunstein CR. Nudge: Improving decisions about health, wealth and happiness. London: Penguin Books; 2009.
15. Paluck EL, Shepherd H, Aronow PM. Changing climates of conflict: A social network experiment in 56 schools. Proc Natl Acad Sci USA. 2016;113(3):566–571. http://dx.doi.org/10.1073/pnas.1514483113
16. Hallsworth M, Chadborn T, Sallis A, Sanders M, Berry, D, Greaves F, et al. Provision of social norm feedback to high prescribers of antibiotics in general practice: A pragmatic national randomised controlled trial. Lancet. 2016;387(10029):1743–1752. http://dx.doi.org/10.1016/s0140-6736(16)00215-4
17. Berkowitz AD. Fostering healthy norms to prevent violence and abuse: The social norms approach [document on the Internet]. c2010 [cited 2016 Feb 10]. Available from: http://www.alanberkowitz.com/articles/Preventing%20Sexual%20Violence%20Chapter%20-%20Revision.pdf
18. Perkins HW. The emergence and evolution of the social norms approach to substance abuse prevention. In: Perkins HW, editor. The social norms approach to preventing school and college age substance abuse: A handbook for educators, counselors, and clinicians. San Francisco: Jossey-Bass; 2003. p. 1–18.
19. Fabiano PM, Perkins HW, Berkowitz A, Linkenbach J, Stark C. Engaging men as social justice allies in ending violence against women: Evidence for a social norms approach. J Am Coll Health. 2003;52(3):105–112. http://dx.doi.org/10.1080/07448480309595732
20. Gidycz CA, Orchowski LM, Berkowitz AD. Preventing sexual aggression among college men: An evaluation of a social norms and bystander intervention program. Violence Against Women. 2011;17(6):720–742. http://dx.doi.org/10.1177/1077801211409727
21. Katz J, Heisterkamp HA, Fleming WM. The social justice roots of the Mentors in Violence Prevention model and its application in a high school setting. Violence Against Women. 2011;17(6):684–702. http://dx.doi.org/10.1177/1077801211409725
22. Perkins HW, Craig DW, Perkins JM. Using social norms to reduce bullying: A research intervention among adolescents in five middle schools. Group Process Intergr Relat. 2011;14(5):703–722. http://dx.doi.org/10.1177/1368430210398004
23. Perkins HW, Linkenbach JW, Lewis MA, Neighbors C. Effectiveness of social norms media marketing in reducing drinking and driving: A statewide campaign. Addict Behav. 2010;35(10):866–874. http://dx.doi.org/10.1016/j.addbeh.2010.05.004
24. Allcott H. Social norms and energy conservation. J Public Econ. 2011;95:1082–1095. http://dx.doi.org/10.1016/j.jpubeco.2011.03.003
25. Goldstein NJ, Cialdini RB, Griskevicius V. A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. J Cons Res. 2008;35(3):472–482. http://dx.doi.org/10.1086/586910
26. Gerber AS, Rogers T. Descriptive social norms and motivation to vote: Everybody's voting and so should you. J Polit. 2009;71(1):178–191. http://dx.doi.org/10.1017/s0022381608090117
27. Wenzel M. Misperceptions of social norms about tax compliance: From theory to intervention. J Econ Psychol. 2005;26(6):862–883. http://dx.doi.org/10.1016/j.joep.2005.02.002
28. Neighbors C, Larimer ME, Lewis MA. Targeting misperceptions of descriptive drinking norms: Efficacy of a computer-delivered personalized normative feedback intervention. J Consult Clin Psychol. 2004;72(3):434–447. http://dx.doi.org/10.1037/0022-006x.72.3.434

29. Werch CE, Pappas DM, Carlson JM, DiClemente CC, Chally PS, Sinder JA. Results of a social norm intervention to prevent binge drinking among first-year residential college students. J Am Coll Health. 2000;49(2):85–92. http://dx.doi.org/10.1080/07448480009596288

30. Borsari B, Carey, KB. Descriptive and injunctive norms in college drinking: A meta-analytic integration. J Stud Alcohol. 2003;64(3):331–341. http://dx.doi.org/10.15288/jsa.2003.64.331

31. Foxcroft DR, Moreira MT, Almeida Santimano NML, Smith LA. Social norms information for alcohol misuse in university and college students. Cochrane Database Syst Rev. 2015;12(CD006748):1–143. http://dx.doi.org/10.1002/14651858.cd006748.pub4

32. Cialdini RB, Demaine LJ, Sagarin BJ, Barrett DW, Rhoads K, Winter PL. Managing social norms for persuasive impact. Soc Influence. 2006;1(1):3–15. http://dx.doi.org/10.1080/15534510500181459

33. Turner JC. Social influence. Buckingham: Open University Press; 1991.

34. Turner JC, Hogg MA, Oakes PJ, Reicher SD, Wetherell MS. Rediscovering the social group: A self-categorization theory. Oxford: Basil Blackwell; 1987.

35. Rinker DV, Neighbors C. Do different types of social identity moderate the association between perceived descriptive norms and drinking among college students? Addict Behav. 2014;39(9):1297–1303. http://dx.doi.org/10.1016/j.addbeh.2014.03.018

36. Terry DJ, Hogg MA. Group norms and the attitude-behaviour relationship: A role for group identification. Pers Soc Psychol B. 1996;22(8):776–793. http://dx.doi.org/10.1177/0146167296228002

37. Neighbors C, O'Connor RM, Lewis MA, Chawla N, Lee CM, Fossos N. The relative impact of injunctive norms on college student drinking: The role of reference group. Psychol Addict Behav. 2008;22(4):576–581. http://dx.doi.org/10.1037/a0013043

38. King G, Flisher AJ, Mallett R, Graham J, Lombard C, Rawson T, et al. Smoking in Cape Town: Community influences on adolescent tobacco use. Prev Med. 2003;36(1):114–123. http://dx.doi.org/10.1006/pmed.2002.1128

39. Sinclair M. Attitudes, norms and driving behaviour: A comparison of young drivers in South Africa and Sweden. Transport Res F-Traf. 2013;20:170–181. http://dx.doi.org/10.1016/j.trf.2013.07.001

40. Cain D, Pitpitan EV, Eaton L, Carey KB, Carey MP, Mehlomakulu V, et al. Collective efficacy and HIV prevention in South African townships. J Community Health. 2013;38(5):885–893. http://dx.doi.org/10.1007/s10900-013-9694-9

41. Department of Social Development (DSD), Department of Women, Children and People with Disabilities (DWCPD), United Nations Children's Fund (UNICEF). Violence against children in South Africa. Pretoria: DSD, DWCPD, UNICEF; 2012.

42. Western Cape Government. Integrated Provincial Violence Prevention Policy Framework. Western Cape: Western Cape Government; 2013. https://www.westerncape.gov.za/text/2013/September/violence-prevention-cabinet-policy-final.pdf

43. Norman R, Bradshaw D, Schneider M, Joubert J, Groenewald P, Lewin S, et al. A comparative risk assessment for South Africa in 2000: Towards promoting health and preventing disease. S Afr Med J. 2007;97(7):637–641.

44. Young SD, Hlavka Z, Modiba P, Gray G, Van Rooyen H, Richter L, et al. HIV-related stigma, social norms, and HIV testing in Soweto and Vulindlela, South Africa: National Institutes of Mental Health Project Accept (HPTN 043). J Acq Immun Def Synd. 2010;55(5):620–624. http://dx.doi.org/10.1097/qai.0b013e3181fc6429

45. Carey KB, Scott-Sheldon LAJ, Carey MP, Cain D, Mlobeli R, Vermaak R, et al. Community norms for HIV risk behaviors among men in a South African township. J Behav Med. 2011;34(1):32–40. https://doi.org/10.1007/s10865-010-9284-6

46. Shisana O, Rehle T, Simbayi LC, Zuma K, Jooste S, Zungu N, et al. South African National HIV Prevalence, Incidence and Behaviour Survey, 2012. Cape Town: HSRC Press; 2014.

47. Henry DB, Dymnicki AB, Schoeny ME, Meyer AL, Martin NC. Middle school students overestimate normative support for aggression and underestimate normative support for nonviolent problem-solving strategies. J Appl Soc Psychol. 2013;43(2):433–445. http://dx.doi.org/10.1111/j.1559-1816.2013.01027.x

48. Artz L, Burton P, Ward CL, Leoschut L, Phyfer J, Lloyd S, et al. Optimus Study South Africa: Technical report. Switzerland: UBS Optimus Foundation, 2016.

49. Townsend L, Flisher AJ, Chikobvu P, Lombard C, King G. The relationship between bullying behaviors and high school dropout in Cape Town, South Africa. S Afr J Psychol. 2008;38(1):21–32. http://dx.doi.org/10.1177/008124630803800102

50. Boyes ME, Bowes L, Cluver LD, Ward CL, Badcock NA. Bullying victimisation, internalising symptoms, and conduct problems in South African children and adolescents: A longitudinal investigation. J Abnorm Child Psychol. 2014;42(8):1313–1324. http://dx.doi.org/10.1007/s10802-014-9888-3

51. Lansford JE, Sharma C, Malone PS, Woodlief D, Dodge KA, Oburu P, et al. Corporal punishment, maternal warmth, and child adjustment: A longitudinal study in eight countries. J Clin Child Adolesc Psychol. 2014;43(4):670–685. http://dx.doi.org/10.1080/15374416.2014.893518

52. MacKenzie MJ, Nicklas E, Waldfogel J, Brooks-Gunn J. Corporal punishment and child behavioural and cognitive outcomes through 5 years of age: Evidence from a contemporary urban birth cohort study. Infant Child Dev. 2012;21(1):3–33. http://dx.doi.org/10.1002/icd.758

53. Dawes A, De Sas Kropiwnicki Z, Kafaar Z, Richter L. Corporal punishment of children: A South African national survey. Cape Town: HSRC; 2005.

54. Hancock LC, Henry NW. Perceptions, norms and tobacco use in college residence hall freshmen: Evaluation of a social norms marketing intervention. In: Perkins HW, editor. The social norms approach to preventing school and college age substance abuse: A handbook for educators, counselors, and clinicians. San Francisco, CA: Jossey-Bass; 2003. p. 135–153.

55. Linkenbach J, Perkins HW. MOST of us are tobacco free: an eight-month social norms campaign reducing youth initiation of smoking in Montana. In: Perkins HW, editor. The social norms approach to preventing school and college age substance abuse: A handbook for educators, counselors, and clinicians. San Francisco, CA: Jossey-Bass; 2003. p. 224–234.

56. Shisana O, Labadarios D, Rehle T, Simbayi L, Suma K, Dhansay A, et al. South African National Health and Nutrition Examination Survey (SANHANES-1). Cape Town: HSRC Press; 2014.

57. White K, Simpson B. When do (and don't) normative appeals influence sustainable consumer behaviors? J Marketing. 2013;77(2):78–95. http://dx.doi.org/10.1509/jm.11.0278

Patterns of blunt force homicide in the West Metropole of the City of Cape Town, South Africa

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There is currently a lack of information regarding the prevalence of and characteristics associated with blunt force trauma related homicides in South Africa. Information relating to the patterns of blunt force trauma could assist in the development and implementation of interventions targeted at specific areas or individuals as well as direct future research towards areas in need of investigation. This study is a 5-year retrospective review of autopsy reports obtained from Salt River Mortuary (Cape Town, South Africa). The prevalence of blunt force trauma was considered for unnatural deaths with a focus on homicide. The patterns of homicidal blunt force trauma are also presented. A total of 15 519 autopsy cases was analysed. In 1198 (7.72%) of these cases, the cause of death was found to be blunt force trauma and 828 (5.32%) of these cases were classified as homicides. Approximately 11% of blunt force homicide cases occurred in combination with sharp and/or ballistic trauma. Men from poor socio-economic areas were shown to be most at risk of blunt force homicide in the City of Cape Town.

Significance:

- The prevalence of homicidal blunt force trauma in the Western Metropole of the City of Cape Town is comparable to other regions in South Africa.
- The vast majority of victims sustained injury to the head, highlighting the need for further research in cranial blunt force trauma.
- Interventions should target young men, particularly in low socio-economic regions.

Introduction

Globally, trauma is considered to be one of the most common forms of homicide and is frequently categorised into three main groups according to the mechanisms of trauma: blunt, sharp and ballistic. Extensive research on wound pathology has been conducted to better distinguish between trauma mechanisms in order to provide information pertaining to the weapon type so as to clarify the events surrounding death.[1,2]

The wound morphology in blunt force trauma cases varies based on the weapon used, the force with which it was applied and the affected body region.[1,3] Typically, fatal blunt force trauma injuries are a consequence of blows from fists and feet or a variety of blunt implements such as household hammers, wooden clubs or bats. Some cases of blunt force trauma may not lead to sudden death but rather death after a delayed period of days, weeks or months, in which case difficulties may arise in the determination of whether an individual can be held accountable.[4]

Violence is rife in South Africa. Homicide is the second highest contributor to unnatural deaths in the City of Cape Town.[5-7] Previous research has suggested that the largest proportion of homicide deaths in Cape Town is caused by sharp force trauma and firearms; nevertheless, blunt force trauma forms a substantial portion of unnatural deaths.[8]

Literature on blunt force trauma tends to focus on age and sex of the injured, location of injuries, number of body regions involved, defence injuries, weapon, assailant–victim relationship, location of the crime scene and further toxicological analysis of the victims' tissues.[9-12] Nationally there is a dearth of centralised information pertaining to blunt force deaths, hence research is based on data gathered from a variety of resources such as police dockets, hospital records and autopsy reports. Information relating to the patterns of blunt force trauma could assist in the implementation of appropriate interventions targeted at specific areas or individuals. Additionally it can direct research toward aspects of blunt force trauma which are in need of investigation.

In South Africa, there is little information regarding the prevalence and characteristics associated with blunt force trauma related homicides. Therefore, the principal objective of this study was to determine the prevalence of blunt force trauma related deaths and homicides in the West Metropole of the City of Cape Town (Western Cape Province, South Africa). The secondary objective was to describe the characteristics associated with blunt force trauma related homicides in the West Metropole of the City of Cape Town.

Methods

The study is a 5-year retrospective review of autopsy reports obtained from Salt River Mortuary between 1 January 2010 and 31 December 2014. Salt River Mortuary is an M6 Academic Centre which processes more than 3000 cases a year. It services the West Metropole of the City of Cape Town which comprises the Western, Southern, Klipfontein and Mitchells Plain districts.[13]

The prevalence of blunt force trauma was considered for unnatural deaths with a focus on homicide as categorised by pathologists during autopsy. The inclusion criterion was blunt force trauma as the cause of death, as determined by the pathologist. Cases in which the death was not caused solely by blunt force trauma but also included aspects of sharp or ballistic trauma were classified as combination deaths. Cases in which blunt force trauma was train related or as a result of falling from a height or a pedestrian or motor vehicle accident were excluded.

In each case, the characteristic data were collected and recorded in a Microsoft Office Excel® 2013 (Microsoft, Redmond, WA, USA) database. Stata version 13.1 (StataCorp, College Station, TX, USA) was used to perform descriptive statistics to identify the presence of patterns and commonalities for each characteristic. Pearson's chi-squared tests were used to assess the association among groups of characteristics and determine if relative proportions were equal or followed a known distribution. Population data for the relevant drainage area were obtained from the City of Cape Town and based on 2011 census data compiled by StatsSA[14].

Ethical approval for this study was obtained from the Human Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (reference 313/2015).

Results and discussion

Prevalence of blunt force trauma related death

The prevalence of unnatural blunt force trauma death as well as blunt force trauma homicide in the West Metropole of the City of Cape Town from 2010 to 2014 can be seen in Table 1. There was no significant difference in the prevalence of blunt force trauma ($p=0.829$), nor blunt force trauma homicides ($p=0.209$) among the years. During the period of study, a total of 15 519 autopsies were performed at Salt River Medico-legal Mortuary – an average of 3104 cases per year. Of the total number of cases, 1198 (7.72%) cases had blunt force injuries noted as the cause of death, and of these cases 828 (5.32%) were classified as homicides. The mean prevalence over the 5-year period was 8.55/100 000 for blunt force trauma homicides.

Table 1: The prevalence of total blunt force trauma cases and blunt force trauma homicide cases at Salt River Mortuary from 2010 to 2014

Year	Total mortuary intake	Number of blunt force trauma cases (%)	Number of blunt force trauma homicides (%)
2010	2954	229 (7.75)	138 (4.67)
2011	2768	223 (8.06)	160 (5.78)
2012	2990	222 (7.42)	146 (4.88)
2013	3346	247 (7.38)	183 (5.47)
2014	3461	277 (8.00)	201 (5.81)
Mean	**3104**	**240**	**166**
Total	**15 519**	**1198 (7.72)**	**828 (5.32)**

Because of the lack of centralised data focusing on blunt force trauma homicides, it is difficult to make a comparison of these results to previous results in the country. Matzopolous[5] reported from the 2003 National Injury Mortality Surveillance System database that 14% of homicides in South Africa were a result of blunt force trauma. This figure corresponds to approximately 6% of unnatural deaths, similar to the 5.32% reported here. A more recent study in 2014 in Pretoria (Gauteng, South Africa) similarly reported that 6.19% of unnatural deaths were caused by blunt force trauma.[15] However, this figure is a snapshot of a single year and was based on an analysis of autopsy cases in which blood samples were taken for alcohol analysis and excluded cases in which samples for alcohol analysis were not collected. Internationally, blunt force trauma has been shown to account for 41%, 24%, 23% and 18% of homicides in India[10], Sweden[16], China[17] and Norway[12], respectively. Henderson and colleagues[18] also reported that approximately 26% of non-firearm homicides in London (England) were a result of blunt force trauma.

Age of victims

In the current study the mean age of the victims was 31 years, with a standard deviation of 12 years. The age of the victims is widely distributed, ranging from 0 to 82 years, with the principal age group (39%) of victims of homicidal blunt force trauma being 20–29 years. The distribution of cases across age groups can be seen in Figure 1. The overall age distribution of the victims of blunt force trauma homicide is significantly different from the age distribution of the overall intake from Salt River Mortuary ($p<0.001$).

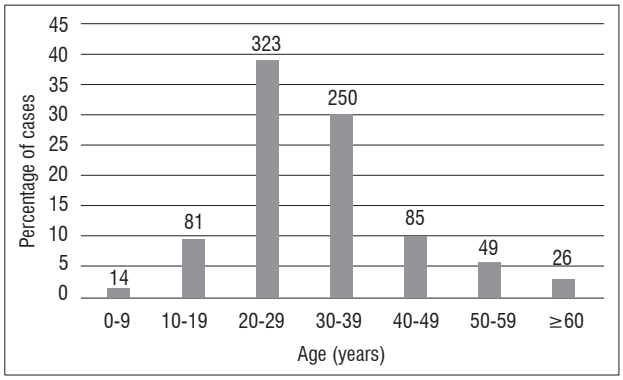

Figure 1: Percentage age distribution of victims of blunt force trauma homicide from 2010 to 2014.

The differences between the age distribution of blunt force trauma homicides and total mortuary intake are demonstrated in Table 2. The overall intake at Salt River Mortuary is primarily composed of cases of unnatural death with a small portion of natural death cases. The age groups 10–19 years, 20–29 years and 30–39 years were overrepresented with the age group 20–29 years being most at risk of blunt force homicide. The results of the current study are analogous with those from South Africa in 2003[5] and 1994[19] in which the age groups 25–29 and 25–34 years had the highest number of recorded homicides, respectively. The age group with the most blunt force homicide victims recorded in South African studies is slightly younger than those reported in British (30–39 years)[18] and Indian (31–40 years)[10] studies. This difference is possibly because of the involvement of younger people in gang activity and violence, as is often the case in the Western Cape.[8,20,21]

Table 2: Comparison of the age distribution between blunt force homicide cases and the overall intake of Salt River Mortuary from 2010 to 2014

Age category (years)	Blunt force trauma homicide %	Salt River Mortuary intake %	Difference %	*p*-value
0–9	1.69	14.62	12.93	< 0.001
10–19	9.78	6.03	3.75	<0.001
20–29	39.01	23.69	15.32	<0.001
30–39	30.19	19.78	10.41	<0.001
40–49	10.27	12.82	2.01	0.0317
50–59	5.92	10.04	4.12	<0.001
≥ 60	3.14	13.02	9.88	<0.001

Sex of victims

Internationally and locally, male individuals account for a greater proportion of homicide victims than do female individuals.[22,23] However, the reported proportions for homicides in South Africa are double the world average for male homicides.[5] This is particularly evident for male individuals aged 15–45 years. The current study demonstrated that there were significantly more male victims than female victims of blunt force homicide between 2010 and 2014 ($p<0.001$). Overall, 90.22% of the victims were male and 9.78% were female, a ratio of 9.22:1. In

comparison, the reported ratio of male to female victims of blunt force homicide in the City of Cape Town during the year 1994 was 6.6:1, indicating an increase in fatalities of male individuals due to blunt force trauma.[19] The male:female ratio for blunt force homicide found in India (6.6:1)[10] and Scandinavian countries (2.3:1)[12] is substantially lower than that seen in the current study. The National Injury and Mortality Surveillance System reported the male to female ratio for all homicides in the city of Cape Town as 8.5:1 in 2003.[5] The results of the current study show a significant overrepresentation of male victims of blunt force trauma homicide when compared to the overall intake at Salt River Mortuary ($p<0.001$). This finding suggests that male individuals are more at risk of blunt force homicide than female individuals (Table 3). Clearly, South African men of working age behave in a manner that puts them at greater risk of violent injury than South African women, as well as men from other countries.

Table 3: Comparison of the sex distribution of blunt force trauma homicide cases with the overall intake of Salt River Mortuary from 2010 to 2014

Sex	Blunt force trauma homicide %	Salt River Mortuary intake %	Difference %	*p*-value
Male	90.22	76.95	13.27	<0.001
Female	9.78	23.05	13.27	<0.001

The explanation for this result is multifaceted and often based on complex socio-biological interactions including perceived masculinity and increased risk-taking behaviour amongst men.[24] In a South African context, three factors have been found to be important in the ideology of masculinity: toughness, control and sexuality.[25] A perceived idea of what it means to be a man results in displays of 'toughness' or 'bravery', thus disagreements are often resolved by arguments and subsequent fighting rather than by peaceful means.[26] This behaviour is further magnified by the presence of alcohol and substance abuse. It has also been reported that high levels of male unemployment and gender inequality within a community may be predictive factors for homicide and assault.[22] The high levels of men involved in blunt force trauma, as well as homicide in general, in the West Metropole of the City of Cape Town may further be because of the high levels of gang violence in which men are usually more heavily involved than women, again as a consequence of poverty and a perceived ideology of masculinity.[8,20]

Blood alcohol levels in victims

It is accepted that alcohol use and intoxication are key risk factors for homicide,[27] with Cape Town having a larger number of alcohol positive homicide cases compared to other areas in South Africa.[5] The blood alcohol concentration (BAC) of victims of blunt force trauma was expressed in grams per 100 millilitres of blood (g/100 mL) and was classified according to four groups: not intoxicated (0 g/100 mL), mildly intoxicated (0–0.05 g/100 mL), intoxicated (0.05–0.15 g/100 mL) and severely intoxicated (0.15–0.4 g/100 mL). The distribution of BAC amongst victims can be seen in Figure 2. BAC was unknown for 354 (42.75%) cases because alcohol analysis was not requested.

Alcohol analysis was requested in 474 (57.25%) cases. From the cases for which alcohol analysis was performed, the majority of victims (66.67%) was not intoxicated. The 158 (33.33%) cases in which blood alcohol was detected, had a mean BAC of 0.169 g/100 mL in a range of 0.01–0.41 g/100 mL. In the 2014 study conducted in Pretoria, 38% of the blunt force trauma cases were victims who tested positive for blood alcohol with a mean BAC of 0.13 g/100 mL.[15] It appears that the majority of victims of blunt force trauma in South Africa are not intoxicated; however, when alcohol is involved, victims tend to be on the higher end of the intoxication spectrum.

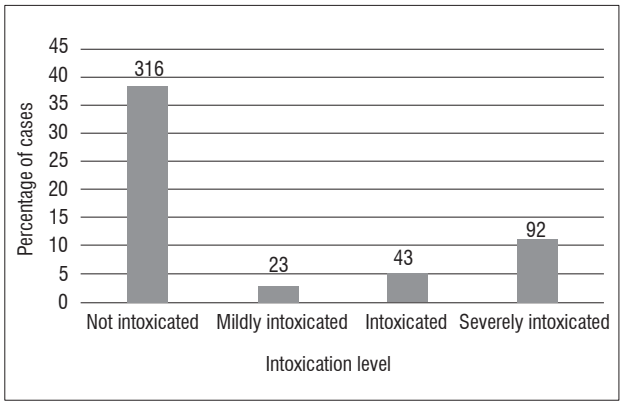

Figure 2: Percentage distribution of the blood alcohol concentration levels in victims of blunt force trauma.

A significant association was found between age and BAC ($p=0.012$); the highest levels of intoxication being in the 20–29 years age category, with severe intoxication occurring more frequently than mild intoxication. Intoxication occurred within all age groups, excluding the 0–9 year age group. All intoxication levels were seen in both male and female victims. Because of the small number of female blunt force trauma victims in this study, it was difficult to make associations between female victims and alcohol use. However, the 17% of severely intoxicated females is lower than that found by Mathews et al.[28] in which 56% of female blunt force trauma victims in the Western Cape were severely intoxicated. Differences between these results could be because we included all ages and Mathews et al. excluded cases in which the victims were younger than 14 years old.

Day and month of death

An association was found between the distribution of blunt force homicide cases and the days of the week ($p<0.001$). The highest number of blunt force homicides (23.67%) occurred on Sundays (Figure 3). The number of homicides that occurred during the weekend accounted for 40.82% of the total number of blunt force homicide cases. These results are similar to those of a 2003 study which reported that 49% of all homicides in Cape Town took place over the weekend.[5] It is thought that this trend could be attributed to people spending more time taking part in social drinking over the weekend.[18] Evidence of this pattern can be seen in Figure 4, which demonstrates that Sundays had the highest number of cases with mild to severe intoxication.

In addition to research suggesting a correlation between the homicide rate and days of the week, studies also often report a possible association between certain months or seasons of the year. In London it was found that the homicide rate increases during the warmer summer months[18] which is contrary to the results produced in the current study which showed no recognisable pattern for the distribution of blunt force homicides over the course of the year from 2010 to 2014. A possible explanation for this may be the moderate climate in South Africa and much higher crime rate overall in comparison with Britain.[19]

Number and location of injuries

Injury profiles were similar for all years of the study. There was a high degree of variability in the severity of the blunt force attacks; the number of external injuries to the body ranged from 0 to 70 per case, with an average of 14 (±12) injuries per case (Table 4). The cases in which no injuries were reported were indicative of cases in which no visible signs of blunt force trauma were present externally. Very high numbers of injuries were mostly in cases with extensive areas of abrasion. Information pertaining to the number of assailants and weapons used was not uniformly reported or available but cases showing multiple combination injuries are thought to be associated with multiple aggressors – often seen in cases of community assault particularly in the form of 'mob' or 'vigilante' justice, which is common in the Western Cape.[8,29]

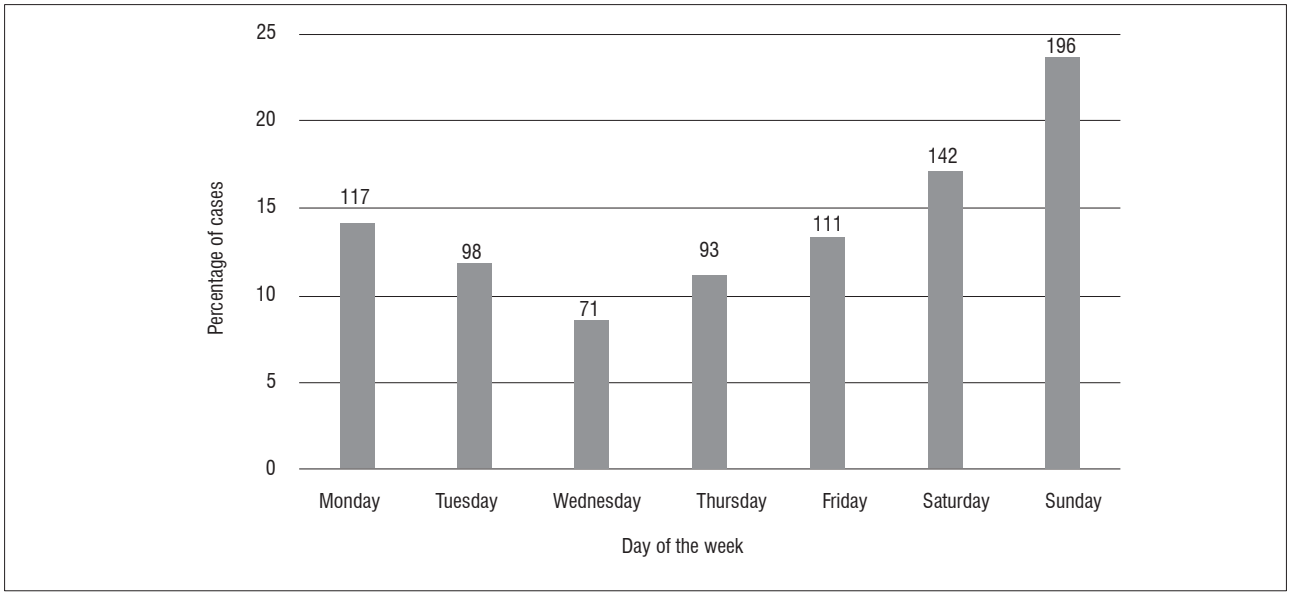

Figure 3: Percentage distribution of blunt force homicide cases from 2010 to 2014 across the days of the week.

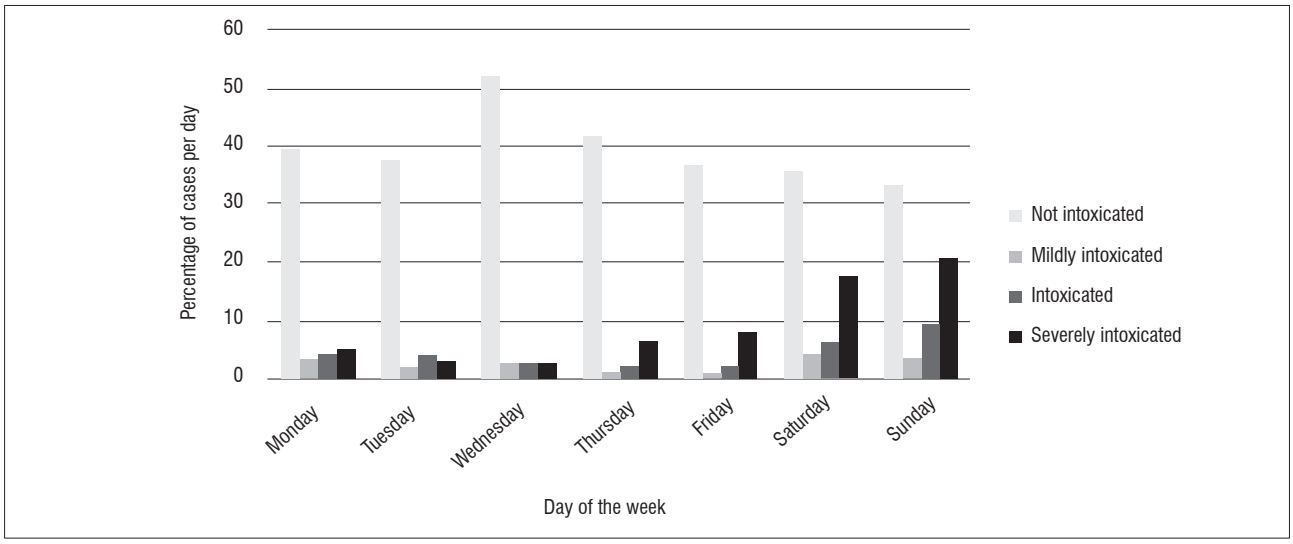

Figure 4: Percentage distribution of intoxication levels during the week as a percentage of the total blunt force trauma homicide cases per day from 2010 to 2014.

Table 4: Distribution of the number of external blunt force injuries per case from 2010 to 2014 and the regional distribution of the blunt force injuries

	Number of injuries per case				Number of injuries per body region (%)						
Number of cases	Mean	s.d.	Minimum	Maximum	Head	Neck	Chest	Back	Legs	Arms	Abdomen
828	14	12	0	70	772 (93%)	174 (21%)	328 (40%)	303 (37%)	441 (53%)	498 (60%)	168 (20%)

A total of 90 blunt force homicide cases (10.86%) were classified as combination deaths involving two or more trauma types. A recent study at Tygerberg Forensic Pathology Services, Cape Town found that almost half of the cases classified as community assault involved multiple trauma types with blunt force trauma forming the basis of the majority of injuries sustained.[30] Mob attacks have been described as vicious attacks and are often perpetrated by groups without discipline or membership to a particular cause or faction and are thus often heated and unstructured.[8] It is therefore no surprise that victims of such 'justice' often bear injuries from multiple implements.

During the period of investigation, many victims sustained a high number of injuries, the location of which tended to be spread over the body. The head was the body region which most often (93%) showed signs of blunt force trauma (Table 4). Of these cases, 192 (23%) involved the head as the only injured body region whilst 580 (70%) involved injury to the head in addition to other regions (Figure 5).

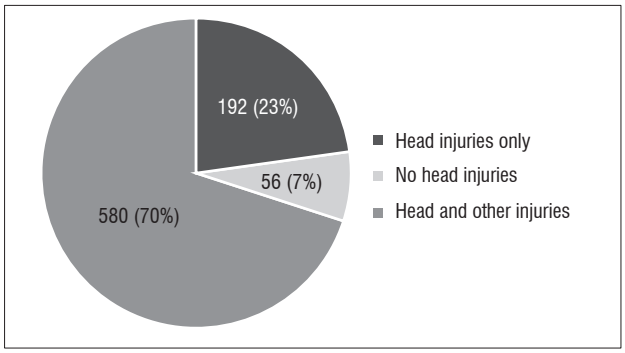

Figure 5: Proportion of head injuries in blunt force trauma homicides.

Defensive injuries could contribute to the large number of wounds located on the arms and legs and may account for these regions being the second and third most affected body regions, respectively, in blunt force attacks. The high number of cases involving the head echoes the findings of Ambade and Godbole[10] who recorded 81% of cases of blunt force homicide involving the head. A more complete injury profile of blunt force attacks would be possible if hospital records (which provide injury information of victims who survive blunt force attacks) are combined with autopsy reports.

Crime scene locations

The West Metropole of the City of Cape Town comprises areas with varied socio-economic statuses. Poor socio-economic status has been shown to be correlated with high rates of homicide.[22,31] The current study concurs with the finding of elevated levels of homicide in poor socio-economic areas. The physical location of the crime scene refers to the physical context of the crime scene and was categorised as indoors (in formal or informal housing), outdoors and unknown. There was no significant difference in the distribution of the physical crime scene locations of blunt force homicides across the years ($p=0.421$). As seen in Figure 6, a significant proportion of victims (43%) was killed in an outdoor context, compared to those killed at other locations ($p<0.001$).

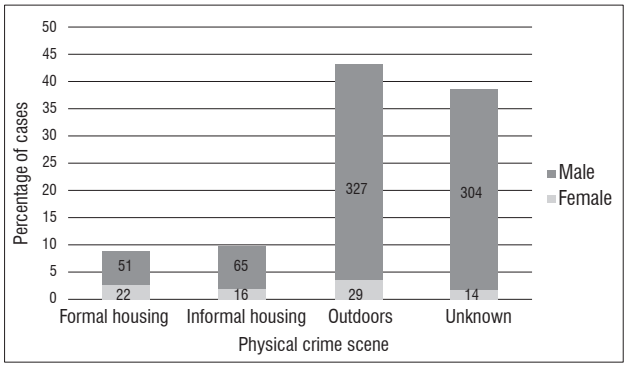

Figure 6: Percentage distribution of total number of victims and sex distribution in physical crime scene locations.

Although there was a much higher number of male than female victims, when the number of cases per physical crime scene location was analysed separately for each gender, a difference in the proportional distribution of female and male victims was noted. A significantly greater proportion of female victims (46.91%) were killed indoors in formal or informal housing compared with male victims (15.53%) ($p<0.001$). These results correspond to those of previous English and South African studies which concluded that a greater percentage of women than men are killed in their domiciles.[5,18] A reason put forward for this global trend is the difference in the interaction of socio-biological factors and gender roles within society, leading to men being more likely than women to interact aggressively, especially with strangers away from their homes.[24] From a South African perspective, it has been reported that more than half of all female homicide victims in South Africa are killed by an intimate partner (that is, a current or former boyfriend/husband/same sex partner or rejected lover) indoors.[32] Furthermore, homicide perpetrated by an intimate partner often results in blunt force injuries.[33] Considering these factors, it is not surprising that we found that the majority of female victims in the current study was murdered within formal or informal housing.

Conclusion

The current study highlights the prevalence of homicidal blunt force trauma in Cape Town and provides insights into the patterns associated with victims of such crimes. A paucity of literature surrounding this topic exists. However, the results of the current study broadly concur with previous studies undertaken in South Africa but provide a more detailed analysis of blunt force injuries in cases of homicide. In the West Metropole of the City of Cape Town, the prevalence of blunt force trauma homicide between 2010 and 2014 was 5.32%. Young men from areas of poor socio-economic status comprised the majority of the victims. Interventions, especially those that target young men, may be needed for these areas. There was a high number of injuries associated with blunt force homicides located on the head, highlighting the importance of focusing resources and research on cranial trauma. Future research should attempt to obtain a more complete injury profile of blunt force trauma by including the investigation of non-fatal blunt force trauma.

Authors' contributions

C.C. was the lead author, collected and analysed the data, and wrote the first draft. C.G.M. supervised the study, conceptualised and designed the project, and assisted with data analysis. M.H. supervised the study and contributed conceptually. All authors contributed to drafting the article and approved the final version.

References

1. Hart GO. Fracture pattern interpretation in the skull: Differentiating blunt force from ballistics trauma using concentric fractures. J Forensic Sci. 2005;50(6):1276–1281. http://dx.doi.org/10.1520/JFS2004219
2. Ohshima T. Forensic wound examination. Forensic Sci Int. 2000;113(1–3):153–164. http://dx.doi.org/10.1016/S0379-0738(00)00269-3
3. Mole CG, Heyns M, Cloete T. How hard is hard enough? An investigation of the force associated with lateral blunt force trauma to the porcine cranium. Leg Med. 2015;17(1):1–8. http://dx.doi.org/10.1016/j.legalmed.2014.07.008
4. Saukko P, Knight B. Knight's forensic pathology. 3rd ed. London: Arnold; 2004. p. 229–230. https://doi.org/10.1201/b13642
5. Matzopoulos R. Violent deaths in SA: The 2003 National Injury Mortality Surveillance System. SA Crime Q. 2005;13:29–36.
6. Norman R, Matzopoulos R, Groenewald P, Bradshaw D. The high burden of injuries in South Africa. Bull World Health Organ. 2007;85(9):695–702. http://dx.doi.org/10.2471/BLT.06.037184
7. Groenewald P, Bradshaw D, Daniels J, Matzopoulos R, Bourne D, Blease D, et al. Cause of death and premature mortality in Cape Town, 2001–2006. Cape Town: South African Medical Research Council; 2008.
8. Buur L, Jensen S. Introduction: Vigilantism and the policing of everyday life in South Africa. Afr Stud. 2004;63(2):139–152. http://dx.doi.org/10.1080/00020180412331318724
9. Wahlsten P, Koiranen V, Saukko P. Survey of medico-legal investigation of homicides in the city of Turku, Finland. J Clin Forensic Med. 2007;14:243–252. http://dx.doi.org/10.1016/j.jcfm.2006.07.007
10. Ambade VN, Godbole HV. Comparison of wound patterns in homicide by sharp and blunt force. Forensic Sci Int. 2006;156:166–170. http://dx.doi.org/10.1016/j.forsciint.2004.12.027
11. Fischer J, Kleemann WJ, Tröger HD. Types of trauma in cases of homicide. Forensic Sci Int. 1994;68:161–167. http://dx.doi.org/10.1016/0379-0738(94)90355-7
12. Rogde S, Hougen HP, Poulsen K. Homicide by blunt force in 2 Scandinavian capitals. Am J Forensic Med Pathol. 2003;24(3):288–291. http://dx.doi.org/10.1097/01.paf.0000083362.87731.fd

13. Western Cape Department of Health. Forensic Pathology Services: Our facilities [homepage on the Internet]. No date [updated 2014 Mar 15; cited 2016 Jul 13]. Available from: https://www.westerncape.gov.za/general-publication/our-facilities

14. City of Cape Town. City statistics and population census [home page on the Internet]. No date [cited 2016 Jul 13]. Available from: http://www.capetown.gov.za/Family%20and%20home/education-and-research-materials/data-statistics-and-research/cape-town-census

15. Ehmke U, Du Toit-Prinsloo L, Saayman G. A retrospective analysis of alcohol in medico-legal autopsied deaths in Pretoria over a 1 year period. Forensic Sci Int. 2014;245:7–11. http://dx.doi.org/10.1016/j.forsciint.2014.09.009

16. Ericsson A, Thiblin I. Injuries inflicted on homicide victims: A longitudinal victiminologic study of lethal violence. Forensic Sci Int. 2002;130:133–139. http://dx.doi.org/10.1016/S0379-0738(02)00380-8

17. He M, Fang Y, Lin J, Ma K, Li B. Unnatural deaths in Shanghai from 2000 to 2009: A retrospective study of forensic autopsy cases at the Shanghai Public Security Bureau. PLoS One. 2015;10(6), e0131309, 10 pages. http://dx.doi.org/10.1371/journal.pone.0131309

18. Henderson JP, Morgan SE, Patel F, Tiplady ME. Patterns of non-firearm homicide. J Clin Forensic Med. 2005;12:128–132. http://dx.doi.org/10.1016/j.jcfm.2004.10.011

19. Lerer LB, Matzopoulos RG, Phillips R. Violence and injury mortality in the Cape Town metropole. S Afr Med J. 1997;87(3):298–301.

20. Morrell R, Jewkes R, Lindegger G. Hegemonic masculinity/masculinities in South Africa: Culture, power, and gender politics. Men Masc. 2012;15(1):1–20. http://dx.doi.org/10.1177/1097184X12438001

21. Van Wyk B, Theron W. Fighting gangsterism in South Africa: A contextual review of gang and anti-gang movements in the Western Cape. Acta Criminol. 2005;18(3):51–60.

22. Seedat M, Van Niekerk A, Jewkes R, Suffla S, Ratele K. Violence and injuries in South Africa: Prioritising an agenda for prevention. Lancet. 2009;374:1011–1022. https://doi.org/10.1016/S0140-6736(09)60948-X

23. Reza A, Mercy JA, Krug E. Epidemiology of violent deaths in the world. Inj Prev. 2001;7:104–111. http://dx.doi.org/10.1136/ip.7.2.104

24. Gartner R, Baker K, Pampel FC. Gender stratification and the gender gap in homicide victimization. Soc Probl. 1990;37(4):593–612. http://dx.doi.org/10.1525/sp.1990.37.4.03a00120

25. Luyt R. The male attitude norms inventory II: A measure of masculinity ideology in South Africa. Men Masc. 2005;8(2):208–209. http://dx.doi.org/10.1177/1097184X04264631

26. Ratele K. Masculinity and male mortality in South Africa. Afr Saf Promot. 2008;6(2):19–41. http://dx.doi.org/10.4314/asp.v6i2.31587

27. Room R, Babor T, Rehm J. Alcohol and public health. Lancet. 2005;365:519–530. http://dx.doi.org/10.1016/S0140-6736(05)17870-2

28. Mathews S, Abrahams N, Jewkes R, Martin LJ, Lombard C. Alcohol use and its role in female homicides in the Western Cape, South Africa. J Stud Alcohol Drugs. 2009;70:321–327. http://dx.doi.org/10.15288/jsad.2009.70.321

29. Shields N, Nadasen K, Pierce L. The effects of community violence on children in Cape Town, South Africa. Child Abuse Negl. 2008;32:589–601. http://dx.doi.org/10.1016/j.chiabu.2007.07.010

30. Herbst CI, Tiemensma M, Wadee SA. A 10-year review of fatal community assault cases at a regional forensic pathology facility in Cape Town, South Africa. S Afr Med J. 2015;105(10):848–852. http://dx.doi.org/10.7196/SAMJnew.8274

31. Schuurman N, Cinnamon J, Matzopoulos R, Fawcett V, Nicol A, Hameed SM. Collecting injury surveillance data in low- and middle-income countries: The Cape Town Trauma Registry pilot. Glob Public Health. 2011;6(8):874–889. http://dx.doi.org/10.1080/17441692.2010.516268

32. Mathews S, Abrahams N, Martin LJ, Van der Merwe L, Jewkes R. Every six hours a woman is killed by her intimate partner: A national study on female homicide in South Africa. Cape Town: Medical Research Council; 2004.

33. Mathews S, Abrahams N, Jewkes R, Martin LJ, Lombard C, Vetten L. Injury patterns of female homicide victims in South Africa. J Trauma. 2009;67:168–172. http://dx.doi.org/10.1097/TA.0b013e318184822f

Isolation and characterisation of endocrine disruptor nonylphenol-using bacteria from South Africa

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Endocrine disrupting chemicals (EDCs) are synthetic chemicals that alter the function of endocrine systems in animals including humans. EDCs are considered priority pollutants and worldwide research is ongoing to develop bioremediation strategies to remove EDCs from the environment. An understanding of indigenous microorganisms is important to design efficient bioremediation strategies. However, much of the information available on EDCs has been generated from developed regions. Recent studies have revealed the presence of different EDCs in South African natural resources, but, to date, studies analysing the capabilities of microorganisms to utilise/degrade EDCs have not been reported from South Africa. Here, we report for the first time on the isolation and enrichment of six bacterial strains from six different soil samples collected from the Mpumalanga Province, which are capable of utilising EDC nonylphenol as a carbon source. Furthermore, we performed a preliminary characterisation of isolates concerning their phylogenetic identification and capabilities to degrade nonylphenol. Phylogenetic analysis using 16S rRNA gene sequencing revealed that four isolates belonged to *Pseudomonas* and the remaining two belonged to *Enterobacteria* and *Stenotrophomonas*. All six bacterial species showed degradation of nonylphenol in broth cultures, as HPLC analysis revealed 41–46% degradation of nonylphenol 12 h after addition. The results of this study represent the beginning of identification of microorganisms capable of degrading nonylphenol, and pave the way for further exploration of EDC-degrading microorganisms from South Africa.

Significance:
- First report of endocrine disruptor nonylphenol-using bacteria from South Africa
- Six bacterial species capable of using nonylphenol as a carbon source were isolated
- Results will pave the way for further exploration of endocrine disruptors degrading microbes from South Africa

Introduction

Endocrine disruptors or endocrine disrupting chemicals (EDCs) are chemicals that can alter the functioning of endocrine systems in humans and other animals including wildlife, and can thus cause cancerous tumour development, birth defects and other developmental disorders.[1,2] Many chemicals have been identified as EDCs, and many are used in the formulation of various pharmaceutical products, pesticides, industrial chemicals, heavy metals, persistent organochlorines and other organohalogens, alkylphenols, and synthetic and natural hormones.[2,3] These environmental pollutants mimic natural hormones of the endocrine system and display either oestrogenic or androgenic activities.[1,2,4] They can thus have adverse effects by either unnaturally inhibiting or stimulating the endocrine system and/or hormonal production.[1,2,4] Exposure to EDCs increases the chance of physiological abnormalities and alters cognitive function in animals, including humans.[1,2] Physiological abnormalities include low sperm count and decreased sperm quality[5], as well as premature puberty in both girls[6] and boys[7]. Several other metabolic disorders have been reported, including different types of cancers and thyroid-related problems including obesity.[1,2,8]

Investigations have also shown that these types of chemicals also affect other animals. Effects of EDCs on aquatic species have been well documented.[9] EDCs have been reported to have adverse effects on invertebrates and wildlife populations.[10] Female snails exposed to tributylin exhibited masculinisation (a disorder called imposex in which female snails develop a male sex organ, including a penis and vas deferens), which in turn led to a decline in the population.[11] Alligators of Lake Apopka (Florida, USA) were reported to have impaired sexual development and function as a result of exposure to dichlorodiphenyltrichloroethane (DDT).[12] Exposure to dichlorodiphenyldichloroethylene (DDE) resulted in a decline in numbers of bald eagles in Europe and North America.[13]

To date, information concerning EDCs has been primarily derived from studies conducted in developed countries.[2] Much information is still, however, lacking from large parts of Africa, Asia and Central and South America.[2] Studies on EDCs from South Africa in particular are very scarce. A report presented by the Water Research Commission of South Africa revealed the presence of EDCs in South African water.[14] In addition to this report, studies conducted in a few places within South Africa have also revealed the presence of EDCs. DDT, DDE and phthalate esters have been found in Limpopo[15-17]; oestrone, oestradiol and oestriol (steroids hormones) in the Western Cape[18] and in KwaZulu-Natal[19]; *p*-nonylphenol, diethylhexyl phthalate and dibutyl phthalate in Gauteng[20]; and lastly DDT, chlordane, hexachlorobenzene, heptachlor and endosulfan in the Eastern Cape[21]. In addition, a large number of EDCs was found in upstream and downstream sections of wastewater treatment plants.[22,23]

As a result of their adverse effects on humans and wildlife, EDCs are considered to be priority pollutants, and worldwide research is ongoing to develop remediation strategies to remove these chemicals from the environment.

Strategies for removal – including advanced oxidation processes[24], electrochemical separation and degradation technologies[25] and bio-remediation and combinatorial techniques[26,27] – have been extensively investigated. Bioremediation is a particularly attractive approach, as it represents natural and economically feasible processes for detoxification of environmental pollutants under environmental conditions. An understanding of indigenous microorganisms is therefore important to facilitate the design of efficient bioremediation strategies. However, to date, studies on the analysis of the capabilities of microorganisms to utilise/degrade EDCs have not been reported from South Africa. This study is the first of its kind on the enrichment, isolation, identification and further assessment of the EDC-degradation capability of bacteria from South African soils.

Materials and methods

Soil sample collection and preparation

Soil samples were aseptically collected from soil at different coal-fired power stations in and around the Mpumalanga Province, South Africa. The selected sampling areas are represented in a schematic diagram with GPS coordinates (Figure 1). Soil samples (5 g) were re-suspended in 30 mL of DNase-free and RNase-free water.[28,29] The samples were vigorously vortexed for 5 min, followed by incubation on a rotary shaker for 1 h at room temperature at 100 rpm.[28,29] After incubation, the soil was allowed to settle out of solution (30 min), and the supernatants were collected and immediately used for isolation of microorganisms.

Medium preparation

All chemicals and reagents used in this study were purchased from Sigma-Aldrich (Johannesburg, South Africa), unless otherwise stated. Minimal medium[28,29] with added trace element solution[30] was used for isolation of microorganisms. The minimal medium consisted of 8.5 g/L $Na_2HPO_4.2H_2O$, 3.0 g/L KH_2PO_4, 0.5 g/L NaCl, 1.0 g/L NH_4Cl, 0.5 g/L $MgSO_4.7H_2O$, 14.2 mg/L $CaCl_2$ and 0.15 g/L KCL. The minimal medium was supplemented with 10 mL of trace element solution[30], consisting of 0.4 mg/L $CuSO_4$, 1.0 mg/L KI, 4.0 mg/L $MnSO_4.H_2O$, 4.0 mg/L $ZnSO_4.7H_2O$, 5.0 mg/L H_3BO_3, 1.2 mg/L $Na_2MO_4.2H_2O$ and 2.0 mg/L $FeCl_3.6H_2O$, per litre of medium. Technical grade nonylphenol (catalogue number 290858) was added as a sole source of carbon to a final concentration of 5 mM.

Enrichment procedure

Supernatant (1 mL) from the soil samples was used to inoculate 100 mL of minimal medium in a 500-mL conical flask, supplemented with nonylphenol as the sole carbon source. A control was set up to contain medium and nonylphenol, without inoculation of soil samples. After 4 weeks of incubation at 37 °C at 100 rpm, 1 mL of culture was used to inoculate fresh minimal medium (100 mL) with nonylphenol as the sole carbon source. This serial enrichment of bacterial isolates was repeated until a single, homogenous culture was obtained. Aliquots (100 μL) of cultures were spread on minimal medium agar plates with nonylphenol (5 mM) as the sole carbon source, to monitor the growth of microorganisms at 37 °C. The minimal medium plates with nonylphenol were prepared as described elsewhere.[31] Bacterial growth was also analysed by measuring the absorbance at 600 nm.

Isolation of genomic DNA and amplification of 16S rRNA gene

Genomic DNA (gDNA) from bacterial isolates was extracted using the ZR Fungal/Bacterial DNA MiniPrep kit (catalogue number D6005, Inqaba Biotec, Pretoria, South Africa) according to the manufacturer's protocol.

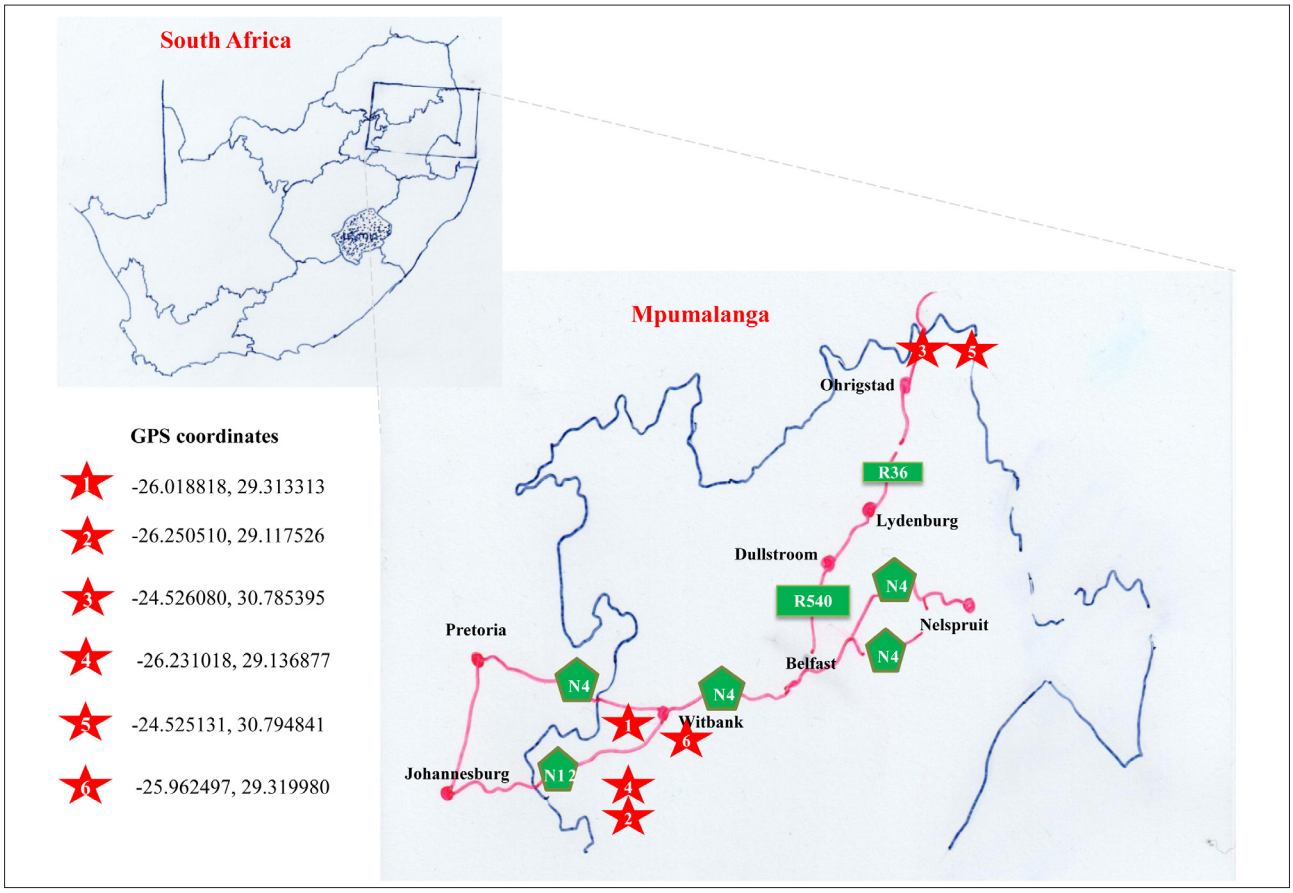

Figure 1: Schematic representation of soil sample collection areas in Mpumalanga, South Africa. The numbers 1 to 6 in stars indicate the areas from which the soil samples were collected. The GPS coordinates of the sampling areas are given in the figure.

The gDNA was visualised using agarose gel electrophoresis, and gDNA concentration was measured using a SimpliNano microvolume spectrophotometer (catalogue number GE29-0617-12, Sigma-Aldrich, St. Louis, MO, USA). The isolated gDNA was used for amplification of the 16S rRNA gene. The 16S rRNA gene was amplified by polymerase chain reaction (PCR) using primers 63f and 1387r as described elsewhere.[32] A KAPA HiFi HotStart PCR kit (catalogue number KK2501, KAPA Biosystems, Wilmington, MA, USA) was used to amplify the 16S rRNA gene according to manufacturer's instructions. The PCR products were run on a 0.8% agarose gel and were purified using the Wizard® SV Gel and PCR Clean-Up System (catalogue number A9281, Promega, Madison, WI, USA).

16S rRNA gene sequencing

Samples were prepared for sequencing using the BigDye™ Terminator V3.1 Cycle Sequencing Kit (catalogue number 4337455, Thermo Fischer Scientific, Waltham, MA, USA). The aforementioned primers 63f and 1387r[32] were used for sequencing. The sequencing reactions were performed according to the parameters described by the manufacturer. Sequencing reactions were purified using the EDTA-ethanol method described by the manufacturer, and submitted for sequencing using a 3130xl Genetic Analyzer (Applied Biosystems, Foster City, CA, USA). Consensus sequences were derived from the sequences obtained from the forward and reverse primer reactions for each product, using Geneious® R9 9.1.2. software.

Phylogenetic analysis

16S rRNA gene sequences of bacterial isolates were subjected to BLAST analysis at NCBI (the US National Center for Biotechnology Information) against 16S ribosomal RNA sequences (Bacteria and Archaea) to identify the closest homologs. Among the resulting hits, the 16S rRNA sequences with 100% or 99% identity homologs were selected. Based on the obtained bacterial species, the type strains belonging to each species were selected, and the 16S rRNA sequences were retrieved from elsewhere (http://www.bacterio.net/). The *Escherichia coli* ATCC 11775 type strain 16S rRNA gene sequence (also retrieved from http://www.bacterio.net/) was used as an out-group. Phylogenetic analysis was carried out using the maximum likelihood method based on the Tamura–Nei model.[33] Initial tree(s) for the heuristic search were obtained by applying the neighbour-joining method to a matrix of pairwise distances estimated using the maximum composite likelihood approach. All positions containing gaps and missing data were eliminated. Evolutionary analyses were conducted in MEGA5.[34] Phylogenetic analysis included the isolate 16S rRNA gene sequence, hit homologs and type strain 16S rRNA gene sequences. The phylogenetic tree was presented with branch lengths, and the bacterial isolates identified in this study are highlighted in bold font.

Nonylphenol degradation

A degradation study using whole cells was carried out as described elsewhere[35,36] to assess the capabilities of the bacterial isolates to degrade nonylphenol. A single colony of isolates from minimal medium plate containing nonylphenol as the carbon source was used to inoculate 5 mL of Luria–Bertani broth, which was then cultured overnight at 150 rpm at 37 °C. The growth of the isolates was measured at 600 nm after diluting the culture in Luria–Bertani broth. The cultures were then washed twice with saline (0.9% sodium chloride solution), followed by inoculation with an equal amount of each overnight bacterial culture for all six isolates onto separate, fresh minimal media (5 mL) containing nonylphenol (2.5 mM) as a carbon source in 50-mL glass tubes (test cultures). The test cultures were incubated for 12 h at 37 °C at 150 rpm. After incubation, 5 mL of ethyl acetate was added to the test cultures, which were then vortexed for 5 min at maximum speed, followed by centrifugation for 5 min at 2500 *g* at room temperature. After centrifugation, two distinct fractions were separated by a thin middle layer composed of bacterial cell debris. The upper organic fraction containing nonylphenol was removed from the lower aqueous fraction into a fresh glass tube. The extraction was repeated twice, followed by evaporation of the organic fraction. The remaining residue was re-suspended in 200 μL of HPLC-grade methanol. Minimal medium with nonylphenol but without culture was used as a control and treated the same as the test culture.

HPLC analysis of nonylphenol was carried out following the method described elsewhere, with modifications.[35,36] Briefly, the abovementioned methanol samples were filtered through 0.45-μm glass fibre filters and analysed using a Shimadzu Prominence instrument (Shimadzu, Roodepoort, South Africa) equipped with a C18 analytical column (4.6 mm × 250 mm; particle size 5 μm from Sigma-Aldrich, South Africa) and with a dual wavelength UV/Vis detector. Separation was achieved using a 22.5-min linear gradient of acetonitrile in water (50% to 96.5%, and then re-equilibrated for 10 min at 50% acetonitrile at a flow rate of 1.25 mL/min). A volume of 5 μL of sample was injected for analysis. Nonylphenol was detected at 277 nm, and the percentage degradation of nonylphenol by test cultures was related to the control nonylphenol, which was taken as 100%.

Statistical analysis

All experiments were carried out in triplicate and results were subjected to statistical analysis as described elsewhere.[35,36] The activities, in terms of percentage degradation, of the different bacterial isolates were analysed for means and standard deviations and compared for statistical differences using a Student's *t*-test on GraphPad QuickCalcs software package (GraphPad Software Inc., CA, USA).

16S rRNA gene sequences accession numbers

16S rRNA gene sequences of bacterial isolates identified in this study were submitted to GenBank (https://www.ncbi.nlm.nih.gov/genbank/), with the following accession numbers: KX364074 (*Pseudomonas nitroreducens* strain LBQSKN1), KX364075 (*Pseudomonas putida* strain LBQSKN2), KX364076 (*Stenotrophomonas* sp. LBQSKN3), KX364077 (*Enterobacter asburiae* strain LBQSKN4), KX364078 (*Pseudomonas* sp. LBQSKN5) and KX364079 (*Pseudomonas* sp. LBQSKN6).

Results and discussion

Enrichment and isolation of nonylphenol-utilising bacteria

The sampling areas selected for this study (represented in Figure 1) have been reported to harbour polycyclic aromatic hydrocarbons (PAHs).[37] PAHs are hydrophobic compounds well known for their carcinogenicity and mutagenicity towards humans.[38,39] In this study, we aimed to test the ability of bacterial species growing in the presence of PAHs to degrade EDCs, as these chemicals are also hydrophobic and aromatic in nature. To isolate microorganisms capable of utilising nonylphenol as a sole source of carbon, we followed a standard enrichment method. Soil samples collected from six different places (Figure 1) were inoculated into minimal medium supplemented with nonylphenol as a carbon source. After 4 weeks of incubation, growth of bacteria was observed on minimal medium plates supplemented with nonylphenol as a carbon source, as well as assessed through spectrophotometry. The initial bacterial growth on plates was non-homogenous, suggesting the presence of more than one type of species. After three successive serial cultures, a homogenous population of bacteria was observed on minimal medium plates, indicating that successive serial culturing resulted in the enrichment of a single type of bacteria that are capable of utilising nonylphenol as a sole source of carbon. In this study, six bacteria were isolated from the six different soil samples.

Identification of bacterial isolates

In order to identify the enriched bacterial isolates, 16S rRNA gene sequence-based phylogenetic analysis was carried out. The 16S rRNA genes from the gDNA of bacterial isolates were PCR amplified using the 63f and 1387r primer set as described elsewhere.[32] Analysis of the PCR amplified products on agarose gel showed prominent DNA bands with approximate sizes of ≥1200 base pairs (Figure 2). This analysis indicates specific amplification of the 16S rRNA gene. The amplified 16S rRNA gene was gel purified and subjected to sequence analysis using the same primers used for its amplification. Sequence analysis was performed using both forward and reverse primers, yielding a consensus sequence of 300–500 overlapping base pairs between the sequences. The sizes of the 16S rRNA sequences obtained for each of the bacterial isolates are presented in Table 1. The 16S rRNA sequence of Isolates 1 and 2 showed 100% identity to *Pseudomonas* spp., while Isolates 5

and 6 also had 99% identity to *Pseudomonas* spp. (Table 1). Isolate 3 showed 99% identity to *Stenotrophomonas* spp. and Isolate 4 showed 99% identity to *Enterobacter* spp. This indicates that most of the isolates belong to *Pseudomonas* (Table 1). Phylogenetic analysis of isolates based on 16S rRNA gene sequences compared to the 16S rRNA gene sequences of hit species, highlighted the differential alignment of bacterial isolates with different species (Figure 3). Based on the phylogenetic alignment, the six bacterial isolates were named as shown in Table 1. Furthermore, homology analysis (per cent identity) of 16S rRNA gene sequences among bacterial isolates (Table 2) revealed that Isolates 3 and 4 have low per cent identity compared with that of the other isolates, clearly reinforcing that they in fact belong to different bacterial genera. Species assigned to *Pseudomonas* on the other hand showed high per cent identity (Table 2), demonstrating that they belong to the same genus.

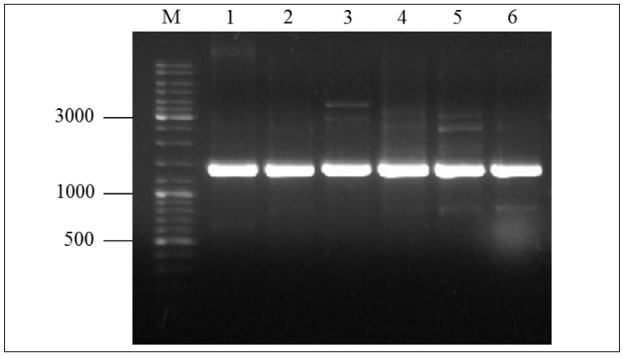

Figure 2: Agarose gel electrophoresis analysis of 16S rRNA genes amplified from six bacterial isolates. PCR amplified products were run on 1% agarose gel. Lane M indicates the DNA ladder (O'GeneRuler DNA Ladder Mix 100–10 000 base pair, catalogue number SM1173, ThermoFisher). Markers with high intensity were indicated by their size. Lanes 1 to 6 indicate the PCR amplified 16S rRNA gene of the respective bacterial isolates.

Degradation of nonylphenol by bacterial species

Whole-cell nonylphenol degradation experiments were carried out to assess the nonylphenol degradation capability of each bacterial isolate. As shown in Figure 4, all bacterial isolates showed degradation of nonylphenol. The degradation of nonylphenol by bacterial isolates ranged from 41% to 46% (Figure 4). However, the difference in percentage of nonylphenol degradation by all six bacterial species was considered to be the same, because the percentage differences among the isolates was not statistically significant ($0.2<p<0.7$). Nonylphenol degradation by the bacterial species identified in this study is reinforced by the literature. Species belonging to the genus *Pseudomonas* have been shown to degrade EDCs such as di-*n*-butyl phthalate[40], *p*-nonylphenol[41] and polyethoxylated nonylphenols[42,43]. Bacterial species belonging to *Stenotrophomonas* were previously found to be capable of using either nonylphenol or octylphenol as a sole carbon source.[44] For species belonging to the well-known human-pathogenic and plant association *Enterobacter*, degradation of EDCs has been reported particularly for bisphenol A[45], polychlorinated biphenyls[46], endosulfan[47], dibutyl phthalate[48] and nonylphenol[49].

All of the bacterial species isolated in this study also have the capability to degrade PAHs. PAH degradation by *Pseudomonas* species is well reported.[50-54] Degradation of PAHs using *Stenotrophomonas*[55], in particular *Stenotrophomonas maltophilia*[56-58], has been investigated. Hydrocarbon degradation capabilities for some of these species have also been demonstrated with aliphatic[59] and aromatic hydrocarbons[60]. This suggests that the soil samples used in this study, from areas where PAHs were reported to be present, harbour bacterial species that are capable of degrading both classes of xenobiotics, PAHs and EDCs.

Conclusion

The distribution of EDCs, their effects towards living organisms and microorganisms capable of degrading ECDs, and the mechanisms of EDC degradation have been thoroughly documented by the developed world. Information on these matters is, however, lacking from Africa, Asia and Central and South America.

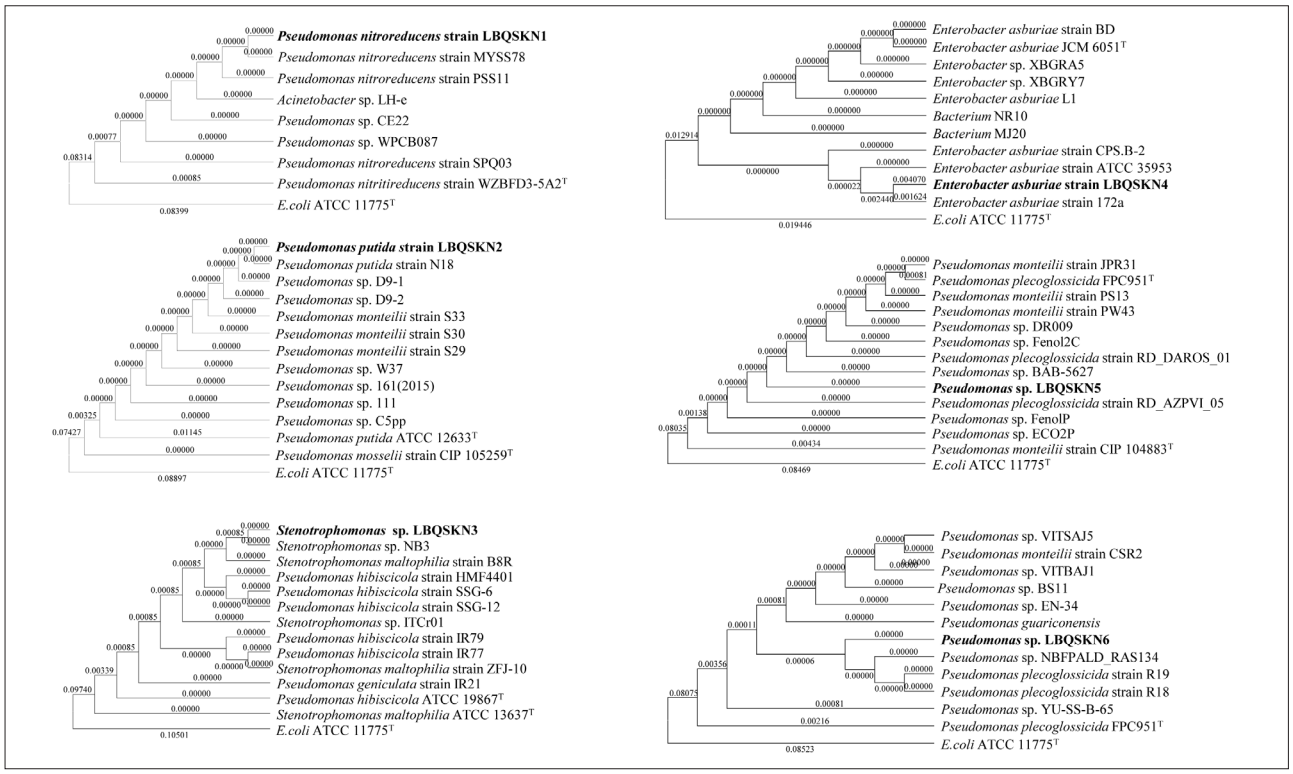

Figure 3: Phylogenetic analysis of the 16S rRNA gene sequences of the bacterial isolates. 16S rRNA gene sequences of the type strains belonging to the same genus and an out-group bacterial species (*E. coli*) were also included in the analysis. Superscript letter 'T' next to strain name indicates the type strain. Each bacterial isolate was named based on its alignment to the homolog bacterial species. Branch lengths are also shown in the tree. Bacterial species isolated and named in this study are highlighted in bold font.

Table 1: Bacterial isolates identified

Sample	16S rRNA sequenced gene size (base pair)	GenBank accession number	NCBI Blast hit results			Name assigned to the bacterial isolate
			Dominant bacteria genus	% Identity	% Query cover	
1	1242	KX364074	*Pseudomonas*	100	100	*Pseudomonas nitroreducens* strain LBQSKN1
2	1239	KX364075	*Pseudomonas*	100	100	*Pseudomonas putida* strain LBQSKN2
3	1196	KX364076	*Stenotrophomonas*	99	100	*Stenotrophomonas* sp. LBQSKN3
4	1240	KX364077	*Enterobacter*	99	100	*Enterobacter asburiae* strain LBQSKN4
5	1245	KX364078	*Pseudomonas*	99	100	*Pseudomonas* sp. LBQSKN5
6	1237	KX364079	*Pseudomonas*	99	100	*Pseudomonas* sp. LBQSKN6

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Table 2: Homology (percentage identity) analysis of 16S rRNA gene sequences of bacterial isolates

	***Pseudomonas nitroreducens* strain LBQSKN1**	***Pseudomonas putida* strain LBQSKN2**	***Stenotrophomonas* sp. LBQSKN3**	***Enterobacter asburiae* strain LBQSKN4**	***Pseudomonas* sp. LBQSKN5**	***Pseudomonas* sp. LBQSKN6**
Pseudomonas nitroreducens strain LBQSKN1	100.00	96.29	85.08	82.33	96.44	95.79
Pseudomonas putida strain LBQSKN2	96.29	100.00	85.41	83.63	99.84	99.51
Stenotrophomonas sp. LBQSKN3	85.08	85.41	100.00	80.69	85.41	85.26
Enterobacter asburiae strain LBQSKN4	82.33	83.63	80.69	100.00	83.83	83.63
Pseudomonas sp. LBQSKN5	96.44	99.84	85.41	83.83	100.00	99.35
Pseudomonas sp. LBQSKN6	95.79	99.51	85.26	83.63	99.35	100.00

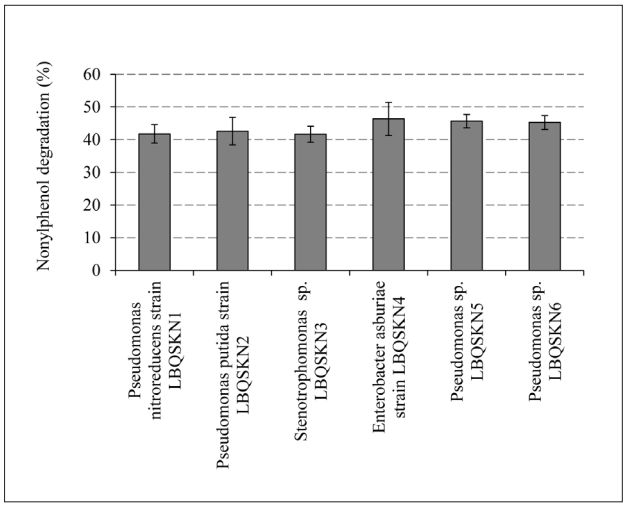

Figure 4: Analysis of nonylphenol degradation by bacterial isolates. Percentage degradation of nonylphenol by bacterial isolates was related to the control nonylphenol, which was taken as 100% as described elsewhere[35,36]. The values represent mean±s.d. for three biological replicates. Percentage degradation among different bacterial isolates was found to be not statistically significant ($0.2<p<0.7$).

Our study is thus the first of its kind from South Africa, in which we successfully enriched, isolated, identified and demonstrated nonylphenol degradation capabilities of indigenous bacterial strains. The areas from which soil samples were collected were previously reported to be polluted with PAHs, and their selection resulted in the isolation of bacterial species capable of degrading EDC nonylphenol, suggesting that these organisms have the capability to degrade a variety of xenobiotic chemicals. Further investigations on the capacity of the isolates to degrade different EDCs and PAHs are currently underway. The results presented in this study will lead to the isolation and characterisation of microorganisms from different parts of South Africa that are capable of degrading different EDCs, and will thus enrich EDC-related information from Africa.

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Authors' contributions

K.S. and C.W.T. conceived and designed the experiments. K.S. provided funding for the study. All authors were involved in performing the experiments, analysing the data and writing the manuscript.

References

1. Diamanti-Kandarakis E, Bourguignon JP, Giudice LC, Hauser R, Prins GS, Soto AM, et al. Endocrine-disrupting chemicals: An Endocrine Society scientific statement. Endocr Rev. 2009;30(4):293–342. https://doi.org/10.1210/er.2009-0002
2. World Health Organization (WHO) / United Nations Environment Programme (UNEP). State of the science of endocrine disrupting chemicals – 2012 In: Bergman A, Heindel JJ, Jobling S, Kidd KA, Zoeller RT, editors. Geneva: UNEP / Inter-Organization Programme for the Sound Management of Chemicals, WHO; 2013. Available from: http://www.who.int/ceh/publications/endocrine/en/
3. International Panel of Chemical Pollution (IPCP). Overview report I: A compilation of lists of chemicals recognised as endocrine disrupting chemicals (EDCs) or suggested as potential EDCs [document on the Internet]. c2016 [cited 2016 Sep 12]. Available from: http://wedocs.unep.org/handle/20.500.11822/12218
4. De Falco M, Forte M, Laforgia V. Estrogenic and anti-androgenic endocrine disrupting chemicals and their impact on the male reproductive system. Front Environ Sci. 2015;3, Art. #3, 12 pages. http://dx.doi.org/10.3389/fenvs.2015.00003
5. Marques-Pinto A, Carvalho D. Human infertility: Are endocrine disruptors to blame? Endocr Connect. 2013;2(3):15–29. https://doi.org/10.1530/EC-13-0036
6. Fowler PA, Bellingham M, Sinclair KD, Evans NP, Pocar P, Fischer B, et al. Impact of endocrine-disrupting compounds (EDCs) on female reproductive health. Mol Cell Endocrinol. 2012;355(2):231–239. https://doi.org/10.1016/j.mce.2011.10.021
7. Zawatski W, Lee M. Male pubertal development: Are endocrine-disrupting compounds shifting the norms? J Endocrinol. 2013;218(2):1–12. https://doi.org/10.1530/JOE-12-0449
8. Schug TT, Janesick A, Blumberg B, Heindel JJ. Endocrine disrupting chemicals and disease susceptibility. J Steroid Biochem Mol Biol. 2011;127(3–5):204–215. https://doi.org/10.1016/j.jsbmb.2011.08.007
9. Soares A, Guieysse B, Jefferson B, Cartmell E, Lester JN. Nonylphenol in the environment: A critical review on occurrence, fate, toxicity and treatment in wastewaters. Environ Int. 2008;34(7):1033–1049. https://doi.org/10.1016/j.envint.2008.01.004
10. Flint S, Markle T, Thompson S, Wallace E. Bisphenol A exposure, effects, and policy: A wildlife perspective. J Environ Manage. 2012;104:19–34. https://doi.org/10.1016/j.jenvman.2012.03.021
11. Matthiessen P, Gibbs PE. Critical appraisal of the evidence for tributyltin-mediated endocrine disruption in mollusks. Environ Toxicol Chem. 1998;17(1):37–43. https://doi.org/10.1002/etc.5620170106
12. Guillette Jr LJ, Gross TS, Masson GR, Matter JM, Percival HF, Woodward AR. Developmental abnormalities of the gonads and abnormal sex hormone concentrations in juvenile alligators from contaminated and control lakes in Florida. Environ Health Perspect. 1994;102(8):680–688. https://doi.org/10.2307/3432198
13. Cooke AS. Shell thinning in avian eggs by environmental pollutants. Environ Pollut. 1973;4(2):85–152. http://dx.doi.org/10.1016/0013-9327(73)90009-8
14. Burger AEC, Nel A. Scoping study to determine the potential impact of agricultural chemical substances (pesticides) with endocrine disruptor properties on water resources of South Africa. WRC report no. 1774/1/08. Pretoria: Water Research Commission; 2008.
15. Aneck-Hahn NH, Schulenburg GW, Bornman MS, Farias P, De Jager C. Impaired semen quality associated with environmental DDT exposure in young men living in a malaria area in the Limpopo Province, South Africa. J Androl. 2007;28(3):423–434. https://doi.org/10.2164/jandrol.106.001701
16. Aneck-Hahn NH, Bornman MS, De Jager C. Oestrogenic activity in drinking waters from a rural area in the Waterberg District, Limpopo Province, South Africa. Water SA. 2009;35(3):245–252.
17. Fatoki OS, Bornman M, Ravandhalala L, Chimuka L, Genthe B, Adeniyi A. Phthalate ester plasticizers in freshwater systems of Venda, South Africa and potential health effects. Water SA. 2010;36(1):117–126. https://doi.org/10.4314/wsa.v36i1.50916
18. Swart N, Pool E. Rapid detection of selected steroid hormones from sewage effluents using an ELISA in the Kuils River water catchment area, South Africa. J Immunoassay Immunochem. 2007;28(4):395–408. https://doi.org/10.1080/15321810701603799
19. Manickum T, John W. Occurrence, fate and environmental risk assessment of endocrine disrupting compounds at the wastewater treatment works in Pietermaritzburg (South Africa). Sci Total Environ. 2014;468–469:584–597. https://doi.org/10.1016/j.scitotenv.2013.08.041
20. Mahomed SI, Voyi KVV, Aneck-Hahn NH, De Jager C. Oestrogenicity and chemical target analysis of water from small-sized industries in Pretoria, South Africa. Water SA. 2008;34(3):357–364.
21. Fatoki OS, Awofolu OR. Levels of organochlorine pesticide residues in marine-, surface-, ground- and drinking waters from the Eastern Cape Province of South Africa. J Environ Sci Health. 2004;39(1):101–114. https://doi.org/10.1081/PFC-120027442
22. Olujimi OO, Fatoki OS, Odendaal JP, Okonkwo JO. Endocrine disrupting chemicals (phenol and phthalates) in the South African environment: A need for more monitoring. Water SA. 2010;36(5):671–682. https://doi.org/10.4314/wsa.v36i5.62001
23. Olujimi OO, Fatoki OS, Odendaal JP, Daso AP. Chemical monitoring and temporal variation in levels of endocrine disrupting chemicals (priority phenols and phthalate esters) from selected wastewater treatment plant and freshwater systems in Republic of South Africa. Microchem J. 2012,101:11–23. https://doi.org/10.1016/j.microc.2011.09.011
24. Matilainen A, Sillanpää M. Removal of natural organic matter from drinking water by advanced oxidation processes. Chemosphere. 2010;80(4):351–365. https://doi.org/10.1016/j.chemosphere.2010.04.067
25. Sirés I, Brillas E. Remediation of water pollution caused by pharmaceutical residues based on electrochemical separation and degradation technologies: A review. Environ Int. 2012;40:212–229. https://doi.org/10.1016/j.envint.2011.07.012
26. Liu Z, Kanjo Y, Mizutani S. Removal mechanisms for endocrine disrupting compounds (EDCs) in wastewater treatment — Physical means, biodegradation, and chemical advanced oxidation: A review. Sci Total Environ. 2009;407(2):731–748. https://doi.org/10.1016/j.scitotenv.2008.08.039
27. Gavrilescu M, Demnerova K, Aamand J, Agathos S, Fava F. Emerging pollutants in the environment: Present and future challenges in biomonitoring, ecological risks and bioremediation. Nat Biotechnol. 2015;32(1):147–156. https://doi.org/10.1016/j.nbt.2014.01.001
28. Boldrin B, Tiehm A, Fritzsche C. Degradation of phenanthrene, fluorene, fluoranthene, and pyrene by a *Mycobacterium* sp. Appl Environ Microbiol. 1993;59(6):1927–1930.
29. Zhang H, Kallimanis A, Koukkou AI, Drainas C. Isolation and characterization of novel bacteria degrading polycyclic aromatic hydrocarbons from polluted Greek soils. Appl Microbiol Biotechnol. 2004;65(1):124–131. https://doi.org/10.1007/s00253-004-1614-6
30. Zeng J, Lin XG, Zhang J, Li XZ. Isolation of polycyclic aromatic hydrocarbons (PAHs)-degrading *Mycobacterium* spp. and the degradation in soil. J Hazard Mater. 2010;183(1–3):718–723. https://doi.org/10.1016/j.jhazmat.2010.07.085
31. Porter AW, Hay AG. Identification of *opdA*, a gene involved in biodegradation of the endocrine disrupter octylphenol. Appl Environ Microbiol. 2007;73(22):7373–7379. https://doi.org/10.1128/AEM.01478-07
32. Marchesi JR, Sato T, Weightman AJ, Martin TA, Fry JC, Hiom SJ, et al. Design and evaluation of useful bacterium-specific PCR primers that amplify genes coding for bacterial 16S rRNA. Appl Environ Microbiol. 1998;64(2):795–799.
33. Tamura K, Nei M. Estimation of the number of nucleotide substitutions in the control region of mitochondrial DNA in humans and chimpanzees. Mol Biol Evol. 1993;10(3):512–526.
34. Tamura K, Peterson D, Peterson N, Stecher G, Nei M, Kumar S. MEGA5: Molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. Mol Biol Evol. 2011;28(10):2731–2739. https://doi.org/10.1093/molbev/msr121

35. Syed K, Porollo A, Lam YW, Yadav JS. A fungal P450 (CYP5136A3) capable of oxidizing polycyclic aromatic hydrocarbons and endocrine disrupting alkylphenols: Role of Trp^{129} and Leu^{324}. PLoS ONE. 2011;6(12), e28286, 14 pages. https://doi.org/10.1371/journal.pone.0028286.

36. Syed K, Porollo A, Lam YW, Grimmet PE, Yadav JS. A catalytically versatile fungal P450 monooxygenase (CYP63A2) capable of oxidizing higher polycyclic aromatic hydrocarbons, alkylphenols and alkanes. Appl Environ Microbiol. 2013;79(8):2692–2702. https://doi.org/10.1128/AEM.03767-12

37. Okedeyi OO, Nindi MM, Dube S, Awofolu OR. Distribution and potential sources of polycyclic aromatic hydrocarbons in soils around coal-fired power plants in South Africa. Environ Monti Assess. 2012;185(3):2073–2082. https://doi.org/10.1007/s10661-012-2689-7

38. Pashin YV, Bakhitova LM. Mutagenic and carcinogenic properties of polycyclic aromatic hydrocarbons. Environ Health Perspect. 1979;30:185–189.

39. Rengarajan T, Rajendran P, Nandakumar N, Lokeshkumar B, Rajendran P, Nishigaki I. Exposure to polycyclic aromatic hydrocarbons with special focus on cancer. Asian Pac J Trop Biomed. 2015;5(3):182–189. http://doi.org/10.1016/S2221-1691(15)30003-4

40. Liao CS, Chen LC, Chen BS, Lin SH. Bioremediation of endocrine disruptor di-*n*-butyl phthalate ester by *Deinococcus radiodurans* and *Pseudomonas stutzeri*. Chemosphere. 2010;78(3):342–346. https://doi.org/10.1016/j.chemosphere.2009.10.020

41. Chakraborty J, Dutta TK. Isolation of a *Pseudomonas* sp. capable of utilizing 4-nonylphenol in the presence of phenol. J Microbiol Biotechnol. 2006;16(11):1740–1746.

42. John DM, White GF. Mechanism for biotransformation of nonylphenol polyethoxylates to xenoestrogens in *Pseudomonas putida*. J Bacteriol. 1998;180(17):4332–4338.

43. Ruiz Y, Medina L, Borusiak M, Ramos N, Pinto G, Valbuena O. Biodegradation of polyethoxylated nonylphenols. ISRN Microbiol. 2013;2013, Art. #284950, 9 pages. http://dx.doi.org/10.1155/2013/284950.

44. Toyama T, Murashita M, Kobayashi K, Kikuchi S, Sei K, Tanaka Y, et al. Acceleration of nonylphenol and 4-*tert*-octylphenol degradation in sediment by *Phragmites australis* and associated rhizosphere bacteria. Environ Sci Technol. 2011;45(15):6524–6530. https://doi.org/10.1021/es201061a

45. Badiefar I, Yakhchali B, Rodriguez-Couto S, Veloso A, Garcia-Arenzana J-M, Matsumura Y, et al. Biodegradation of bisphenol A by the newly-isolated *Enterobacter gergoviae* strain BYK-7 enhanced using genetic manipulation. RSC Advances. 2015;5(37):29563–29572. https://doi.org/10.1039/C5RA01818H.

46. Jia LY, Zheng AP, Xu L, Huang XD, Zhang Q, Yang FL. Isolation and characterization of comprehensive polychlorinated biphenyl degrading bacterium, *Enterobacter* sp. LY402. J Microbiol Biotechnol. 2008;18(5):952–957.

47. Abraham J, Silambarasan S. Plant growth promoting bacteria *Enterobacter asburiae* JAS5 and *Enterobacter cloacae* JAS7 in mineralization of endosulfan. Appl Biochem Biotechnol. 2015;175(7):3336–3348. https://doi.org/10.1007/s12010-015-1504-7

48. Fang CR, Yao J, Zheng YG, Jiang CJ, Hu LF, Wu YY, et al. Dibutyl phthalate degradation by *Enterobacter* sp. T5 isolated from municipal solid waste in landfill bioreactor. Int Biodeterior Biodegradation. 2010;64(6):442–446. https://doi.org/10.1016/j.ibiod.2010.04.010

49. Kageyama S, Morooka N. Effect of detergents on growth of bacteria. J Home Economics Japan. 2005;56(1):41–47.

50. Dong C, Bai X, Sheng H, Jiao L, Zhou H, Shao Z. Distribution of PAHs and the PAH-degrading bacteria in the deep-sea sediments of the high-latitude Arctic Ocean. Biogeosciences. 2015;12(7):2163–2177. https://doi.org/10.5194/bg-12-2163-2015

51. Ma Y, Wang L, Shao Z. *Pseudomonas*, the dominant polycyclic aromatic hydrocarbon-degrading bacteria isolated from Antarctic soils and the role of large plasmids in horizontal gene transfer. Environ Microbiol. 2006;8(3):455–465. https://doi.org/10.1111/j.1462-2920.2005.00911.x

52. Ma J, Xu L, Jia L. Degradation of polycyclic aromatic hydrocarbons by *Pseudomonas* sp. JM2 isolated from active sewage sludge of chemical plant. J Environ Sci. 2012;24(12):2141–2148. https://doi.org/10.1016/S1001-0742(11)61064-4

53. Ma J, Xu L, Jia L. Characterization of pyrene degradation by *Pseudomonas* sp. strain Jpyr-1 isolated from active sewage sludge. Bioresour Technol. 2013;140:15–21. https://doi.org/10.1016/j.biortech.2013.03.184

54. Zhang Z, Hou Z, Yang C, Ma C, Tao F, Xu P. Degradation of *n*-alkanes and polycyclic aromatic hydrocarbons in petroleum by a newly isolated *Pseudomonas aeruginosa* DQ8. Bioresour Technol. 2011;102(5):4111–4116. https://doi.org/10.1016/j.biortech.2010.12.064

55. Mangwani N, Shukla SK, Kumari S, Rao TS, Das S. Characterization of *Stenotrophomonas acidaminiphila* NCW-702 biofilm for implication in the degradation of polycyclic aromatic hydrocarbons. J Appl Microbiol. 2014;117(4):1012–1024. https://doi.org/10.1111/jam.12602

56. Boonchan S, Britz ML, Stanley GA. Surfactant-enhanced biodegradation of high molecular weight polycyclic aromatic hydrocarbons by *Stenotrophomonas maltophilia*. Biotechnol Bioeng. 1998;59(4):482–494. https://doi.org/10.1002/(SICI)1097-0290(19980820)59:4<482::AID-BIT11>3.0.CO;2-C

57. Juhasz AL, Stanley GA, Britz ML. Microbial degradation and detoxification of high molecular weight polycyclic aromatic hydrocarbons by *Stenotrophomonas maltophilia* strain VUN 10,003. Lett Appl Microbiol. 2000;30(5):396–401. https://doi.org/10.1046/j.1472-765x.2000.00733.x

58. Singh A, Kumar K, Pandey AK, Sharma A, Singh SB, Kumar K, et al. Pyrene degradation by biosurfactant producing bacterium *Stenotrophomonas maltophilia*. Agric Res. 2015;4(1):42–47. https://doi.org/10.1007/s40003-014-0144-4

59. Yousaf S, Ripka K, Reichenauer TG, Andria V, Afzal M, Sessitsch A. Hydrocarbon degradation and plant colonization by selected bacterial strains isolated from Italian ryegrass and birdsfoot trefoil. J Appl Microbiol. 2010;109(4):1389–1401. https://doi.org/10.1111/j.1365-2672.2010.04768.x

60. Obayori OS, Salam LB, Omotoyo IM. Degradation of weathered crude oil (Escravos Light) by bacterial strains from hydrocarbons-polluted site. Afr J Microbiol Res. 2012;6(26):5426–5432.

Proximate and fatty acid composition of cooked South African Cape snoek (*Thyrsites atun*)

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Cape snoek (*Thyrsites atun*) is an important source of protein for people in South Africa; however, nutritional information thereof is limited. The proximate and fatty acid compositions of raw and cooked (80 °C) snoek muscles were determined according to official AOAC methods. The mean moisture, ash, total lipids and protein for raw snoek were 72.8±1.86%, 1.3±0.09%, 4.0±1.16 and 21.5±1.35%, respectively. Cape snoek is very high in palmitic acid (24.65±1.43%), oleic acid (18.21±2.64%), eicosapentaenoic acid (EPA, 9.11±2.06%) and docosahexaenoic acid (DHA, 19.70±3.25%). With the exception of total lipids, cooking significantly reduced moisture (69.40±2.03%) and ash (1.12±0.12%), and increased protein (24.47±1.39%) content. It is concluded that Cape snoek is very high in protein and can be classified as a low-fat fish which is rich in EPA and DHA.

Significance:

- Cape snoek is a low-fat fish, containing less than 4% fat, and is high in EPA (9.11±2.06%) and DHA (19.70±3.25%).
- Cape snoek is thus a healthy, cheap and high-protein food source, with a high content of omega-3 fatty acids.

Introduction

Thyrsites atun (Cape snoek) is a medium-sized, pelagic predator and has been an important commercial marine fish species in South Africa since the early 1800s.[1] Initially, snoek was caught with hand lines and trawled after 1960, but today it forms part of a diverse informal, artisanal and commercial fishery industry. South African snoek can be found in temperate waters from the West Coast to the East Coast of South Africa.[1,2] In the Cape (West Coast) region of South Africa, snoek is an important source of readily available and affordable protein to many medium- and low-income households. Snoek is prepared in several different ways, from oven baking and microwave cooking to cooking over flames or coals (locally known as 'braaing') and smoking.

Among the food resources of the world, fish and fishery products are very important sources of animal protein. The high nutritional quality and health benefits of consuming marine fish and fishery products have been well documented over many years[3-7] as the fishing industry has become a fast-growing industry focused on healthy eating. Most of the focus has been on the health benefits of n-3 polyunsaturated fatty acids (PUFAs); however, besides essential n-3 PUFAs, fish are a major source of high-quality protein because of the balanced content in amino acids, especially essential amino acids necessary for physical and mental well-being.[8] Marine fish also provide certain vitamins and minerals such as iodine, selenium and zinc.[9,10]

Fish are classified as either fatty (>10% fat), medium fat (5–10% fat), low fat (2–4% fat) or lean (<2% fat) according to the percentage fat in the muscle.[11,12] In general, marine fish species are high in n-3 PUFAs, particularly eicosapentaenoic acid (ECP, C20:5n-3) and docosahexaenoic acid (DHA, C22:6n-3), as well as in monoenes such as C18:1n-9, and the saturated fatty acid C16:0 (palmitic acid). The fatty acid profile of marine fish is dependent on their type of diet. Within inshore waters, adult (>75 cm), sub-adult (50–75 cm) and juvenile (25–49 cm) Cape snoek feed mainly on anchovies (*Engraulis capensis*) and sardines (*Sardinops ocellatus*), while in offshore waters, adult snoek mainly feed on sardines, round herring (*Spratelloides robustus*) and hake (*Merluccius* spp.).[1]

In general, fish muscle contains very low quantities of carbohydrates with the percentage carbohydrates, depending on the species of fish, ranging between 0.2% and 1.5%[13]; this low percentage results in fish muscle obtaining a relatively high post-mortem pH compared to that of mammalian muscle. The pH in fish muscle drops from 7.0 to 6.5 during early post-mortem storage[13,14], whereas in bovine muscle, the pH falls to between 5.4 and 5.7 within 24 h post-mortem. The high post-mortem pH content of fish muscle enables the rapid growth of naturally occurring, Gram-negative, pH-sensitive psychrotrophic bacteria, such as *Pseudomonas* and *Shewanella*; these bacteria can reach numbers of up to 10^6–10^8 cfu/g within a few days[13] and result in rapid spoilage of fish.

Few studies have examined the nutritional composition of South African marine fish species. Information available about the nutritional value of raw and cooked Cape snoek is scarce. It is becoming increasingly difficult to put aside the fact that proximate analysis has a fundamental function in the application of various processing methods. Proximate analysis is the determination of major nutrients through assessment of the moisture, ash, crude protein, crude fibre and carbohydrate contents. In addition, proximate analysis makes a critical contribution on raw material quality aspects, sensory evaluations, consumer perception and shelf life. The aim of this study was therefore to determine the proximate and fatty acid compositions of raw and cooked Cape snoek (*Thyrsites atun*) in order to quantify the nutritional value and make the information available to consumers and processors, for nutritional tables for South African foodstuffs and for academic databases.

Materials and methods

Sample preparation

In total, 10 flecked (eviscerated but not filleted) snoek (*Thyrsites atun*), caught at Stompneus Bay (Cape Town, South Africa) during the winter month of June, were collected from a fish-processing facility in Brackenfell, Cape Town. The mean weight of the flecked snoek, with head and tail still attached, was 1.93±0.37 kg. The snoek were transported (duration of about 30 min) on ice in cooler boxes to the laboratories of the Department of Animal Sciences, Stellenbosch University (Stellenbosch, South Africa). Muscle samples of 100–200 g were removed from the left and right sides of each flecked snoek at a location from the centre (abdominal area) of each flecked fish such that both dorsal and ventral muscles were sampled. Samples from the left sides were kept raw, while samples from the right sides were placed into a plastic bag and cooked in a water bath at 80 °C (boiling) for 1 h. Thereafter, individual samples were vacuum packed and frozen at -20 °C until proximate and fatty acid analyses were performed.

Proximate analysis

The skin and bones were removed from all tissue samples before the samples were homogenised. All proximate analyses were done in duplicate. Moisture content was determined by drying the homogenised sample in a drying oven at 100 °C for 24 h. The dried samples were allowed to cool in a desiccator for 30 min. The samples were weighed and the moisture content was determined according to the Association of Official Analytical Chemists (AOAC)'s[15] official method 934.01. Crude protein was determined by the Kjeldahl's method on a FP-428 Nitrogen and Protein Determinator (Leco, Saint Joseph, MI, USA). The nitrogen content was multiplied with the appropriate factor (6.2 x N) according to the AOAC[16] official method 992.15. Total lipids were determined by solvent extraction according to the method described by Lee et al.[17] Ash was determined according to the official AOAC[18] method 942.05. Carbohydrates (CHO) were calculated as follows:

CHO (g/100 g) = dry matter - protein - fat - ash,

where dry matter is calculated as 100 – moisture content.

Fatty acid analysis

The fatty acid profiles for both the raw and cooked samples were determined by gas chromatography with the following specifications: column, SP-2560, 100 m x 0.25 mm ID, 0.20 μm film (cat no. 24056); oven of 140 °C for 5 min to 240 °C at 4 °C/min; helium at 20 cm/s as carrier gas; FID detector, 260 °C; and injection at 1 μL, 260 °C and split of 100:1. C17:0 was used as the internal standard and to facilitate calculation of the actual amount of individual fatty acids. Fatty acid methyl esters (FAME) were identified by using differences in retention times, compared with the retention time of the standard FAME mixture (Supelco 37 Component FAME mix, C4–C24, cat no. 47885-U, Bellefonte, PA, USA). The fatty acids in grams were calculated and are expressed as a percentage based on the internal standard C17:0.

Statistical analysis

The proximate and fatty acid data were subjected to a one-way analysis of variance using SAS version 9.0 statistical software. Significant differences between means were determined by least significant difference, with a significance level of 0.05.

Results

The proximate composition of raw and cooked Cape snoek muscle is summarised in Table 1. The mean percentages of (the percentage value is equivalent to g/100 g muscle tissue or meat) moisture, ash, total lipids and protein for raw Cape snoek were 72.8±1.86%, 1.3±0.09%, 4.0±1.16% and 21.5±1.35%, respectively. The carbohydrate content of raw and cooked snoek was calculated as 0.5±0.80% and 0.7±1.60%, respectively.

Table 1: Proximate composition (% mean ± standard deviation) of raw and cooked† Cape snoek (*Thyrsites atun*) muscle

	Moisture (%)	Ash (%)	Total lipids (%)	Protein (%)	Carbohydrates (%)
Raw	$72.8^{a} \pm 1.86$	$1.3^{a} \pm 0.09$	$4.0^{a} \pm 1.16$	$21.5^{a} \pm 1.35$	$0.5^{a} \pm 0.80$
Cooked	$69.4^{b} \pm 2.03$	$1.1^{b} \pm 0.12$	$4.3^{a} \pm 1.01$	$24.5^{b} \pm 1.39$	$0.7^{b} \pm 1.60$

†*Samples were cooked in a water bath at 80 °C.*

a,b*Within a column, values with different superscripts are significantly different (p<0.05).*

Table 2: Fatty acid composition (% mean ± standard deviation) of raw and cooked† Cape snoek (*Thyrsites atun*) muscle

Fatty acid	Raw snoek muscle	Cooked snoek muscle
C14:0	$3.60^{a} \pm 1.62$	$3.51^{a} \pm 1.03$
C15:0	$0.44^{a} \pm 0.06$	$0.41^{a} \pm 0.59$
C16:0	$24.65^{a} \pm 1.43$	$23.21^{b} \pm 0.99$
C18:0	$6.87^{a} \pm 1.40$	$6.61^{a} \pm 1.25$
C20:0	$0.13^{a} \pm 0.02$	$0.14^{a} \pm 0.03$
C21:0	$0.19^{a} \pm 0.01$	$0.19^{a} \pm 0.04$
C22:0	$0.09^{a} \pm 0.05$	$0.11^{b} \pm 0.06$
C24:0	$0.21^{a} \pm 0.09$	$0.25^{b} \pm 0.06$
Total SFAs	**$36.36^{a} \pm 1.67$**	**$34.29^{b} \pm 1.70$**
C14:1	$0.17^{a} \pm 0.02$	$0.17^{a} \pm 0.03$
C15:1	$0.10^{a} \pm 0.01$	$0.09^{a} \pm 0.01$
C16:1	$5.61^{a} \pm 1.39$	$5.47^{a} \pm 1.24$
C20:1	$3.07^{a} \pm 1.39$	$4.16^{b} \pm 1.12$
C24:1	$0.38^{a} \pm 0.05$	$0.40^{a} \pm 0.05$
C18:1n-9c	$18.21^{a} \pm 2.64$	$17.95^{a} \pm 2.66$
C18:1n-9t	$0.15^{a} \pm 0.05$	$0.17^{a} \pm 0.05$
C22:1n-9	$2.42^{a} \pm 1.23$	$2.77^{b} \pm 1.06$
Total MUFAs	**$31.24^{a} \pm 5.01$**	**$31.56^{a} \pm 4.93$**
C18:2n-6c	$1.82^{a} \pm 0.96$	$1.26^{a} \pm 0.09$
C18:2n-6t	$0.05^{a} \pm 0.02$	$0.05^{a} \pm 0.03$
C18:3n-6	$0.25^{a} \pm 0.05$	$0.26^{a} \pm 0.04$
C18:3n-3	$0.70^{a} \pm 0.09$	$0.68^{a} \pm 0.07$
C20:2	$0.08^{a} \pm 0.02$	$0.09^{a} \pm 0.02$
C20:3n-3	$0.09^{a} \pm 0.03$	$0.09^{a} \pm 0.04$
C20:3n-6	$0.27^{a} \pm 0.07$	$0.34^{b} \pm 0.10$
C20:4n-6	$1.06^{a} \pm 0.08$	$1.11^{a} \pm 0.17$
C20:5n-3 (EPA)	$9.11^{a} \pm 2.06$	$10.13^{b} \pm 2.01$
C22:6n-3 (DHA)	$19.70^{a} \pm 3.25$	$20.28^{b} \pm 4.47$
Total PUFAs	**$32.40^{a} \pm 4.11$**	**$34.15^{a} \pm 4.39$**
PUFA:SFA	$0.89^{a} \pm 0.11$	$1.00^{b} \pm 0.13$
n-6:n-3	$0.12^{a} \pm 0.04$	$0.10^{a} \pm 0.01$

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; PUFA, polyunsaturated fatty acids

†*Samples were cooked in a water bath at 80 °C.*

a,b*Within a row, values with different superscripts are significantly different (p<0.05).*

Cape snoek is very high in palmitic acid (C16:0), oleic acid (C18:1n-9c), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Table 2). Marine fish, in general, are characteristically low in linoleic and linolenic acid,[3] and Cape snoek are no exception with 1.26±0.09% linoleic acid and 0.68±0.07% α-linolenic acid, respectively, for cooked samples (Table 2). Marine fish species are further characterised by high levels of long-chain n-3 PUFAs and low levels of n-6 fatty acids, which gives them a high n-3:n-6 ratio (or low n-6:n-3 ratio), which is nutritionally seen as beneficial to human health and well-being.[4,19] Cape snoek samples had very low n-6:n-3 ratios of 0.12±0.04 for raw samples and 0.01±0.01 for cooked samples (Table 2), making Cape snoek a healthy fish for human consumption.

Cooking the fish at 80 °C significantly ($p<0.05$) increased the concentration of behenic (C22:0), ligoceric (C24:0), gondoic (C20:1), erucic (C22:1n-9) and homo-g-linolenic (C20:3n-6) acids, ECP and DHA, but not palmitic acid. Similar to results found by Türkkan et al.[20] for baked seabass (*Dicentrarchus labrax*), the total saturated fatty acid (SFA) content of raw Cape snoek reduced from 36.36±1.67% to 34.29±1.70% for cooked samples ($p<0.05$; Table 2). In contrast, cooking had no significant effect on monounsaturated fatty acids (MUFAs) and PUFAs of snoek samples.

Discussion

Cooked snoek muscle had a significantly lower ($p<0.05$) moisture content than raw snoek. Cooking methods such as boiling and microwave cooking significantly decrease moisture content in fish muscle.[20-23] In contrast to the findings of Gokoglu et al.[21] and Türkkan et al.[20], in which cooked samples had higher ash content than raw samples, cooked snoek samples had a lower ash content than raw samples. The reason for this finding is unclear as, similarly to the studies conducted by Gokoglu et al.[21] and Türkkan et al.[20], the skin from all snoek samples was removed before proximate analysis was performed. It could be argued that the minerals (ash) leached out during cooking (linked to the ~3% moisture loss experienced; Table 1); however, more research is required to quantify this assumption. Similarly to other research studies[20-22], cooking (boiling) significantly increased the protein (24.47±1.39% for cooked vs 21.48±1.35% for raw) content of Cape snoek but not the total lipid content (4.34±1.01% for cooked vs 3.99±1.16% for raw). It may be argued that a ~3% moisture loss concentrated the crude protein, carbohydrate and fat contents which thus showed an increase.

According to Koubaa et al.[12] and Huynh and Kitts[11], fish are classified as fatty (>10% fat), medium fat (5–10% fat), low fat (<5% fat) or lean (<2%) according to the percentage fat in the muscle. With a total lipid content of 4.0±1.16% for raw Cape snoek and 4.3±1.01% for cooked snoek muscle (skin removed), Cape snoek may be classified as a low-fat fish. Cape snoek contains a similar amount of fat (4.0±1.16%) to pink salmon (*Oncorhynchus gorbusha*) fillets (3.95±0.79%).[11] However, the proximate composition of South African Cape hake (*Merluccius capensis*) and South African pilchards (*Sardinops ocellatus*) have not been published and thus a comparison with other economically important South African marine fish species is difficult.

When comparing the protein content of raw Cape snoek to that of the raw muscle of other marine fish species – such as European hake (*Merluccius merluccius*) with a protein content of 17.88±0.70%[24], seabass (*Dicentrarchus labrax*; 18.47±0.43%)[20] and cod (*Gadus morhua callarias*; 17.4±0.9%)[7] – raw snoek muscle has a high protein content of 21.5±1.35%. Compared with the protein content of freshwater fish species, such as rainbow trout (*Oncorhynchus mykiss*) with a protein content of 19.80±0.04%[21], catfish (*Clarias gariepinus;* 16.24%)[25] and silver catfish (*Rhamdia quelen;* 15.5±0.19%)[22], Cape snoek can be seen as a fish with high protein content. It may be hypothesised that the piscivorous diet of Cape snoek may partly contribute to the high protein content of Cape snoek muscle, but European hake is also piscivorous, feeding primarily on blue whiting (*Microsmesistius poutassou*), poor cod (*Trisopterus minutus*) and Norway pout (*Trisopterus esmarki*)[26], while Cape snoek feeds on crustaceans, cephalopods and small fish such as anchovies and pilchards, as well as round herring and hake (*Merluccius* spp.)[1]. It must further be kept in mind that the nutritional composition of fish, including the fatty acid composition, is influenced by factors such as season of the year, feeding habits, and sex, age and maturity of the fish.[7,11,27,28]

In general, fish muscle contains very low quantities of carbohydrates. The percentage carbohydrates in fish muscle, depending on the species of fish, ranges between 0.2% and 1.5%,[13] resulting in fish muscle having a relatively high post-mortem pH as compared to that of mammalian muscle. The pH in fish muscle drops from 7.0 to 6.5 during early post-mortem storage[13,14] while in bovine muscle the pH falls to ~5.4 within 24 h post-mortem. The carbohydrate contents of raw and cooked snoek were calculated as 0.5±0.80% and 0.7±1.60%, respectively (Table 1).

In comparison with other economically important marine fish species, raw Cape snoek muscle has a similar EPA and DHA content as pink salmon muscle (*Onchorhynchus gorbuscha*; EPA of 8.17±0.78% and DHA of 19.34±1.11%),[11] but lower than that of Pacific hake (*Merluccius productus*; EPA of 12.91±1.51% and DHA of 22.08±1.28%) and sardine (*Sardinops sagax*; EPA of 11.43±1.08% and DHA of 32.65±3.44%), making Cape snoek a good source of DHA.

The fatty acid content of the raw Cape snoek was similar to that reported for this species collected off the coast of southeastern Australia,[29] although the reported data were from only three fish. The raw Cape snoek had higher SFA, lower MUFA and similar PUFA content to that from Australia. However, the n-6:n-3 was similar between the two studies (South Africa=0.12; Australia=0.21).

Boiling Cape snoek muscle in water significantly reduced the fatty acid content, while not altering the MUFA and PUFA contents, making cooking in water a healthy option for preparing Cape snoek. In addition, Cape snoek seems to contain a good balance between SFAs, MUFAs, and PUFAs, with a PUFA:SFA ratio of 0.89±0.11 for raw samples and 1.00±0.13 for cooked samples. A PUFA:SFA ratio of ≥0.45 is recommended in the UK.[30]

Conclusions

Cooking Cape snoek by boiling at 80 °C for 1 h significantly increased the protein content, reduced the moisture and ash contents, and had no effect on the total lipid content of skinless muscle. The proximate composition of Cape snoek has not been published before and it is concluded, from the results of this study, that raw Cape snoek is a medium-fat (5–10% fat) to low-fat (2–4% fat) fish containing less than 4% fat; however, cooking increased (concentrated) the fat content to just above 4%. Cape snoek also has a relatively high protein content compared to other economically important marine fish species, making it a very good source of animal protein. However, further studies are recommended to determine the proximate and fatty acid profile of other economically important South African marine species, such as Cape hake (*Merluccius capensis*), Cape dory (*Zeus capensis*) and South African pilchard (*Sardinops ocellatus*). It is further suggested to determine the total lipid and fatty acid composition of Cape snoek skin, because in many cases the snoek is cooked with the skin intact and/or consumed with the skin. It is also suggested to investigate the effects of different cooking methods on the proximate and fatty acid composition of Cape snoek.

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Authors' contributions

S.S.H. wrote the first and final drafts; L.C.H. assisted with editing.

References

1. Griffiths MH. Life history of South African snoek, *Thyrsites atun*: A pelagic predator of the Benguela ecosystem – Pisces: Gempylidae. Fish Bull. 2002;100:690–710.

2. Crawford RJM, Underhill LG, Venter JD. Handline catches and stock identity of snoek *Thyrsites atun* off South Africa and Namibia. S Afr J Marine Sci. 1990;9(1):95–99. https://doi.org/10.2989/025776190784378745

3. Steffens W. Effects of variation in essential fatty acids in fish feeds on nutritive value of freshwater fish for humans. Aquaculture. 1997;151:97–119. https://doi.org/10.1016/S0044-8486(96)01493-7

4. Simopoulos AP. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother. 2002;56:365–379. https://doi.org/10.1016/S0753-3322(02)00253-6

5. Moyad MA. An introduction to dietary/supplemental omega-3 fatty acids for general health and prevention: Part II. Seminar article. Urol Oncol. 2005;23:36–48. https://doi.org/10.1016/j.urolonc.2005.03.001

6. Domingo JL. Omega-3 fatty acids and the benefits of fish consumption: Is all that glitters gold? A review. Environ Int. 2007;33:993–998. https://doi.org/10.1016/j.envint.2007.05.001

7. Usydus Z, Szlinder-Richert J, Adamczyk M, Szatkowska U. Marine and farmed fish in the Polish market: Comparison of the nutritional value. Food Chem. 2011;126:78–84. https://doi.org/10.1016/j.foodchem.2010.10.080

8. Schiepers OJG, De Groot RHM, Jolles J, Van Boxtel MPJ. Fish consumption, not fatty acid status, is related to quality of life in a healthy population. Prostaglandins Leukot Essent Fatty Acids. 2010;83:31–35. https://doi.org/10.1016/j.plefa.2010.02.030

9. Vlieg P. Selenium concentration of the edible part of 74 New Zealand fish species. J Food Compost Anal. 1990;3:67–72. https://doi.org/10.1016/0889-1575(90)90010-J

10. Kim Y. Vitamins. In: Nollet LML, Toldrá F, editors. Handbook of seafood and seafood products analysis. London: CRC Press; 2010. p. 327–350. https://doi.org/10.1201/9781420046359-c19

11. Huynh MD, Kitts DD. Evaluating nutritional quality of Pacific fish species form fatty acid signatures. Food Chem. 2009;114:912–918. https://doi.org/10.1016/j.foodchem.2008.10.038

12. Koubaa A, Abdelmouleh A, Bouain A, Mihoubi NB. Experimental and statistical investigations of the global chemical composition of six trawling fish of the Gulf of Gabés (Mediterranean Sea). J Marine Biol Association UK. 2010:1–7. https://doi.org/10.1017/S0025315410000640

13. Françoise L. Occurrence and role of lactic acid bacteria in seafood products. A review. Food Microbiol. 2010;27:698–709. https://doi.org/10.1016/j.fm.2010.05.016

14. Chéret R, Delbarre-Ladrat C, De Lamballerie-Anton M, Verrez-Bagnis V. Calpain and cathepsin activities in post-mortem fish and meat muscles. Food Chem. 2007;101:1474–1479. https://doi.org/10.1016/j.foodchem.2006.04.023

15. Association of Official Analytical Chemists (AOAC). Loss on drying (moisture) at 95–100 °C for feeds. AOAC official method 934.01. In: AOAC international official methods of analysis. 17th ed. Arlington, VA: AOAC; 2002.

16. Association of Official Analytical Chemists (AOAC). Protein (crude) in animal feed and pet food. AOAC official method 992.15. In: AOAC international official methods of analysis. 17th ed. Arlington, VA: AOAC; 2002.

17. Lee CM, Trevino B, Chaiyawat M. A simple and rapid solvent extraction method for determining total lipids in fish tissue. J AOAC Int. 1996;2:79.

18. Association of Official Analytical Chemists (AOAC). Ash of animal feed. AOAC official method 942.05. In: AOAC international official methods of analysis. 17th ed. Arlington, VA: AOAC; 2002.

19. Candela M, Astiasarán I, Bello J. Effects of frying and warmholding on fatty acids and cholesterol of sole (*Solea solea*), codfish (*Gadus morrhua*) and hake (*Merluccius merluccius*). Food Chem. 1997;58:227–231. https://doi.org/10.1016/S0308-8146(96)00169-0

20. Türkkan AU, Cakli S, Kilinc B. Effects of cooking methods on the proximate composition and fatty acid composition of seabass (*Dicentrarchus labrax*, Linnaeus, 1758). Food Bioprod Process. 2008;86:163–165. https://doi.org/10.1016/j.fbp.2007.10.004

21. Gokoglu N, Yerlikaya P, Cengiz E. Effects of cooking methods on the proximate composition and mineral content of rainbow trout (*Oncorhynchus mykiss*). Food Chem. 2004;84:19–22. https://doi.org/10.1016/S0308-8146(03)00161-4

22. Weber J, Bochi VC, Ribeiro CP, Victório A de M, Emanuelli T. Effect of different cooking methods on the oxidation, proximate and fatty acid composition of silver catfish (*Rhamdia quelen*) fillets. Food Chem. 2008;106:140–146. https://doi.org/10.1016/j.foodchem.2007.05.052

23. Ersoy B. Effects of cooking methods on the proximate, mineral and fatty acid composition of European eel (*Anguilla anguilla*). Int J Food Sci Tech. 2011;46:522–527. https://doi.org/10.1111/j.1365-2621.2010.02546.x

24. Roncarati A, Brambilla G, Meluzzi A, Iamiceli AL, Fanelli R, Moret I, et al. Fatty acid profile and proximate composition of fillets from *Engraulis encrasicholus*, *Mullus barbatus*, *Merluccius merluccius* and *Sarda sarda* caught in Tyrrhenian, Adriatic and Ionian seas. J Appl Ichthyol. 2012;28:545–552. https://doi.org/10.1111/j.1439-0426.2012.01948.x

25. Foline OF, Rachael AM, Iyabo BE, Fidelis AE. Proximate composition of catfish (*Clarias gariepinus*) smoked in Nigerian Stored Products Research Institute (NSPRI): Developed kiln. Int J Fish Aquaculture. 2011;3(5):95–97.

26. Osman H, Suriah AR, Law EC. Fatty acid composition and cholesterol content of selected marine fish in Malaysian waters. Food Chem. 2001;73:55–60. https://doi.org/10.1016/S0308-8146(00)00277-6

27. Du Buit MH. Diet of hake (*Merluccius merluccius*) in the Celtic Sea. Fish Res. 1996;28:381–394. https://doi.org/10.1016/S0165-7836(96)00516-4

28. Nakamura Y-N, Ando M, Seoka M, Kawasaki K, Tsukamasa Y. Changes of proximate and fatty acid compositions of the dorsal and ventral ordinary muscles of the full-cycle cultured Pacific bluefin tuna *Thunnus orientalis* with the growth. Food Chem. 2007;103:234–241. https://doi.org/10.1016/j.foodchem.2006.07.064

29. Pethybridge H, Daley R, Virtue P, Butler ECV, Cossa D, Nichols PD. Lipid and mercury profiles of 61 mid-trophic species collected off south-eastern Australia. Mar Freshw Res. 2010;61:1092–1108. https://doi.org/10.1071/MF09237

30. Warriss PD. Meat science: An introductory text. Wallingford: CABI Publishing; 2000.

Strengthening mutual accountability and performance in agriculture in Southern Africa

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We critically assessed experiences in the implementation of agricultural joint sector reviews in supporting mutual accountability in Southern Africa, focusing on the lessons learned, the challenges and recommendations for improvement. Empirical data were gathered from four countries that have implemented joint sector reviews: Malawi, Mozambique, Swaziland and Zambia. The results show that recent efforts to conduct joint sector review assessments in these countries have raised the quest for increased accountability for action and results. Despite progress to strengthen mutual accountability in the countries, monitoring and evaluation capacity remains a concern, especially at sub-national levels. The mutual accountability process and implementation of the agricultural joint sector review processes in the respective countries have come a long way in facilitating sector-wide engagement of stakeholders in planning, implementation and monitoring and evaluation of agricultural policies and programmes. These processes are critical to ensure effective implementation and realisation of development impacts of agricultural priorities in the national agricultural investment plans.

Significance:

- The implementation of the CAADP mutual accountability framework is critical to ensure effective implementation and realisation of development impacts of agricultural priorities in the national agricultural investment plans.
- Agriculture joint sector reviews facilitate sector-wide engagement of stakeholders in planning, implementation, and monitoring and evaluation of agricultural policies and programmes.

Introduction

There are various international initiatives that aim to improve aid effectiveness, including the 2005 Paris Declaration, the 2008 Accra Agenda for Action and the 2011 Busan Partnership for Effective Development Co-operation. These initiatives focus on improving aid effectiveness through better alignment, harmonisation, results reporting and monitoring, among other objectives. Despite the slow progress towards mutual accountability in the 2008 progress report on implementing the Paris Declaration compared to other principles of the declaration, several initiatives – such as forums for debates, peer reviews and arrangements – have been developed to strengthen mutual accountability and oversee performance between donors and partners.[1] The 2011 Busan Global Partnership for Effective Development Co-operation embraced the commitments set out in the 2005 Paris Declaration and 2008 Accra Agenda for Action to implement efforts aimed at enhancing effectiveness of development partnerships.[2,3] In strengthening mutual accountability, the Global Partnership for Effective Development Co-operation (which followed the Busan Partnership) reaffirmed the commitment to jointly assess country systems based on mutually agreed diagnostic tools. Strengthening mutual accountability for development results through creating and reinforcing shared agendas and strengthening partnerships, among others, helps ensure that complementary efforts in development are transparent and results focused.[1]

The African Heads of State and Government adopted the 2014 Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods which reaffirmed the commitments of the 2003 Maputo Declaration and resolved additional commitments and targets with heightened emphasis on implementation, results and impacts. In line with the international resolutions on aid effectiveness, such as the 2005 Paris Declaration, the 2008 Accra Agenda for Action and the 2011 Busan Global Partnership; the Malabo Declaration's commitment to accountability stresses the continent's resolve to strengthen achievement of results anchored with effective and efficient implementation capacity and optimisation of resources.[4] The seventh commitment of the 2014 Malabo Declaration focuses on strengthening mutual accountability to actions and results through a systematic regular review process guided by the Comprehensive Africa Agriculture Development Programme (CAADP) Results Framework.[4,5] The CAADP Implementation Strategy and Roadmap identifies the Agricultural Joint Sector Review as the principal instrument for operationalising the mutual accountability framework and reporting on agreed commitments while serving as a good platform to discuss implementation.[4]

Monitoring and evaluation of agricultural development programmes and policies remains one critical area requiring support among African countries in their implementation of the CAADP programme. To strengthen mutual accountability for results and provide evidence-based support to agricultural policy/programme planning and implementation, current monitoring and evaluation systems need to be improved in most countries on the continent. This monitoring and evaluation is critical to ensure that the requirements of accountability to commitments and results, as well as learning from the Malabo Declaration and CAADP Mutual Accountability Framework, are satisfied. Despite progress made in implementing agricultural joint sector reviews (JSRs) in Southern Africa, there have been no efforts to provide a systematic, regional review of the experiences in terms of lessons learned, analysis of the challenges and recommendations for improvement. In this paper, we use experiences from the implementation of JSRs in Malawi, Mozambique, Swaziland and Zambia in an effort to fill this empirical gap.

Background

The 2014 Malabo Declaration commits the African heads of states and government to strengthening mutual accountability for actions and results by promoting evidence-based agricultural policy planning and implementation processes through peer review, dialogue, benchmarking and the adoption of best practices.[5] The African Union Commission, NEPAD Planning and Coordinating Agency, regional economic communities, country stakeholders and development partners regard the improvement of country policy processes as critical to ensure successful implementation of national agriculture and food security investment plans and advance the CAADP agenda. The African Union Commission and NEPAD Planning and Coordinating Agency adopted the Mutual Accountability Framework which sets the principles for mutual review and the CAADP Results Framework which identifies priority areas and performance indicators for tracking targets in the Malabo Declaration.

Agricultural JSRs are a key instrument for supporting mutual accountability and implementing the CAADP Results Framework. The JSRs collectively review the effectiveness of policies and institutions in the agriculture sector, as well as the extent to which intended results and outcomes in the sector are being realised. Overall, the JSR processes are expected to serve as a management and policy support tool for inclusive stakeholder planning, programming, budget preparation and execution, monitoring and evaluation, and overall development of the agriculture sector by allowing a broad spectrum of stakeholders to gain insights into and influence the sector's overall policies and priorities.[6]

The JSRs implemented in the agriculture sector have focused on: (1) policy and institutional reviews, (2) a review of progress toward sector results and outcomes and (3) a review of the status and quality of the JSR process in the country. The policy and institutional reviews focused on the coherence, consistency and adequacy of the policy mix and institutional architecture in ensuring successful implementation of national agriculture and food security investment plans. The focus of the second objective was on measuring progress made toward targeted results and declared commitments, including key agriculture sector targets, such as growth, productivity, and other major results defined in national agriculture and food security investment plans and other policy and programme documents. This objective included a review of budgetary allocations, investments, financial support, capacity building, and organisational commitments made by governments, donors and non-state actors. The third objective focused on identifying actions to address the gaps and weaknesses in the sector review process, in terms of technical and institutional capacity, and to promote best practices in those processes.[6] This background provides the analytical framework applied in this paper to review progress of the experiences of implementation of agricultural sector JSRs in Southern Africa.

Methodology and data

The paper is based on data gathered from JSR assessments conducted by the Regional Strategic Analysis and Knowledge Support System (ReSAKSS) of Southern Africa in Malawi, Mozambique, Swaziland and Zambia. The analysis of the experiences and lessons learned from the JSR assessments in Southern Africa was conducted within the framework of the JSRs facilitated by ReSAKSS and the International Food Policy Research Institute in supporting the strengthening of the CAADP Mutual Accountability Framework. The data collection process for the JSR process in the respective countries was based on the following approach. The process mainly relied on qualitative methods for gathering required data. These methods included an extensive review of the literature targeting the respective country's main development strategy frameworks including key agricultural sector policies. JSR reports from other countries were also reviewed to provide lessons in implementation of JSRs in the Southern Africa region. In addition to reviewing literature, the most knowledgeable stakeholders were engaged to gather data and other important documents for review in each of the countries. The stakeholders engaged were identified during the inception meetings of the JSR processes and engagements with the respective Ministries of Agriculture. The stakeholders engaged ranged from government officials (particularly in the Ministries of Agriculture and Finance), development partners, private sector representatives, civil society organisations and representatives of farmer organisations. The engagements were mainly in the form of semi-structured interviews with the identified respondents. The information gathered was collated and analysed for the respective sections of the JSR report for each country. The data collected and analysed were validated together with the national JSR report for each country at an agriculture sector-wide validation workshop that provided a platform for stakeholders to externally review the report and data before the report was finalised.

The analysis in this paper is guided by the focus of the JSR assessments conducted in the study countries which aimed at collectively reviewing the effectiveness of policies and institutions in the agricultural sector, the status and quality of the agricultural JSR process itself, and the extent to which intended results and outcomes in the sector were being realised. We provided technical support in the planning, implementation and review of the JSR assessments in these countries, which provided us with a better perspective of the JSR assessment processes and outcomes in all the study countries.

The JSR assessments in Malawi and Mozambique were conducted at least twice (including non-alliance and Grow Africa annual reporting). In Swaziland and Zambia, JSR assessments were conducted in 2015. The two sets of countries provide a unique combination of two countries that have advanced in implementing JSRs (namely Malawi and Mozambique) and two which have conducted maiden JSR assessments in the agricultural sector (Swaziland and Zambia). Although the findings focus on JSR experiences in the agricultural sector in Southern Africa, the discussions of the findings can be of interest to other sectors and countries both in the region and elsewhere in Africa.

Results and discussion

Experiences in the implementation of agricultural JSRs in support of mutual accountability in the focus countries (Malawi, Mozambique, Swaziland and Zambia) were analysed according to an assessment of the lessons learned, the challenges experienced and recommendations made for improvement. The subsequent analysis and discussion is structured around experiences on: status and quality of agricultural JSRs assessments; policy and institutional reviews; financial and non-financial commitments; and monitoring and evaluation.

Experiences on the status and quality of agricultural JSRs

The selected countries are at different stages in terms of implementing the CAADP agenda. Table 1 summarises the agricultural JSR or similar activities of each country. Malawi and Mozambique have significantly advanced in implementing their National Agricultural Investment Plans while Zambia and Swaziland are at the initial phases of operationalising their investment plans. Findings from the four countries indicate that each country has some kind of agricultural sector monitoring and evaluation intervention (or review) that has been instituted to track progress and or encourage sector-wide engagements with stakeholders. For example, Malawi, in their first JSR report in 2014, reported that the country had JSRs focused on tracking performance of the Agricultural Sector-Wide Approach Programme.[7] Mozambique reported the existence of the Programmatic Aid Partners dialogue platform which annually evaluates the effectiveness of donor's aid, including reviewing commitments and performance indicators.[8] Both Malawi and Mozambique have signed cooperation agreements with the Group of Eight (G8) New Alliance for Food Security and Nutrition, which was launched in April 2013, and Mozambique has entered an agreement with the Agricultural Development Policy Operation – a project of the World Bank. The New Alliance is a shared commitment by the respective governments, private sector and development partners to achieve sustained and inclusive agricultural growth. As members of the New Alliance Cooperation Agreement, both countries have to produce annual reports on progress made on achievements. To date they have produced New Alliance reports for 2014 and 2015.

Zambia and Swaziland indicated a different status with respect to agricultural JSRs. Zambia, for instance, had an agricultural JSR during the Agricultural Sector Investment Programme (ASIP) between 1996 and 2000.[9] These reviews were discontinued when the Agricultural Sector Investment Programme was phased out and they have been conducting ad hoc reviews of agricultural sector programmes and or projects mainly driven by development partners. Since finalisation of the National Agricultural Investment Plan and drafting of the national Joint Sector Review Roadmap with support from the European Union, Zambia has been setting up structures to revive agricultural JSRs. The 2015 JSR report for Zambia combined efforts from what the country was already doing as indicated in their JSR roadmap and the African Union/ReSAKSS JSR support for member states. Swaziland, on the other hand, implemented her maiden JSR report in 2015 supported by ReSAKSS Southern Africa. The country had had only agricultural sector reviews consisting of ministerial quarterly reports submitted to parliament and reports of performance targets to the office of the Prime Minister.[10]

The findings also showed that, through conducting the agricultural JSRs, these four countries realised and/or revived the need to institute the implementation of the JSR as a way of enhancing mutual accountability of action and results. In a separate study, Holvoet and Inberg[11] – based on experiences from the education sectors in Burkina Faso, Mali and Niger – found that JSRs facilitated harmonisation, coordination, leadership and wide stakeholder participation and prioritised accountability. Evidence from the current study also indicates the important contribution of the JSR processes in the respective countries. For example, Swaziland has expressed an interest to implement the action plan from the 2015 JSR process and is also setting up monitoring and evaluation structures to coordinate the evaluation of agricultural sector activities, including ensuring that credible and adequate data are available. Malawi has advanced in implementing their annual agricultural sector review which now starts with planning at the beginning of the year and a review of performance at the end of the year (around October/November). Mozambique has stepped up efforts to develop indicators for tracking commitments and performance of the implementation of their national agricultural investment plan (PNISA).

Experiences on policy and institutional reviews

The policy reviews showed that within each of the four countries, there were a number of agricultural policies addressing various aspects in the sector. Table 2 summarises the ratings on progress on institutional and policy actions. Although the policies were rated adequately in covering priority issues in the agricultural sector in the different countries (see Table 2), the main challenge was that, in some cases, these policies were not harmonised to clearly complement each other. Furthermore, it was reported that, although some of these policies were adequate 'on paper', they were not being implemented. For instance, the main

Table 1: Joint sector review (JSR) assessment activities in the focus countries

Country	JSR assessment	Other sector review activities for advancing mutual accountability
Malawi	JSR (2014); New Alliance Report (2014; 2015)	Agriculture sector status report; Technical Working Groups (e.g. on monitoring and evaluation); Sectoral Working Group
Mozambique	JSR (2014); New Alliance Report (2014; 2015)	Agriculture Development Operation with World Bank; Programmatic Aid Partners dialogue platform; Technical Working Groups; Agriculture Sector Coordination Committee
Zambia	JSR (2015)	National JSR roadmap; Agricultural Sector Advisory Group; Special Stakeholder meetings called by the Minister
Swaziland	JSR (2015)	Ad hoc ministerial reports to parliament and quarterly reports to the Office of the Prime Minister on performance targets; donor-driven programme evaluations

Sources: JSR reports from each country[7-10]

Table 2: Summary ratings on the implementation of policy dimensions

Policy dimension	Traffic light rating			
	Malawi	Mozambique	Swaziland	Zambia
Quality of policy planning and execution	Green	Green	Amber	Amber
Consistency of policy mix	Amber	Amber	Amber	Amber
Alignment of NAIP with policies	Green	Green	Amber	Green
Policy implementation status	Amber	Amber	Red	Amber
Adequacy of policy coverage	Amber	Amber	Green	Amber

Green indicates that the commitment has been achieved to a reasonable degree; amber that the commitment has been partly achieved but additional attention is required; and red that the commitment has not yet been achieved.

NAIP, National Agriculture Imagery Program

challenge in Swaziland was that agricultural policies usually did not have clear targets or implementation, monitoring and evaluation plans.[10] In some cases, such as in Malawi, there is no overarching agricultural policy to guide investments and implementation of priorities in the sector, despite the country having many agricultural sector policy commitments and frameworks.[7] In Mozambique, the various policies and strategies are influenced by long-term standing development goals and immediate crises and challenges which the country faces.[8]

The other key findings with agricultural policies was that they tended to be centralised to the respective ministry and higher offices of government with no sector-wide stakeholder engagements, such as in Mozambique and Swaziland. In such cases, the development, implementation, monitoring and evaluation of agricultural policies becomes the role of the respective ministry or central government, sometimes involving only a few development partners. However, in Mozambique for example, the development of the Strategic Plan for Agricultural Sector Development in 2011 was reported to have followed a participatory approach (involving government institutions, farmer organisations, private sector, development partners and civil society). This together with implementation of the CAADP process has helped improve participation of sector-wide stakeholders in policy planning and implementation processes. In contrast, Zambia reported that their processes from identifying policy gaps, policy development, planning and implementation involved wide stakeholder engagements.[9] Overall, key lessons learned from the experiences include the need to ensure that agricultural policies are harmonised and complement each other clearly to enhance their planned impact. Also, these monitoring efforts help contribute to revising agricultural sector policies reflecting the priority needs in each country as elaborated through sector engagements. Engagement of all sector stakeholders is critical to facilitate transparency and accountability for action and results.

In all four countries, the respective ministries of agriculture are responsible for leading the agricultural JSR processes. The planning, implementation and (sometimes) monitoring and evaluation involved various departments and government agencies as well as non-state actors. However, institutional involvement in agricultural sector stakeholder engagements varies from country to country. The main issues regarding institutional review were the lack of coordination within and among different institutions, lack of institutional implementation capacity and lack of participation of non-state actors (see Table 3 which illustrates ratings from experiences in the four countries). In Swaziland, some of the stakeholders, especially the non-state actors (the private sector, farmer organisations, civil society, etc.), reported that the engagements in agricultural sector policy/programme planning was superficial – usually only to 'rubber stamp' what the government and development partners had already decided and agreed on.[10] Non-state actors' participation was rated better for their involvement in policy and programme formulation compared to that for implementation. However, active involvement of non-state actors in monitoring and evaluation of progress from the different agricultural policies and programme would be more effective if they were involved during the implementation phase as well.

The findings with regard to ratings in Table 3 show that in Malawi, Mozambique and Swaziland, coordination within government institutions was rated as 'Red'. The same rating applied for involvement of non-state actors in policy/programme planning and implementation in Swaziland; and institutional implementation capacity (especially monitoring and evaluation capacity) in Mozambique and Swaziland. The different reports indicated lack of coordinated efforts, especially within government institutions. Despite the presence of some structures for different ministries to mutually engage on various issues, it was noted that most of the respective designated officials failed to participate (for example in Malawi and Swaziland) and government ministries and departments continued to work in silos most of the time. Institutional implementation capacity was reported to be one of the critical areas requiring strengthening, especially in Mozambique and Swaziland. For example, in Mozambique the argument was that most of the implementation was being done with the support of international organisations and there was a critical need to have local institutional capacity strengthened.[8]

Table 3: Summary of ratings of institutional dimensions in the four countries

Institutional dimension	Traffic light rating			
	Malawi	Mozambique	Swaziland	Zambia
Coordination within government institutions	Red	Red	Red	Amber
Participation of non-state actors in policy and programme formulation	Green	Green	Amber	Green
Participation of non-state actors in policy and programme implementation	Amber	Amber	Red	Amber
Institutional alignment with the NAIP	Amber	Green	Amber	Green
Institutional implementation capacity	Amber	Red	Red	Amber
Coordination among development partners	Amber	Green	Amber	Green

Green indicates that the commitment has been achieved to a reasonable degree; amber that the commitment has been partly achieved but additional attention is required; and red that the commitment has not yet been achieved.

NAIP, National Agriculture Imagery Program

This is a very typical governance problem in almost all countries in Southern Africa, although some countries have made special efforts to overcome the 'silo' problem. In some cases the 'silo' problem had entrenched itself: departments were functioning as dynasties beholden to their ministers; there was an organisational culture of jealousy and suspicion; and officials did not understand that developmental problems typically require different sectors. Overall, this is a complex issue that requires further detailed qualitative research to unpack it.

Evidence from the different JSR reports in the four countries indicates that the implementation of the CAADP agenda has encouraged agricultural sector stakeholders to engage with one another. However, gaps were reported in terms of effective engagement and consultation with all sector stakeholders. In all four countries, it was clear that most of the engagements were among government ministries, agents and development partners. Non-state actors – especially farmer organisations, civil society and private sector – were largely excluded and more efforts are required to effectively engage these groups of stakeholders. For instance, the Malawi 2014 JSR report indicates that the main shortfall of the Agriculture Sector Report which describes the sector's performance in the previous year fails to adequately address activities and issues of non-state actors. The work of the New Alliance and Grow Africa as well as Non-State Actors Coalition provides important platforms for addressing the above shortfall in agricultural sector engagements.

Similar to the intra-government coordination discussed above, some of the salient issues concerning engagements between government and sector stakeholders include the reluctance of officials to share information or resources; their suspicion of the capacity or agendas of non-state organisations or donors; and their inability to appreciate the unique contribution that non-state organisations can make. Conversely, sector stakeholders in some cases are suspicious of government requesting information on their activities. This situation also requires further detailed research to help find workable solutions to facilitate mutual engagement and sharing within the agriculture sector.

In addition, in all four countries, there was growing interest and implementation of structures to engage all agricultural sector stakeholders not previously engaged in various aspects. For example, Malawi and Mozambique are already part of the New Alliance and Grow Africa annual reporting programme which tracks commitments and achievements among various actors, including government, development partners and the private sector. In Zambia and Swaziland, the JSR processes also engaged sector-wide stakeholders including state and non-state actors. The experiences from the implementation of the JSR showed the enthusiasm and commitment by various non-state actors who felt they have been excluded for too long and wanted to make positive contributions in the planning, implementation and evaluation of programmes and policies within the agricultural sector.

Experiences on financial and non-financial commitments

Financial and non-financial commitments include: budgetary allocations; investments; financial support; capacity building; and organisational commitments made by governments, donors and non-state actors; and key agriculture sector targets, such as growth, productivity and other major results defined in the national agricultural investment plans and other policy and strategic documents.[6] The experiences on financial and non-financial commitments made by various key stakeholders (government, development partners, private sector, farmer organisations, etc.) indicated that for Zambia and Swaziland, the reported commitments were mainly by government and development partners. In these two countries, involvement of non-state actors regarding making concrete commitments is still lacking and is an area requiring much intervention. On the other hand, Malawi and Mozambique – through their involvement in the New Alliance Cooperation Framework Agreement – experienced substantial commitments and achievements from government, development partners and the private sector.[7,8]

The realisation of financial and non-financial commitments is critical for these countries to achieve their agriculture sector growth and development targets. The failure by an actor to meet their commitments affects successful implementation of agricultural policies and programmes, which affects the final output and impact. From the above experiences, it is clear that more effort is required, especially in non-New Alliance countries such as Swaziland and Zambia, to engage non-state actors to actively and effectively participate in the implementation of agricultural policies and programmes through commitments (both financial and non-financial). In Malawi and Mozambique, the focus should be on ensuring that the implementation of the commitments is generating the required impact – that is, the focus is more on the effectiveness of the support provided. Given the growing scarcity of resources for development work, it is critical that the available resources are put to their best available use to generate the greatest impacts in the sector.

Experiences on monitoring and evaluation and development impacts

The JSR assessments included evaluation of the capacity of the different ministries to implement monitoring and evaluation of agricultural policies/programmes and development impacts. The four countries lack institutionalised monitoring and evaluation capacity to provide regular up-to-date data and analysis of impacts from various agricultural policies/programmes and development impacts. For example, Mozambique, Malawi and Zambia reported that a lack of decentralised data along functional, geographical, sub-sectoral or commodity lines remains a challenge to inform evidence-based planning at lower levels.[7-9] Overall – in all countries – effective monitoring and evaluation suffers from limited availability of quality data; unreliable or non-existent evaluation of policies/programmes; and limited capacity to apply technical evaluation tools. There has been an increasing emphasis on results from development interventions in recent years.[12] To strengthen mutual accountability for results and provide evidence-based support to agricultural policy/programme planning and implementation, robust monitoring and evaluation systems are needed in most countries on the continent.

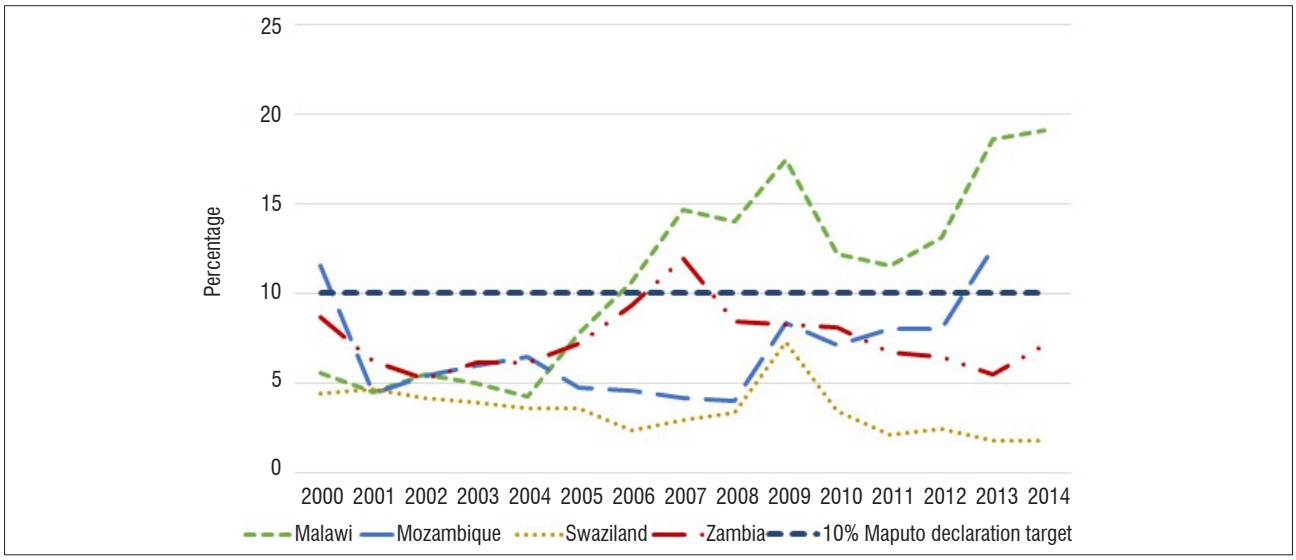
ReSAKSS has made efforts to set up national-level Strategic Analysis and Knowledge Support System (SAKSS) nodes aimed at addressing this gap, and the operationalisation of these nodes is critical for addressing the capacity gap. The SAKSS nodes would help strengthen capacity in strategic analysis, data collection, analysis, knowledge management and sharing among sector stakeholders. However, among the four countries – despite progress made in Malawi, Mozambique and Zambia – there is no operational SAKSS node. In addition, the Ministries of Agriculture themselves lack properly functioning monitoring and evaluation departments or units and rely on outside support, which usually is related to specific programmes as required by the donor.

The agricultural sector JSR processes in the four countries have contributed to the need and implementation of measures to improve monitoring and evaluation in the agricultural sector in the respective countries. For example, Swaziland realised from the JSR processes how a lack of a proper monitoring and evaluation system and structures affects their planning and implementation of agricultural policies and programmes, including how having the same can enhance evidence-based decision-making and implementation. At the time of writing, the Ministry of Agriculture in Swaziland was planning on setting up and operationalising a monitoring and evaluation function that would address the current challenges. In Malawi, for example, the institutionalisation of the annual agricultural JSR process and the subsequent Agricultural Sector Performance Report have helped enhance monitoring and evaluation capacity in the ministry. Further efforts are, however, required to operationalise the country SAKSS node to enhance monitoring and evaluation capacity among other functions.

In terms of performance of the agricultural sector, for the purpose of this paper, we only considered the two priority indicators of the CAADP: attaining at least a 10% agricultural share of the total national budget to achieve a 6% annual agricultural GDP growth rate. Various other indicators are presented in the various JSR reports of each country. Figure 1 summarises the agriculture budget in terms of the share of the total national budget for each country. Malawi has consistently achieved the 10% agricultural budget target since 2008, while Mozambique achieved the same in 2010 and 2014.

Table 4: Monitoring and evaluation challenges in the four countries

Country	Monitoring and evaluation challenges
Malawi	Weak monitoring and evaluation at district levels although evidence from the district is used at the national level Limited capacity to gather data and synthesise information at district levels Lack of proper information sharing mechanism between the Ministry of Agriculture and Water Development, and partners (other government ministries, private sector, NGOs, etc.) Limited availability of quality data and technical analytical capacity to apply evaluation tools, especially at low levels such as at district level Evaluation usually done by external consultants
Mozambique	The national agricultural investment plan (PNISA) fails to provide details of the monitoring and evaluation plan Besides the overall goals (increasing agricultural sector growth and reducing chronic child malnutrition and hunger) there are no other indicators defined for measuring progress Indicators of the PNISA were left to be identified by agencies involved at programme and sub-programme levels and this is yet to be finalised Lack of decentralised data along functional, geographical, sub-sectoral or commodity lines remains a challenge to inform evidence-based planning at lower levels
Swaziland	Lack of operational monitoring and evaluation system for the agricultural sector Lack of decentralised data along functional, geographical, sub-sectoral or commodity lines remains a challenge to inform evidence-based planning at lower levels
Zambia	Lack of decentralised data along functional, geographical, sub-sectoral or commodity lines remains a challenge to inform evidence-based planning at lower levels



Sources: JSR reports from each country[7-10]

Figure 1: Agriculture percentage share of total national budget.

Zambia has also made some progress in increasing the budget allocation for agriculture. For Swaziland, the invariable low share of the agriculture budget as a component of the total national budget is attributed to various factors, including poor budget execution rates by the Ministry of Agriculture, which, in turn, prompts budget cuts in subsequent years. Another reason is unstable earnings from the Southern African Customs Union, which makes up the largest proportion of the country's revenue.[10]

Despite the progress made in these countries, the main remaining issue is to ensure the quality of the allocation and actual expenditure of the financial resources. All the countries raised concerns regarding ensuring that priority programmes within the national investment plans receive adequate funding from these national agricultural budgets. The JSR report makes it clear that without adequate financial resources allocated to implement priority investment plans in agriculture, the expected development impacts would be difficult to achieve. Therefore, targeted resource allocation to high development priority areas in agriculture would have the greatest impact if the necessary resources are allocated to allow implementation.

Conclusion and recommendations

The Malabo Declaration's commitment to accountability stresses the continent's resolve to strengthen achievement of results anchored with effective and efficient implementation capacity and optimisation of resources. The CAADP Implementation Strategy and Roadmap identifies the agricultural JSR as the principal instrument for operationalising the mutual accountability framework and reporting on agreed commitments and as a platform to discuss implementation. Our main objective in this paper was to critically assess the experiences of four countries – Malawi, Mozambique, Swaziland and Zambia – in the implementation of agricultural JSRs in supporting mutual accountability in Southern Africa. The analysis focused on assessing the lessons learned, challenges experienced and recommendations made for improvement. The key findings and recommendations are summarised below.

In all the countries reviewed, agricultural policies and/or programmes are still mainly fragmented; however, there are various efforts in each of the countries to harmonise these agricultural policies and programmes. In addition, in cases in which these processes have been completed, the challenge that remains is to effectively bring all stakeholders together in the actual implementation of the policies and programmes. Evidence from the different JSRs in the four countries indicates that the implementation of the CAADP agenda has enhanced stakeholders engagement within the agricultural sector; however, more effort is required to strengthen coordination, especially among government departments. In addition, the realisation of financial and non-financial commitments is critical for the countries to achieve their agriculture sector growth and development targets. The failure by an actor to meet their commitments affects the successful implementation of agricultural policies and programmes, which ultimately affects the final output and impact.

Despite progress in the countries to strengthen mutual accountability, monitoring and evaluation capacity remains a concern, especially at low levels of government. This concern is also linked to the lack of reliable and good quality data at these levels. More efforts are required to strengthen monitoring and evaluation and ongoing efforts in each country should be upscaled. This effort is critical to provide quality, evidence-based support to agricultural policy/programme planning and implementation. The efforts by ReSAKSS to set up national-level SAKSS nodes aims to address this gap, and the operationalisation of these nodes is critical for addressing the capacity gap. The SAKSS nodes would help strengthen capacity in strategic analysis, data collection, analysis, knowledge management and sharing among sector stakeholders.

The recent efforts to conduct JSR assessments in the countries have raised the quest for increased accountability for action and results and each country is implementing measures to improve on these aspects. It is therefore important to note that, although the JSR assessment activities are not the only reason for increasing efforts to ensure mutual accountability, they have really contributed to strengthening ongoing efforts in these countries. In addition, the overall CAADP mutual accountability process and implementation of the CAADP agenda in the respective countries have gone a long way in facilitating sector-wide engagement of stakeholders in planning, implementation, and monitoring and evaluation of agricultural policies and programmes. CAADP mutual accountability is critical to ensure effective implementation and realisation of development impacts of agricultural priorities in the national agricultural investment plans.

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Authors' contributions

C.N. conceptualised the article content and compiled the first draft. G.M. and S.N. revised the manuscript and made conceptual contributions.

References

1. Working Party on Aid Effectiveness. Aid effectiveness. A Progress Report on Implementing the Paris Declaration. Paris: OECD/DAC; 2008.
2. Development Assistance Committee (DAC), Organisation for Economic Co-operation and Development (OECD). Paris Declaration on Aid Effectiveness. Paris: OECD/DAC; 2005.
3. Development Assistance Committee (DAC), Organisation for Economic Co-operation and Development (OECD). 2008 Survey on monitoring the Paris Declaration. Effective aid by 2010? What it will take. Paris: OECD/DAC; 2008.
4. African Union Commission. Implementation strategy and roadmap to achieve the 2025 vision on CAADP. Addis Ababa: African Union; 2015.
5. African Union Commission. Malabo declaration on accelerated agricultural growth and transformation for shared prosperity and improved livelihoods. Addis Ababa: African Union; 2014.
6. Regional Strategic Analysis and Knowledge Support System (ReSAKSS). Facilitating improved joint sector review (JSR) processes and report at country level. JSR Support Memo. Addis Ababa: ReSAKSS; 2015.
7. Government of Malawi. Malawi agriculture joint sector review (JSR) assessment report. Lilongwe: Ministry of Agriculture and Water Development; 2014.
8. Government of Mozambique. Mozambique agriculture joint sector review (JSR) assessment report. Maputo: Ministry of Agriculture; 2014.
9. Government of Zambia. Zambia agriculture joint sector review (JSR) assessment report. Lusaka: Ministry of Agriculture and Livestock; 2015.
10. Government of Swaziland. Swaziland agriculture joint sector review (JSR) assessment report. Mbabane: Ministry of Agriculture; 2015.
11. Holvoet N, Inberg L. Joint sector reviews – M&E experiments in an era of changing aid modalities: Experiences from JSRs in the education sectors of Burkina Faso, Mali and Niger. Public Admin Devel. 2009;29(3):204–217. https://doi.org/10.1002/pad.538
12. White H. An introduction to the use of randomised control trials to evaluate development interventions. J Dev Effect. 2013;5(1):30–49. https://doi.org/10.1080/19439342.2013.764652

A case study from the southern Cape linefishery 1: The difficulty of fishing in a changing world

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Variability on multiple temporal and spatial scales exposes fishers and fishing communities to multiple stressors. The impact and interplay of these stressors need to be considered to improve our understanding of social-ecological linkages if sustainable livelihoods are to be promoted. To this end, participant-led research was conducted in the small-scale traditional commercial linefishery of the southern Cape (South Africa) between Witsand and Mossel Bay. Knowledge and perceptions regarding stressors responsible for changes in the social-ecological system, which ultimately affect the fishers' ability to fish successfully, were recorded using semi-formal interviews and focus groups with 50 participants. The results presented not only offer valuable insights into the day-to-day experiences of these fishers, but also expose knowledge gaps that exist in micro-scale interactions influencing the fishery system. An analysis of various stressors is presented, which includes the impacts of and responses to climate variability; challenges presented by fisheries policies and regulatory frameworks; social and economic considerations; inadequate infrastructure; and general political considerations. The development of a more comprehensive understanding of stressors that affect the social-ecological system at various scales provides valuable insights into a fishery system that is currently not well described, and provides the basis for analyses into vulnerability and resilience.

Significance:

- Understanding the impact and interplay of stressors at multiple scales is important if sustainable livelihoods are to be promoted.
- This research provides insight into the day-to-day experiences of fishers whilst exposing knowledge gaps that exist at a micro-scale.

Introduction

The Benguela Current Large Marine Ecosystem is an eastern boundary current system dominated by coastal upwelling. It is a very productive region and sustains important fisheries for Angola, Namibia and South Africa.[1] The Benguela Current Large Marine Ecosystem displays a high amount of variability and consists of four shelf subsystems, including the Agulhas Bank subsystem off the southern Cape coast.[2,3] The roughly triangular Agulhas Bank extends approximately 117 km (63 nautical miles) off Cape Agulhas, within the South African exclusive economic zone. This study focused on the small-scale commercial linefishery that operates in the inshore area of the Agulhas Bank and primarily targets silver kob (*Argyrosomus inodorus*). The traditional linefishery in South Africa is a boat-based, multi-user, multi-species and multi-area fishery that targets 50 commercially important fish species.[4,5] Rights allocation in this sector is done in accordance with a total applied effort, which limits the amount of effort that may be expended. The first allocation of fishing rights in line with the current total applied effort took place in 2003. This allocation, fraught with challenges, resulted in 450 rights granted. Crew not included in the initial allocation were subsequently granted interim relief permits for subsistence purposes.[6]

A range of anthropogenic stressors such as resource scarcity, poor socio-economic conditions, and policy and regulatory challenges affect the inshore social-ecological system of the southern Cape. These stressors cause commercial small-scale fishers and their communities to become increasingly vulnerable to local and global changes in the fishery system.[7] In future, fishers will need to cope with and adapt to multi-scalar social and ecological changes. Their communities will be required to enhance their strategies to achieve resilient livelihoods. In this paper, we discuss the stressors that make these fishers vulnerable to change. In conjunction, we provide analyses and discussion of the current strategies employed by fishers in reaction to change caused by these stressors in a paired paper.[8]

Recent research has illustrated that stressors that give rise to fishers' vulnerability to change commonly encompass a wide range of factors that include micro- and macro-level changes to social and environmental systems.[9,10] Studies of stressors highlight situational and contextual factors and their relative importance in the configuration of the local social developmental context.[4] The impact of responses is shaped and mediated by social, cultural, economic, technological, political and institutional factors.[10] Whilst vulnerability has been defined in numerous ways by various authors,[7,11-13] studies carried out in the African context emphasise the need to capture the changing nature of risks.[8,10] Southern African studies[11,14-17] have shown that there are clear risks posed to individuals, households and communities that are unable to cope with multiple stressors, let alone adapt to them. Interactions between stressors may have unexpected outcomes for both human well-being and livelihoods with serious implications for efforts to reduce vulnerability of resource users. Stressors and interactions amongst them have the potential to remain hidden, thereby spreading across various scales and leaving social units subject to the risk of double and/or multiple exposure.[18] This spread can result in the effect of a stressor being felt more than once through different pathways.

Understanding exposure and sensitivity of stressors across scales, paired with effective action, could be key to effectively reducing the vulnerability of fishers. To ascertain how people are affected by, and unable to cope with, stressors, it is necessary to move beyond linear vulnerability assessments that are based on processes and outcomes.[10] Turner et al.[19] propose a sustainability/vulnerability framework for which to analyse elements of a bounded system at a particular scale.[7] Cutter et al.[20] suggest that a place-based approach can be used to position local vulnerability within the larger contexts to compliment the approach outlined by Turner et al.[19] The framework proposed by Turner et al.[19] maintains that certain elements are integral to an extended vulnerability and sustainability assessment; these elements must consequently be included in any vulnerability analysis that seeks to encourage sustainability.

Research area and methodology

Participant-led research was carried out in six towns located within a 155-km stretch of the southern Cape coastline: Mossel Bay, Gouritsmond, Melkhoutfontein, Still Bay, Vermaaklikheid and Witsand (Figure 1). Interviews were conducted between July 2013 and February 2014 with 50 individual participants comprising skippers, boat owners, crew, members from associated industry, as well as spouses/partners. Both one-on-one, semi-structured interviews and several group interviews of varying sizes were conducted. Group interviews were favoured by some participants as they felt more comfortable in that setting. For the groups, participant details and responses were recorded as individual responses with only those attendees that actively participated throughout and on all topics recorded as a participant. No group consensus was reached or required and responses were captured and coded on the scale of the individual in the analysis. The sample size of 50 represented approximately 30% of the total number of possible participants from the area. This number (150) was derived from data obtained from the Department of Agriculture, Forestry and Fisheries (DAFF) from active commercial handline fishing rights for 2011. Participants dictated the time, duration and format of interviews according to the integrity of a participant-led research process. Interviews and discussions were audio recorded and later transcribed with participants' permission and anonymity was maintained. Data were analysed by means of thematic analysis.

Despite efforts to ensure the even distribution of participants in terms of role and geographical location, this goal was not attainable (Table 1). However, the uneven distribution was not a hindrance as participant responses remained consistent throughout the research. The uneven distribution is particularly evident in the relatively small numbers of crew members who participated. Many skippers/boat owners and right holders functioned as gatekeepers, who at times inadvertently restricted access to their crew. This restriction, along with other factors such as the gender bias and a natural distrust of 'outsiders', made it difficult to approach the crew members. However, crew members are also more mobile within the sector than other role players and many (per participants) were not present in the area at the time of the research.

Results and discussion

Participants provided information on factors that impede their ability to fish successfully. Table 2 reflects stressors identified by participants in response to the question 'What are those things that make it difficult for you to fish successfully?'. Three major groupings of stressors were identified during thematic data analyses, namely major, mid-range and minor stressors. Major stressors were those mentioned by more than 80% of participants. These stressors consisted of policy and regulation, changes in the natural environment, as well as the impact of the inshore trawl fishery on the local linefishery. Mid-range stressors were mentioned by 50% to 80% of respondents and included stressors related to enforcement and implementation of policy, economic factors and 'political' issues amongst fishers. Minor stressors were mentioned by less than half of the participants and consisted of geography of the local area, infrastructure, social factors, lack of knowledge (for example in financial planning), fishing methods, and impacts of other marine species (e.g. seals and sharks). Some of the minor stressors identified were unique to specific towns, e.g. geographical location (remoteness) that was specific to Vermaaklikheid.

Stressors are discussed below in the context of the three broad groups outlined in Table 2, with attention to the major stressors. These stressors speak to changes observed in the natural (sub-) system followed by those that emanate from the human–social (sub-) system.

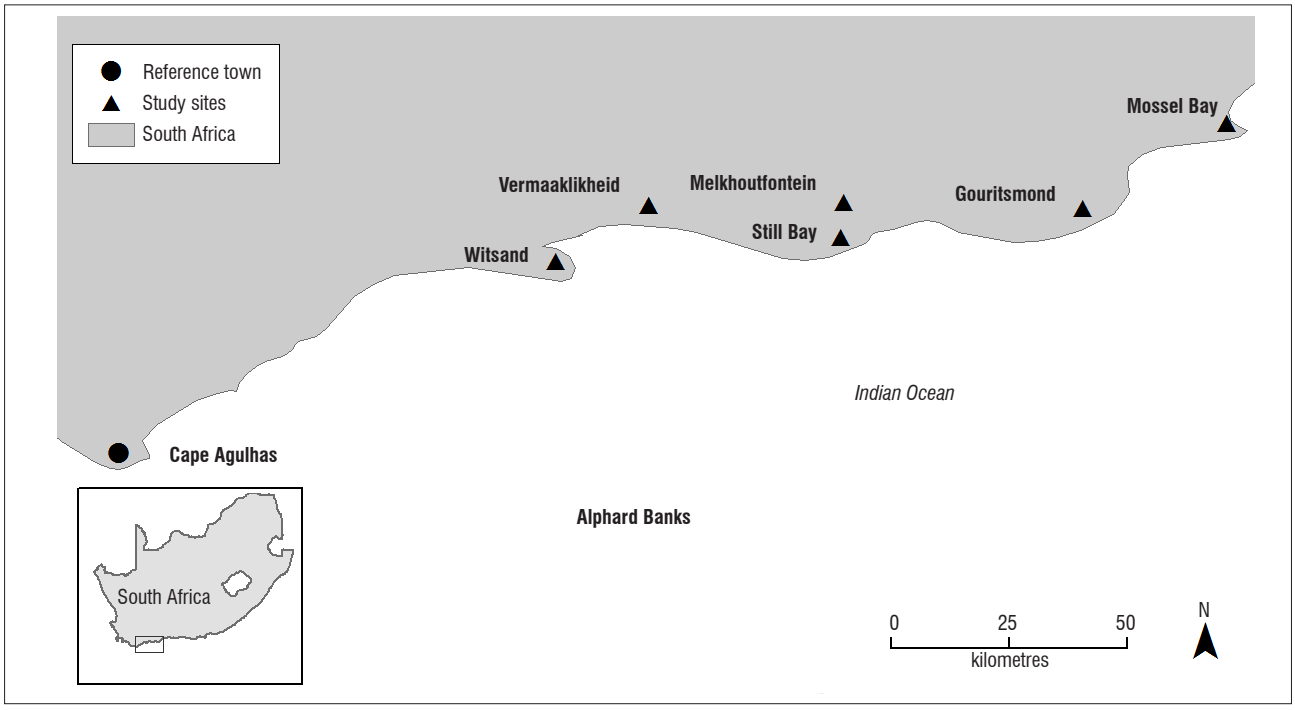

Figure 1: Map of the research area in the southern Cape. The map shows the six towns that were directly involved in the study: Mossel Bay, Gouritsmond, Still Bay, Melkhoutfontein, Vermaaklikheid and Witsand.

Table 1: Composition of the total group of participants

	Role			
Town	**Skipper/boat owner and/or rights holder**	**Crew**	**Associated industry**	**Partner/spouse**
Mossel Bay	5	0	0	0
Gouritsmond	1	0	0	0
Melkhoutfontein	2	3	1	0
Still Bay	7	1	8	2
Vermaaklikheid	3	9	0	7
Witsand	1	0	0	0
Total	**19**	**13**	**9**	**9**

Table 2: Stressors identified by participants. Stressors identified by 80% or more of all participants were termed 'major', those identified by 50–79% 'mid-range' and by less than half of the participants as 'minor'.

Major stressors		**Mid-range stressors**		**Minor stressors**	
Stressor	**%**	**Stressor**	**%**	**Stressor**	**%**
Policy and regulation	92%	Enforcement and implementation of policy	76%	Geography of area	48%
Climate variation	90%	Economic (in terms of capital)	76%	Inadequate infrastructure	46%
Other fishing sectors (such as inshore trawl)	84%	'Political issues' (amongst fishers and sector)	76%	Social factors	46%
		Socio-economic	70%	Lack of knowledge (financial planning, literacy level, etc.)	44%
				Fishing methods	26%
				Other marine species (e.g. seals)	14%

Variability in the natural system

Recognising that observed changes in the natural system occur at various temporal scales, reported daily impacts show a link between the ability of fishers to proceed to sea (climate variation and its effects on weather) and the abundance and behaviour of target species in areas of operation. Importantly, interview data suggest that no single driver of change is identifiable, but rather a collection of stressors that indicate high variability and/or change at various temporal and spatial scales.

Globally, large-scale changes in the marine environment can manifest as changes in sea surface temperature (SST), large-scale circulation patterns, stratification and nutrient availability.[21] Non-climatic stressors linked to climate change include ocean acidification, pollution, habitat alteration and destruction, coastal eutrophication, the spread of invasive species and fishing pressures.[21] It is difficult to predict how different marine habitats respond to these stressors, especially at smaller, localised scales. While quantified data are available on large scales for some of these stressors, regional impacts are not easily identifiable or quantifiable at smaller, localised scales.[21,22] Seasonal, inter-annual and decadal-scale variability in winds, SST, bottom oxygen and primary productivity have been documented for the Agulhas Bank.[3,23-25] Inshore systems are particularly exposed to human-mediated pressures that drive change over multiple spatial and temporal scales, affecting not only the marine environment but also the fishing communities that interact with them.[22,26-28]

Physical variability

Participant observations indicated a general warming trend (air and/or SST) with unseasonable prevailing wind conditions (winds arriving late and shifts between southeasterly and southwesterly winds). Shifts in wind conditions resulted in a deterioration of sea state and fewer available sea days. Prevailing economic conditions (price of fuel and bait) forced fishers to go to sea on days on which weather conditions were most favourable, as the likelihood of landing profitable catches was higher, resulting in a further reduction of sea days.

Throughout the study, concerns about environmental stressors were framed in terms of climate change. Participants did not give a clear indication whether the effects of other stressors/drivers within the system were accounted for when such evaluations were made. There was some variation within the participants' responses as to the nature of the variability, making it difficult to determine the exact temporal scale on which the variation was observed.[21]

A small number of 'older generation' participants (older than 50 years) explicitly indicated that they regarded the observed variation as being cyclic. Other participants indicated that although cyclic variation had been previously observed, present events appeared to be increasingly extreme in nature (higher maxima of temperature and wind speeds). This observation is consistent with general climate change expectations in which increases in maxima within normal variability ranges are predicted.[29] However, these participant observations have not been observed in data sets of geostrophic winds and subsequent calculated upwelling on the Agulhas Bank.[25] The majority of participants highlighted a direct relationship between diminishing kob catches (2–3 years prior to this research) and changes/variability in the local climate. However, it was unclear how much participants understood about global and regional climate change and how much of their positive response was driven by media information.

Failure to accurately identify or recognise climate drivers within local contexts may hamper fishers' ability to respond adequately to this stressor. Research conducted in Thailand by Bennett et al.[30] found that a general lack of knowledge of climate change meant that individuals and households were more likely to react to stressors instead of adapting

via active management of the risks and/or planning for climate change. This uncertainty regarding the source, depth and context of the fishers' knowledge of climate change warrants further research.

The hydrology of the Agulhas Bank is primarily driven by the wind regime, the Agulhas Current that runs along the shelf break, as well as the seasonal overturn of shelf waters.[3] Analysis by Rouault et al.[31] (using satellite and modelling studies) indicates a strengthening of the Agulhas Current flow over the past 25 years, resulting in warmer offshore water. Subsequent analyses conducted by Rouault et al.[32] using in-situ and satellite SSTs plus SSTs simulated by sea-ice coverage confirmed offshore warming and inshore cooling which corroborated findings by Roy et al.[33] However, more recent analysis conducted using Pathfinder data (version 5.2) does not confirm these results, indicating instead a consistent warming trend inshore and over the central Agulhas Bank across all seasons, with general warming most distinctive in the early austral summer months.[5] These recent findings are supported by many of the participants' observations of SST increase in the recent past.

There is larger disagreement between signals of different scientific data sets for the Agulhas Bank than for the other subsystems of the Benguela.[3] Furthermore, scientific data are not available to characterise ocean temperature variability and/or trends at the bay scale. This makes it problematic for scientists to relate to changes in temperature observed by participants. This discrepancy draws attention to a scale mismatch of data which is an example of how scale mismatches can result in knowledge gaps.[34]

Biological variability

Kob is not the only linefish species available for exploitation in the area, although it is regarded as the most commercially viable. Other species like silvers/carpenters (*Argyrozona argyrozona*) and reef fish such as red roman (*Chrysoblephus laticeps*) are targeted in the absence of kob. Although close to the productive fishing water of the southwestern Cape, fishers in this area cannot commercially exploit species such as geelbek *(Atractoscion aequidens),* snoek *(Thyrsites atun)* and yellowtail *(Seriola lalandi)* as these are not abundant in their area of operation. Although Cape hake (*Merluccius capensis*) have previously been caught in the area, participants indicated that they had not been available in the recent past. Kob are reef-associated fish with large home ranges and are known to retreat offshore in winter, returning to inshore waters when the coastal upwelling resumes in summer.[4] Participants from Melkhoutfontein and Still Bay referred to this migration from the 'outer' to 'inner' reefs throughout. Fishers expect kob to migrate inshore at the start of austral spring for the start of the 'season' and expect the fish to remain in this area until austral autumn.

The observed change in catches and distribution of kob could be attributed to a recent ecosystem regime shift that has taken place in the southern Benguela. The southward and eastward shift of small pelagic fish in the late 1990s to early 2000s is thought to have been brought about by changes in environmental drivers and subsequently intensified by fishing activities.[35] This hypothesis has been corroborated by Watermeyer[36] who reported changes in the distributions of predatory fish in the southern Benguela in relation to sardines *(Sardinops sagax)* and anchovies (*Engraulis encrasicolus*). Ethnography by Duggan[37] also indicated changed kob 'behaviour' such as fish not biting, shortened residence time and disruption to migration patterns on the Agulhas Bank as told by fishers from Still Bay. Furthermore, fishing pressure (in the form of by-catch) exerted by the inshore trawl fishery operating in the area could also have contributed to a shortage of kob. The belief that the inshore trawl target kob specifically is exacerbated by a shortage (and near absence) of Agulhas sole *(Austroglossus pectoralis)* and inshore Cape hake *(Merluccius capensis*) stocks in the area.[38] Although changes as a result of fishing pressure are well documented,[38,39] the degree and extent of climate-induced changes and their influence on local stock abundance remain uncertain.

Policy and regulation

Policy and the regulation thereof (including enforcement and implementation of policy and regulation) was viewed as the most important stressor in the human–social component of the fishing system and participants expressed continual negative experiences when dealing with policy and regulatory issues.

The *Marine Living Resources Act* (MLRA) uses a fishery-specific, individual rights allocation system to regulate certain fisheries in South Africa. The domestic industry was initially divided into the recreational, commercial and subsistence sectors.[40] Rights were given for the commercial and subsistence sectors with recreational fishery regulated through the issuance of annual permits with specific catch restrictions and the prohibition to sell catches. These rights are statutory permissions granted by the minister to harvest specified marine resources for a period of time (see section 18(6) of the Act).[6,41] The current cohort of traditional handline fishers was granted medium-term rights valid for a period of 8 years that expired at the end of 2013, after which they had to re-apply for rights. The fieldwork for this study took place during this re-application process (termed FRAP 2013). As the previous allocation process had been fraught with inconsistencies and allegations of unfair practice, from the outset, participants did not view the application process in a positive light.

The 'Draft revised Traditional Linefish Policy on the allocation and management of fishing rights: 2013' provided the policy framework for FRAP 2013. This policy sets out two groups of criteria for allocation. Evaluation (exclusionary) criteria seek to exclude anyone who in the current cycle did not comply with regulations set out in the permit conditions. Examples of these evaluation criteria include whether someone is deemed to pose a so-called 'paper quota risk'; whether there is more than one right per household; whether use has been made of a currently allocated right; and whether someone has not been personally involved in the harvesting of the resources as a rights holder and/or cannot prove access to a fishing vessel.[42] The second set of criteria – balancing criteria – calls for the evaluation of applications by means of a weighting system in order to allow for an assessment of the strength of individual applications. The first balancing criterion is transformation of the fishery for which previously disadvantaged applicants were scored positively. The degree of investment made in the fishery by the applicant in terms of, for example, vessels, equipment and fish-processing initiative, was evaluated next. The third balancing criterion seeks to reward the use of traditional wooden deck boats (less than 10 m) if a good performance history could be demonstrated. Past fishing performance, job creation demonstrated by the applicant, historical involvement and reliance on fishing, were all evaluated and scored positively. Lastly, applicants were also scored positively if they had been resident in a traditional fishing village for at least the 10 previous years.[42] Balancing criteria were a source of immense ire for most participants. These frustrations largely related to practical arrangements preceding the allocation. The requirement to provide evidence of compliance created the perception that the process was unnecessarily laborious. Participants felt that the forms were too long, not available in all official languages and did not cater for differing literacy levels. DAFF personnel were not available to explain the forms and assist with the completion. Whilst applicants could in principle have travelled to the regional DAFF office in Mossel Bay to obtain help, not all participants had the means to travel that distance (anything between 46 km and 156 km).

The second and more pertinent set of frustrations was the requirements set by the balancing criteria themselves. Many believed that the criteria should not have been applicable to them, as they did not operate large enterprises or generate enough income to be placed in a position in which they could implement these measures. Participants highlighted the requirement for skippers/boat owners to contribute towards pension funds and medical aid schemes for crew members as one such measure. It was noted that even if these measures were implemented, the nature of the fishery made the implementation nearly impossible to manage. Various skippers indicated that although they had previously set up saving plans for crew members, their crew often failed to manage their plans and let them lapse when moving between boats. The ensuing discussion with skippers and crew alike indicated a generally held opinion that the implementation and administration of pension aid schemes and the like should be centrally managed and not rest with individual right holders.

Issues highlighted around the balancing criteria may be a symptom of another underlying problem. This fishery is currently regulated as a commercial fishery[6] despite displaying characteristics of a small-scale fishery. The formal regulation of small-scale fisheries is a new development in the South African policy landscape. The small-scale fisheries policy (No. 247 of 2012) currently in its early implementation phase, seeks to regulate small-scale and subsistence fisheries. The policy marks a paradigm shift towards a people-centred governance approach in the small-scale fishery. The policy attempts to address social justice issues raised by stakeholders by recognising the role that marine resources could play in poverty alleviation, economic development and the realisation of human rights in South Africa[43] and signals a move away from the individual rights-based approach to community-centred approaches in various small-scale fisheries.[43] Provision is made for current (individual) commercial rights holders to apply to be part of the community-based rights although current rights holders will be required to relinquish their individual rights if successful. It is important to note that the intention is for the community allocation to fall within the laid down total applied effort of the linefishery to avoid an increase in overall catch effort. Whether this aim will be successful remains unclear and communities may need to consider alternative livelihood activities to ensure sustainability (see Gammage et al.[8])

The conversations surrounding fishing rights have a distinct political slant. Regulatory frameworks and policies place emphasis on the transformation of the industry to include previously disadvantaged persons with a focus on traditional fishers. The term 'traditional' appears to be reserved for South Africans who are classified as being previously disadvantaged, effectively leading to the exclusion of fishers who, although Caucasian, have a strong family history with the fishing sectors in question. These fishers thus assume that they will be excluded from the community-based rights allocation process.

The current management structure is a significant contributory factor to many of the policy-related stressors highlighted. To obtain and keep rights, fishers are expected (as per balancing criteria) to prove continual investment in the fishery and their crew which can add an additional cost burden in a system that is already under increasing pressure because of resource scarcity, natural system variability, the regulatory framework and competition within and among fishing sectors. In comparison to other larger-scale fishing sectors operating in the area, handline fishers are not able to compete in terms of tonnage delivered, are unable to ensure consistent supply of fish, have inadequate storage facilities, and have little access to distribution routes and offset points. A historical overview of the economic conflicts in the fisheries of the South African southeast coast[44] shows that this 'conflict' is part of the historical context of the fisheries in the area.

These results show that the small-scale commercial linefishery in the area is effectively operating within a policy gap or vacuum as none of the current policies promulgated caters for their specific sectoral needs, making it extremely difficult for fishers to comply with the 'balancing criteria' that have been set out. The inability to manage this fishery in a sustainable manner may ultimately force the current commercial fishers out of the linefishery, and therefore they will be unable to meet the criteria when renewing rights. However, to date, the fishery continues to operate despite all indications that some regulatory issues have a historical context, pointing to some resilience of this fishery.

Interactions with the inshore trawl sector

The inshore trawl fishery reportedly has a severe impact on the linefishery, ranging from impacts on kob stocks to modification of the benthic habitat, with specific reference to reef health and the impact that discards have on the marine environment. The inshore trawl fishery and ensuing issues evoked some of the most emotional responses from fishers, thus reiterating the historical conflict between the two fisheries.[44,45]

The South African inshore trawl fishery was pioneered at the start of the 20th century as a mixed fishery and operates mainly between Cape Agulhas and the Great Kei River at the eastern boundary of the Agulhas Bank (and east of our study area), targeting hake and Agulhas sole.[45,46] Vessels are limited to a maximum length of 30 m and are excluded from fishing in bays; trawling has in the past generally taken place at depths of 80–110 m.[45] Trawl catches are diverse and landings include several non-target species, such as kob, as by-catch.[45,47] Although recent indications are that the inshore Cape hake and Agulhas sole stocks on the Agulhas Bank are not showing signs of collapse, the impact the sector has on the populations of 'joint product' species, particularly juvenile kob, remains a cause for concern for many of the participants.[45,48]

At the time of this study, the current total allowable catches prescribed for the inshore trawl fishery only included tonnage for the target catch, with no limit set on the amount of by-catch that may be landed. It is indicated that 42% of the total catches landed were fish species other than hake or sole, with a large portion of this by-catch marketable, with a value that comprises 1–30% of the total product value.[45] The linefishery, although not regulated by a total allowable catch, has strict minimum landing size limits imposed on kob, whereas no such restriction exists for the inshore trawl fishery. Scientific data suggest that while the catch quantities for kob and the inshore trawl sector are similar, most of the catches landed by the inshore trawl sector are undersize when considered in terms of the minimum landing size determined for the handline sector.

Participants expressed strong opinions that the inshore trawl are targeting kob. This perception has only recently been verified by data obtained from observer records and resource surveys.[44,49] Kob stock abundance predictions[39] suggest that kob stocks have displayed a small amount of recovery on the southern coast between 1987 and 2011, although the stock is still regarded as overexploited. However, this recovery is not reflected in the experiences of the participants, as they have recorded some of the worst catches in recent years. Most participants link the declining catches to inshore trawl activities, although some have also indicated that variations in SST may play a role in fish abundance and/or availability. Given the historical conflict between the two sectors, it is important to question whether participants are giving other stressors adequate consideration when attributing blame for declining catches.

The matter of by-catch in the inshore trawl industry is currently receiving attention from scientists and managers alike. Greenston[38] assessed whether an individual transferable quota system could be used to manage the inshore trawl industry on the south coast and suggested that precautionary upper catch limits be assigned to either clusters of boats or rights holders as a way to implement the individual transferable quota system in an attempt to more effectively manage by-catch. The implementation of a precautionary upper catch limit for the fishery is currently in pilot phase.[50] Whilst this implementation may increase overall ecological sustainability of inshore trawling, it is unclear whether a reduction of technical interactions will be noticed and acknowledged by the linefishery over the longer term, given the resource scarcity experienced.

Participants also indicated that trawlers are landing catches from the outer reefs before kob can migrate towards the coast in austral spring and are thus interfering with their natural migratory pattern. It becomes clear from discussions that there is some overlap in the area of operation for these fisheries.[44,45] Attwood et al.[45] indicate that the extent of the overlap between the two fisheries is not fully understood and suggest that there may be a seasonal separation in catches between the two fisheries.[44,51] The seasonal offshore-inshore migration of kob does play a role in the availability of kob to both the trawl and handline industry with trawled kob catches higher in the winter months and inshore handline catches higher in summer.[51] Noteworthy is that linefishers have increased their range by buying bigger boats which increases the possible areas of overlap in a situation in which the competition for kob is escalating.

Participants also expressed their concern regarding the impact of trawling on the greater marine and fishery system. Trawling, specifically bottom trawling, impacts on biological and structural levels of the natural system by altering habitat structure and complexity. The reduction of habitat complexity can result in increased predation on juveniles of harvested species as places of refuge for juveniles are reduced. Although the long-

term effects and impacts of repeated trawling and recovery time are not well documented[52], the existence of the long-term effects and impacts of trawling has been established for South African waters[53]. Comparative studies between unfished and heavily trawled areas in the Gulf of Mexico have demonstrated that the direct removal of biological (e.g. sponges and anemones) and sedimentary (e.g. sand waves and depressions) structures results in a reduction in habitat complexity.[52] Failure to resolve issues around 'joint product' will lead to further conflict among the handline and inshore trawl fisheries in the area.

Stressors less mentioned

Stressors less mentioned by participants, such as the impact of inadequate infrastructure (Table 2), are linked directly to social and economic conditions. It is critically important to develop an understanding of the interactions not only of changes in the physical environment but also of social, economic, cultural and political changes that occur at multiple temporal and spatial scales.[22,54-56] Hjerpe and Glaas[57] state that the omission of socio-economic stress leads to critical weakness in local adaptation strategies. It is important to recognise that while fewer participants mentioned these stressors, they are of no less importance than those stressors already discussed.

Economic stressors

The lethargic national economy formed the background to many challenges highlighted by participants as both consumers and fishers. An increase in household costs could be related to both an increase in local desires and expectations and an increase in costs at local (e.g. water, food) and global (e.g. fuel, food, supplies) scales.[56] Whilst input costs and the cost of living are constantly rising, the price of kob per kilo had stayed constant over the preceding 5 years. The fish price is determined by intermediaries who buy the fish from the fishers and resell it, and not by the fishers who carry the input costs. This is not only true for this group of fishers, but also for fishers in other areas of the world. Tuler et al.[54] comment in relation to fishers who participate in commercial fishing activities in New England (USA) that fuel insurance, gear and bait costs have all increased whilst fish prices have remained constant. A study conducted in Thailand describes a similar situation, namely that incomes in coastal communities are not keeping up with rising costs.[56]

The retail price of some alternative target species is considerably lower than that of kob, and input costs to harvest these species are significantly higher. This disparity is particularly applicable to silvers, which are harvested about 30 km away from port. High start-up costs make it difficult for new entrants – boats and motors are expensive, a towing vehicle is required for ski boats, and most fishers do not have the necessary capital at their disposal. Banks are unwilling to lend money to fishers who do not have a consistent income because of legislation that requires proof of steady income, making it difficult to access credit from banks.

Many participants indicated that they have borrowed money for fuel and bait from intermediaries operating in the area. This lending adds to an already perilous situation – many were not landing decent catches and did not necessarily make enough to cover running costs to sustain livelihoods. Repaying loans places an additional burden on the skipper/boat owner, as they bear sole responsibility for running costs. One middleman maintained that he lent money to fishers in cognisance of the fact that he would not have any product to sell if fishers were unable to go to sea.

Fishers operating boats with diesel engines feel that they are in a better position than the fishers operating ski boats with outboard motors, as diesel is subsidised by the government via a tax deduction and petrol is not. However, this saving could be offset, because despite the use of a diesel engine being cheaper on a day-to-day basis, maintenance is costlier. Many participants indicated that their financial situation resulted in the neglect of regular maintenance, which led to major defects that they were unable to repair themselves and cessation of their fishing activities until repairs had been carried out. This decision-making results in individuals and households becoming more vulnerable to stressors in the biophysical environment over longer time periods.[45]

Socio-economic stressors

Poverty and fisheries are intrinsically linked when dealing with a development discourse in which the enduring narrative is that 'people are poor because they fish' with a dependence on fishing seen as a cause of poverty. However, no clear and systemic relationship between poverty and fisheries has yet been defined for the southern Cape region and fishery households are not necessarily the poorest of the poor.[48] Small-scale fishing (in particular) is a livelihood that is characterised by a tradition of adapting to changes in both social and natural environments.[58] Today, rural coastal communities are subject to new types of social and economic pressures.[58] Possible effects from additional socio-economic pressures become increasingly clear when considering Vermaaklikheid and, to a lesser extent, Melkhoutfontein. Vermaaklikheid and Melkhoutfontein are previously disadvantaged communities in which the influence of apartheid on the spatial development of the South African landscape is apparent.[59] Prevailing socio-economic conditions in these communities are not always favourable, and there is a large dependence on government grants and services. There are some important contrasts and similarities between the two communities, with the Vermaaklikheid community being the most similar to a stereotypical fishing community.[60]

Vermaaklikheid (population approximately 400) has only two untarred access roads and is situated a fair distance (42 km) from its closest economic hub, Riversdale. In contrast, the town of Melkhoutfontein is considerably bigger (population approximately 2500), and geographically closer (11 km) to its closest economic hub, Still Bay, with greater accessibility to infrastructure in terms of access roads and transport. Census 2011 data from the two towns indicate lower education levels in Melkhoutfontein and Vermaaklikheid when compared to the other towns in the research area. Remote rural areas may be typified by high transaction costs, transport and communications systems that are impaired, the limitation or absence of access to markets and a low provision of government services and infrastructure.[61] This is reflected in the case of Vermaaklikheid, as all the stressors mentioned by participants align with these general categories. It is clear from the interviews that factors arising from the geographical location and infrastructure of Vermaaklikheid have a distinct impact on the socio-economic conditions and day-to-day functioning of the community. These factors include a lack of access to public services and transport, no easy access to shops and no public schools (although a privately funded school has been established by one of the residents to provide this service to the community). These characteristics may be true for all the communities in the region to a certain extent as the distance to the nearest metropolis (~400 km) also lends a certain amount of remoteness to the area, with the interaction between the region and the metropolis pointing to a classic core-periphery pattern.[62]

The relative remoteness of the area also influences available formal and informal job opportunities. Although official statistics show that the unemployment rate in the area is lower than national and provincial averages, it must be noted that unemployment statistics only consider active job seekers. Fishers who are not fishing are not necessarily actively seeking other employment and do not necessarily regard themselves as being unemployed or a job seeker. These employment statistics do not take discouraged work seekers and those who are surviving on government grants into account, thus the unemployment rate is likely to be higher than the official rate.

Conclusion: The necessity of a systems approach on a small scale

Single stressors and their impacts at a localised scale on fishers in a geographically distinct, but relatively small, area of the southern Cape are described here. Although detailed interactions and inter-relationships of the various stressors highlighted remain unclear at present, it is possible to highlight some examples of multiple-stressor interactions that have become apparent through the research process.

Increases in the fuel price lead to a decrease in disposable income and affect the fishers' ability to carry out maintenance on their boats. This in turn may lead to a compromise in safety standards, resulting in an increased susceptibility to weather stressors, for example if the engine is not performing optimally, navigation of the boat under difficult sea conditions is impaired. In this case, an economic stressor has effectively resulted in a safety stressor, thereby making fishers and their crew more vulnerable to weather stressors. However, the increased input costs such as fuel also have a dampening effect on effort and may lead to a reduction of overfishing. Decreased effort may lead to a decrease in income and thus the economic situation of the fisher and crew may continually worsen in the absence of other income-generating opportunities.

The fishers from Mossel Bay operate deck boats and have overcome overfishing challenges in their immediate area of operation by increasing their range. The bigger boats allow these fishers to operate in rougher sea conditions, but they also require a longer window of good weather because fishers stay at sea for several days in a single trip. The overfishing stressor has thus led to a novel vulnerability to weather conditions on the scale of multiple days, putting additional pressure on fish stocks previously not exploited by this sector. By increasing their ranges, the linefishery is overlapping with the inshore trawl fishery, further fuelling the long-standing conflict between the two fisheries.

The two examples above highlight the complexity of the fishery system in the southern Cape and illustrate how multiple stressors and feedback loops at various scales can interact to form a complex system at various geographical scales. Although it was not within the scope of this study to investigate all these linkages and interactions, the examples of multi-stressor interactions highlighted are an indication that the interactions found and described by Bennett et al.[56] also exist in the South African context. Strategies put in place in response to stressors discussed here are further examined in Part 2, Gammage et al.[8]

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Authors' contributions

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References

1. Benguela Current Commision. Benguela Current Commission [homepage on the Internet]. c2013 [cited 2016 Jul 15]. Available from: http://www.benguelacc.org/index.php/en/about/the-bclme
2. Hutchings L, Van der Lingen CD, Shannon LJ, Crawford RJM, Verheye HMS, Bartholomae CH, et al. The Benguela Current: An ecosystem of four components. Prog Oceanogr. 2009;83(1–4):15–32. http://dx.doi.org/10.1016/j.pocean.2009.07.046.
3. Jarre A, Hutchings L, Kirkman S, Kreiner A, Tchipalanga P, Kainge P, et al. Synthesis: Climate effects on biodiversity, abundance and distribution of marine organisms in the Benguela. Fish Oceanogr. 2015;24(Suppl 1):122–149. http://dx.doi.org/10.1111/fog.12086.
4. Griffiths MH. Long-term trends in catch and effort of commercial linefish off South Africa's Cape Province: Snapshots of the 20th century. S Afr J Mar Sci. 2000;22(1):81–110. http://dx.doi.org/10.2989/025776100784125663.
5. Blamey LK, Shannon LJ, Bolton JJ, Crawford RM, Dufois F, Evers-King H, et al. Ecosystem change in the southern Benguela and the underlying processes. J Mar Syst. 2015;144:9–29. http://dx.doi.org/10.1016/j.jmarsys.2014.11.006.
6. South African Department of Environmental Affairs and Tourism (DEAT). Policy for the allocation and management of commercial fishing rights in the traditional line fishery. Cape Town: DEAT; 2005. p.1–7.
7. Adger WN. Vulnerability. Glob Environ Chang. 2006;16(3):268–281. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006.
8. Gammage LC, Jarre A, Mather C. A case study from the southern Cape linefishery 2: Considering one's options when the fish leave. S Afr J Sci. 2017;113(5/6), Art. #2016-0254, 10 pages. http://dx.doi.org/10.17159/sajs.2017/20160254.
9. O'Brien K, Sygna L, Haugen JE. Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. Clim Change. 2004;64(1–2):193–225. http://dx.doi.org/10.1023/B:CLIM.0000024668.70143.80.
10. Bunce M, Brown K, Rosendo S. Policy misfits, climate change and cross-scale vulnerability in coastal Africa: How development projects undermine resilience. Environ Sci Policy. 2010;13(6):485–497. http://dx.doi.org/10.1016/j.envsci.2010.06.003.
11. Reid P, Vogel C. Living and responding to multiple stressors in South Africa – Glimpses from KwaZulu-Natal. Glob Environ Chang. 2006;16(2):195–206. http://dx.doi.org/10.1016/j.gloenvcha.2006.01.003.
12. Eakin H, Luers AL. Assessing the vulnerability of social-environmental systems. Annu Rev Environ Resour. 2006;31(1):365–394. http://dx.doi.org/10.1146/annurev.energy.30.050504.144352.
13. Füssel HM, Klein RJT. Climate change vulnerability assessments: An evolution of conceptual thinking. Clim Change. 2006;75(3):301–329. http://dx.doi.org/10.1007/s10584-006-0329-3.
14. Ziervogel G, Calder R. Climate variability and rural livelihoods: Assessing the impact of seasonal climate forecasts in Lesotho. Area. 2003;35(4):403–417. http://www.jstor.org/stable/20004345.
15. Eriksen S, Næss L, Klein R, Hammill A, Robledo C, O' Brien K. Portfolio screening for mainstreaming adaptation to climate change. Paper presented at: "Climate or development?"; 2005 October 28–29; Hamburg, Germany.
16. Ziervogel G, Bharwani S, Downing TE. Adapting to climate variability: Pumpkins, people and policy. Nat Resour Forum. 2006;30(4):294–305. http://dx.doi.org/10.1111/j.1477-8947.2006.00121.x.
17. Eriksen S, Silva J. The vulnerability context of a savanna area in Mozambique: Household drought coping strategies and responses to economic change. Environ Sci Policy. 2009;12(1):33–52. http://dx.doi.org/10.1016/j.envsci.2008.10.007.
18. O'Brien KL, Leichenko RM. Double exposure: Assessing the impacts of climate change within the context of economic globalization. Glob Environ Chang. 2000;10:221–232. http://dx.doi.org/10.1016/S0959-3780(00)00021-2.
19. Turner B, Kasperson R, Matson PA, McCarthy JJ, Corell RW, Christensen A, et al. A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci USA. 2003;100(14):8074–8079. http://dx.doi.org/10.1073/pnas.1231335100.
20. Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, et al. A place-based model for understanding community resilience to natural disasters. Glob Environ Chang. 2008;18(4):598–606. http://dx.doi.org/10.1016/j.gloenvcha.2008.07.013.
21. Moloney CL, Fennessy ST, Gibbons MJ, Roychoudhurye A, Shillington FA, Von der Heydene BP, et al. Reviewing evidence of marine ecosystem change off South Africa. Afr J Mar Sci. 2013;35(3):427–448. http://dx.doi.org/10.2989/1814232X.2013.836135.
22. Mead A, Griffiths MH, Branch GM, McQuaid CD, Blamey LK, Bolton J, et al. Human-mediated drivers of change — Impacts on coastal ecosystems and marine biota of South Africa. Afr J Mar Sci. 2013;35(3):403–425. http://dx.doi.org/10.2989/1814232X.2013.830147.
23. Hutchings L, Jarre A, Lamont T, Van den Berg M, Kirkman S. St Helena Bay (Southern Benguela) then and now: Muted climate signals, large human impact. Afr J Mar Sci. 2012;34(4):559–583. http://dx.doi.org/10.2989/1814232X.2012.689672.
24. Howard JAE, Jarre A, Clark A, Moloney CL. Application of the sequential t-test algorithm for analysing regime shifts to the southern Benguela ecosystem. Afr J Mar Sci. 2007;29(3):437–451. http://dx.doi.org/10.2989/AJMS.2007.29.3.11.341.

25. Blamey LK, Howard JAE, Agenbag J, Jarre A. Regime-shifts in the southern Benguela shelf and inshore region. Prog Oceanogr. 2012;106:80–95. http://dx.doi.org/10.1016/j.pocean.2012.07.001.

26. Perry RI, Barange M, Ommer RE. Global changes in marine systems: A social-ecological approach. Prog Oceanogr. 2010;87(1–4):331–337. http://dx.doi.org/10.1016/j.pocean.2010.09.010.

27. Ommer RE, Perry RI, Neis B. Bridging the gap between social and natural fisheries science: Why is this necessary and how can it be done? In: Nielsen J, Dodson JJ, Friedland K, Hamon TR, Musick J, Verspoor E, (editors). Reconciling fisheries with conservation: Proceedings of the Fourth World Fisheries Congress. Symposium 49. Bethesda, MD: American Fisheries Society; 2008. p. 177–185.

28. Jarre A, Ragaller, SM, Hutchings L. Long-term, ecosystem-scale changes in the southern Benguela marine pelagic social-ecological system: Interaction of natural and human. Ecol Soc. 2013;18(4), Art. #55, 15 pages. http://dx.doi.org/10.5751/ES-05917-180455.

29. Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avery KB, et al, editors. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York: Cambridge University Press; 2007. p. 1–996.

30. Bennett NJ, Dearden P, Murray G, Kadfak A. The capacity to adapt?: Communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. Ecol Soc. 2014;9(2), Art. #5, 20 pages. http://dx.doi.org/10.5751/ES-06315-190205

31. Rouault M, Penven P, Pohl B. Warming in the Agulhas Current system since the 1980's. Geophys Res Lett. 2009;36(12):2–6. http://dx.doi/10.1029/2009GL037987.

32. Rouault M, Pohl B, Penven P. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. Afr J Mar Sci. 2010;32(2):237–246. http://dx.doi.org/10.2989/1814232X.2010.501563.

33. Roy C, Van der Lingen C, Coetzee J, Lutjeharms J. Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela. Afr J Mar Sci. 2007;29(3):309–319. http://dx.doi.org/10.2989/AJMS.2007.29.3.1.331.

34. Perry RI, Ommer RE. Scale issues in marine ecosystems and human interactions. Fish Oceanogr. 2003;12(4/5):513–522. http://dx.doi.org/10.1046/j.1365-2419.2003.00254.x.

35. Coetzee JC, Van der Lingen C, Hutchings L, Fairweather T. Has the fishery contributed to a major shift in the distribution of South African sardine? ICES J Mar Sci. 2008;65(9):1676–1688. http://dx.doi.org/10.1093/icesjms/fsn184.

36. Watermeyer K. Ecosystem implications of the recent southward shift of key components in the southern Benguela [PhD thesis]. Cape Town: University of Cape Town; 2015. Available from: http://www.eafsa.uct.ac.za/publications-2015.

37. Duggan GL. In the realm of the Kob Kings: Rethinking knowledges and dialogue in a small-scale fishery [master's dissertation]. Cape Town: University of Cape Town; 2012. Available from: http://hdl.handle.net/11427/11942.

38. Greenston J. Assessing the suitability of an individual transferable quota system to address unregulated by-catch in South Africa's inshore trawl fishery [master's dissertation]. Cape Town: University of Cape Town; 2013. Available from: http://hdl.handle.net/11427/4749.

39. Winker H, Kerwath SE, Attwood CG. Report on age-structured stock assessments and the simulation of the impacts of various fisheries management options for the South African linefishery. Report no. LSWG II. Cape Town: Department of Agriculture, Forestry and Fisheries; 2014.

40. Van Sittert L, Branch G, Hauck M, Sowman M. Benchmarking the first decade of post-apartheid fisheries reform in South Africa. Mar Policy. 2006;30(1):96–110. http://dx.doi.org/10.1016/j.marpol.2005.06.012.

41. Marine Living Resources Act (Act No. 18 of 1998) of South Africa.

42. South African Department of Agriculture, Forestry and Fisheries (DAFF). Draft revised traditional linefish policy on the allocation and management of fishing rights: 2013. Cape Town: DAFF; 2013. p.1–14.

43. Sowman M, Sunde J, Raemaekers S, Schultz O. Fishing for equality: Policy for poverty alleviation for South Africa's small-scale fisheries. Mar Policy. 2014;46:31–42. http://dx.doi.org/10.1016/j.marpol.2013.12.005

44. Visser N. The origins of the present: Economic conflicts in the fisheries of the South African south east coast, circa 1910 – 1950. Marit Stud. 2015;14(1):9. http://dx.doi.org/10.1186/s40152-015-0029-6

45. Attwood CG, Petersen SL, Kerwath SE. Bycatch in South Africa's inshore trawl fishery as determined from observer records. ICES J. Mar. Sci. 2011;68(10):2163–2174 http://doi.dx.org/10.1093/icesjms/fsr162

46. South African Department of Environmental Affairs and Tourism (DEAT). General policy on the allocation and management of long term commercial fishing rights. Cape Town: DEAT; 2005. p.1–48.

47. Walmsley SA, Leslie RW, Sauer WHH. Bycatch and discarding in the South African demersal trawl fishery. Fish Res. 2007;86(1):15–30. http://dx.doi.org/10.1016/j.fishres.2007.03.002

48. Anderson R, Auerswald L, Butterworth D, Cockcroft A, Cooper R, Coetzee J, et al. Status of the South African marine fishery resources. Cape Town: Department of Agriculture, Forestry and Fisheries; 2014. p.1–77.

49. South African Department of Agriculture, Fisheries and Forestry. 2009 Performance review of fishing right holders – Clusters C & D. Cape Town: DAFF; 2012. p.1–85.

50. Greenston JD, Attwood, CG. Assessing the feasibility of a bycatch co-management programme in South Africa's inshore trawl fishery [document on the Internet]. c2013 [cited 2016 Nov 24]. Available from: http://www.rfalliance.org.za/wp-content/uploads/2014/09/RFA-Bycatch-Management-Report.pdf

51. Attwood C, Booth T, Kerwath S, Mann B, Marr S, Bonthuys J, et al., editors. A decade after the emergency: Proceedings of the 4th LineFish Symposium. WWF South Africa Rep Series – 2013/Marine/001. Cape Town: WWF South Africa; 2013.

52. Grekov AA, Pavlenko AA. Comparison of the longline and trawl groundfish fishery in the Barents Sea to develop proposals for the sustainable use of the marine bio-resources in the Barents Sea. Moscow-Murmansk: The World Wildlife Fund; 2011.

53. Atkinson LJ, Field J, Hutchings L. Effects of demersal trawling along the west coast of southern Africa: Multivariate analysis of benthic assemblages. Mar Ecol Prog Ser. 2011;430:241–255. http://dx.doi.org/10.3354/meps08956.

54. Tuler S, Agyeman J, Da Silva PP, LoRusso KR, Kay R. Assessing vulnerabilities: Integrating information about driving forces that affect risks and resilience in fishing communities. Hum Ecol Rev. 2008;15(2):171–184.

55. Perry RI, Ommer RE, Barange M, Jentoft S, Neis B, Sumaila UR. Marine social-ecological responses to environmental change and the impacts of globalization. Fish Fisheries. 2011;12(4):427–450. http://dx.doi.org/10.1111/j.1467-2979.2010.00402.x

56. Bennett NJ, Dearden P, Peredo, AM. Vulnerability to multiple stressors in coastal communities: A study of the Andaman coast of Thailand. Clim Dev. 2015;7(2):37–41. http://dx.doi.org/10.1080/17565529.2014.886993.

57. Hjerpe M, Glaas E. Evolving local climate adaptation strategies: Incorporating influences of socio–economic stress. Mitig Adapt Strateg Glob Chang. 2012;17(5):471–486. http://dx.doi.org/10.1007/s11027-011-9337-3.

58. Salmi P. Rural pluriactivity as a coping strategy in small-scale fisheries. Sociol Rural. 2005;45(1–2):22–36. http://dx.doi.org/10.1111/j.1467-9523.2005.00288.x

59. Lemon A. The apartheid city. In: Lemon A. Homes apart: South Africa's segregated cities. Cape Town: David Philip; 1991. p.1–26.

60. Isaacs M. A social coastal fisheries policy for South Africa? Subsistence fisheries co-management for sustainable livelihoods and poverty alleviation. PLAAS Policy Brief no. 24. Cape Town: PLAAS; 2006. p. 1–8.

61. Béné C, Friend RM. Poverty in small-scale fisheries: Old issue, new analysis. Prog Dev Stud. 2011;11(2):119–144. http://dx.doi.org/10.1177/146499341001100203

62. Baldwin R, Forslid R, Martin P, Otaviano GIP, Robert-Nicoud F. The core-periphery model: Key features and effects. Brakman S, Heijdra BJ, editors. In: The monopolistic competition revolution in retrospect. New York: Cambridge University Press; 2004. p. 213–235.

A case study from the southern Cape linefishery 2: Considering one's options when the fish leave

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Fishers in the small-scale, commercial linefishery in the southern Cape, South Africa, are exposed to variability and change in the marine social-ecological system of which they are a part. Faced with multi-scalar changes within this complex system, fishers employ a wide range of strategies in reaction to change. As part of a broader study of stressors that bring about change in these systems, this contribution examines the fishers' responses to these changes and is based on a participant-led, semi-structured interview process of skippers/boat owners, crew, processors and spouses/partners, in six communities in the southern Cape region, and has been supplemented with appropriate secondary data. The results are discussed using a resilience framework. The data were initially considered thematically by stressor, but results identified that a place-based analysis was equally important. Three major groupings were identified: (1) fishers who adapt and show clear business-orientation, (2) fishers who cope, and (3) fishers who react and are thus caught in a poverty trap. In addition to place-specific history, local feedback loops and indirect effects need to be better accounted for to understand these responses to change at various scales. The results of this study are expected to contribute to the basis of scenario planning in the region.

Significance:

- Analysis of responses to change strategies provides insight into resilience displayed as well as costs and benefits of strategies.
- The description of strategies provides valuable insights into the decision-making processes in linefishery in the southern Cape.
- Cognitive and reflexive decision-making processes are shaped by individuals' and communities' experiences of past and present.
- Practical implications of actions are not always the overriding concern in decision-making, which underscores the importance and influence of culture.
- These results provide important insights into a system that is not well described, and highlight knowledge gaps that require further context-specific research.

Introduction

The failure to recognise integrated social-ecological systems in the marine environment has resulted in the depletion of ocean resources, which negatively impacts resource-dependent communities.[1-4] Coastal communities that rely on fisheries are subjected to an array of political, regulatory, socio-economic and biophysical stressors[5], and remain exposed to multiple stressors[6-9] at various temporal and geographical scales. Response strategies to these changes, broadly classified as either reacting, coping or adapting (see supplementary material for a definition of concepts used in this paper), are also influenced by actions at multiple scales.[10-12] Fishing as a livelihood is complex and dynamic, and concerns not only individuals but also households or groups attempting to make a living to meet various nutritional and economic needs.[13,14]

The livelihood perspective can be used to analyse poverty, vulnerability and marginalisation at the geographical scale of experience.[15] A contemporary view of the livelihood perspective suggests that livelihoods are multidimensional and cover economic, political, cultural, social and ecological aspects of the system. Modern livelihoods are based on a range of assets, income opportunities, as well as product and labour markets located in different places and scales that also interact with other places.[16] Analyses of livelihoods can free us from characterising people in singular roles (such as fishers, farmers or housewives) and instead enable us to recognise that, in order to survive in today's challenging conditions, people and households can hold diverse and various sources of support.[17] Very few livelihood studies have addressed the issue of how peoples' livelihoods can cope and recover from stressors and perturbations; such studies require coupled resilience analyses which also are absent.[18]

The resilience perspective presents a lens through which to not only explore stresses and shocks, but also understand livelihood dynamics. Resilience in this context refers to the capacity of social units to deal with changes in the system whilst continuing to develop with a future-oriented approach and is used to characterise the system's ability to deal with change on various scales.[19,20] Change and renewal may furthermore serve to nurture novelty and innovation in those social-ecological systems that are deemed to be resilient.[13,20] Resilience thinking demands that 'how' and 'whether' adaptive responses are able to maintain long-term functioning of social-ecological systems, while also examining predictability.[12,18] The resilience displayed by a system can be both a positive and negative attribute – whilst resilience in the system will ensure continued existence of the social units as they absorb multiple perturbations, systems that are too resilient may continue to cope and mitigate and resist adapting over the long term, even though long-term adaptation would result in a more desirable state of the system.[11] It is important to discern amongst social adaptations that serve to weaken long-term social-ecological resilience (amplifying responses that result in, for example, acceleration of resource depletion) and adaptations that result in increasing

social-ecological resilience in the longer term (dampening responses that result in, for example, a decrease in resource depletion).[21] The recognition of whether and how social, economic or contextual circumstances may enable different responses is expected to provide insights into discerning which strategies can be adopted in line with conservation and/or development objectives.[22] The concept of resilience can be used as an analytical approach to further the understanding of livelihoods with specific consideration given to the dynamics of how people make a living, as well as the various characteristics of complex adaptive systems with reference given to scale and uncertainty.

The Benguela Current Large Marine Ecosystem, an eastern boundary current system, sustains important fisheries for Angola, Namibia and South Africa.[23] This highly variable ecosystem consists of four shelf subsystems which include the Agulhas Bank subsystem off the southern Cape coast.[24,25] This study places the focus on the small-scale commercial linefishery operating on the inshore Agulhas Bank. This boat-based, multi-user and multi-area fishery exploits 50 commercially important fish species across South Africa.[26,27] A variety of anthropogenic stressors including resource scarcity, poor socio-economic conditions and policy and regulatory challenges affect the inshore social-ecological system of the area. These stressors make small-scale commercial fishers and their communities increasingly vulnerable to local and global changes.[28] Fishers will in the future need to cope with and adapt to multi-scalar social and ecological changes (discussed in a paired paper in this issue, Gammage et al.[29]) and communities will be required to enhance change response strategies to achieve resilience.

The fishery in this area had not had a productive or lucrative fishing season for 4–5 years prior to the study as fishers had been unable to harvest the primary target species in quantities that provide financial sustainability. Participants regard silver kob (*Argyrosomus inodorus*), commonly referred to as kob, as their most economically viable and sustainable target species. Although other species such as silvers/carpenters (*Argyrozona argyrozona*), red fish (such as red roman, *Chrysoblephus laticeps*) and sharks are targeted in the absence of kob, these species are not profitable nor conducive to long-term sustainability of livelihoods. Harvesting of alternative species is a way to keep things 'ticking over', as the high-value, slow-growing red fish are scarce and fishers must travel approximately 30 km offshore to catch the relatively low-value silvers. Resource scarcity has led to a decrease in the number of active boats.[30] The analyses presented focus on the responses to the following questions:

- What strategies do fishers' implement in response to the changes caused by the stressors that have been identified?
- Are there any groupings of strategies, relevant for future management, that can facilitate increased resilience in this area?

Research area and methodology

Participant-led research was carried out in the small-scale commercial linefishery of the southern Cape. The research area encompasses the communities of Mossel Bay, Gouritsmond, Still Bay, Melkhoutfontein, Vermaaklikheid and Witsand (see Figure 1 of Gammage et al.[29]). The interviews took place between July 2013 and February 2014. A total of 50 individuals comprising skippers, boat owners, crew, members from associated industry and spouses/partners participated. The participants dictated the scope and structure of the semi-structured interviews, which aimed at understanding stressors on their livelihoods and responses to these stressors. More details on the research area and methodology are provided in the paired paper.[29]

Results and discussion

Box 1 provides a few selected quotes (organised per theme) from the study respondents to contextualise fishers' experiences. Important context for the results is that fishing rights conditions prohibit fishers from holding other formal alternative sources of income; the range of economic activities and employment opportunities are limited; and there is a high dependence on the national social grant system by members from poorer communities such as Vermaaklikheid and Melkhoutfontein.[30]

Current change response strategies for the overall research area are provided in Tables 1 and 2. Data were initially considered thematically, as shown in these tables, but subsequent analyses identified a spatial variation in responses between different towns.

Box 1: Pertinent statements, arranged according to theme, from participants in the small-scale commercial linefishery in the southern Cape regarding their response to recent change

Increase and/or decrease in effort

I'm on the go; I have a system that works for me. There are times I will have four days in a month that I go to sea instead of 15 times. It does not help to go to sea every day. – Skipper, Witsand (2014)*

Other employment (formal and informal)

We as fishermen may not have another income, but some fishermen help with construction projects because they know if there is fish to be caught, they can go to sea. – Rights holder, Still Bay (2013)*

Sam himself did the spray jobs this year so we employed one or two guys this year to help us. We try when (or what is supposed to happen), when the fishing is good, we are supposed to pack away money. Literally, Sam ties his own boat up, um say from July to especially end of August. And that time he will do building and refurbishments. And then he will get his crew in to help with the fibre glassing and spraying and that is how it is actually supposed to work. – Spouse, Still Bay (2013)

Spousal income

Most of the women have a sort of a job. Most of them. – Skipper, Vermaaklikheid (2014)

Migration (temporary)

The thing is that as the fish become scarce, then the fisherman takes his basket and he goes to Mossel Bay or Knysna, so that guy is not tied to the boat, you understand, if it gets bad then he walks. – Skipper, Witsand (2014)*

Leave fishery

Financing is the main reason [for choosing to exit the fishery] *in the entire industry. It just costs too much money. If only the state could subsidise the fuel, even if only by 50c, it would make a man's life much easier. And this is really the biggest thing. Financing. No one has money today to go to sea.* – Skipper, Still Bay (2013)*

Change of fishing strategy

We have had to change our way of fishing, the ski boat's running costs are ridiculously high (as we know), and the brunt of us are onto deck boats, which are tied up in the harbour and currently we are fishing 81 nautical miles out on the Alphard Banks because that is the only place that we can edge out a living. – Skipper, Mossel Bay (2014)

Downscaling

Suppose I catch 50 kg with a small boat and I caught 50 kg on the big boat then it means that I do not make money when I use the big boat. – Skipper, Melkhoutfontein (2014)*

**Responses translated to English from Afrikaans*.

This resulted in three main groupings of responses: communities of fishers – from Mossel Bay, Witsand and Gouritsmond – who appear to be adapting in the long term ('business-oriented fishers'); those, from Still Bay and Melkhoutfontein, who are coping ('coping fishers'); and those, from Melkhoutfontein, who are reacting ('reacting fishers'). The first group indicated that 'riding out the storm' and/or changing fishing strategy were preferred strategies. The second group indicated that their most widely implemented livelihood strategy was 'riding out the storm', with many also seeking alternative informal employment whilst decreasing catch effort. Fishers from Vermaaklikheid mostly chose to 'ride out the storm' whilst seeking alternative informal employment and relying on spousal income and/or social grants.

Mossel Bay, Witsand and Gouritsmond: The business-oriented fishers

This group of fishers was characterised by a change in fishing strategy classified as diversification (craft, target areas, leaving fishery and engaging in alternative industry); intensification of fishing effort; and 'riding out the storm' (Table 3). This response was largely made possible by effective operation of the fishery as a small business enterprise.

Table 1: Response strategies for which a positive response was recorded by more than 40% of the participants

Strategy (theme)	Percentage of participants	Characteristics of strategy (from fisher data)
'Ride out the storm'	82%	Try to 'get by' on a day-to-day basis Proceed to sea when they have money for input costs (bait and diesel)
Other (informal) employment	62%	Used in conjunction with other strategies like 'riding out the storm' Range of informal activities engaged in include wood gathering and gardening Additional employment opportunities arise in peak holiday periods Some participants engage in activities that draw on previous experience, e.g. boat maintenance, panel beating, bee-keeping. The crew is employed should assistance be required.
Spousal income	48%	An important but undervalued strategy Spouse/partner often provides stable income through formal and informal employment Government social grants also provide an income source (e.g. child/disability grants)

Table 2: Response strategies for which a positive response was recorded by less than 25% of participants

Strategy (theme)	Percentage of participants	Characteristics of strategy (from fisher data)
Decrease effort	24%	Only proceed to sea when profitable catch guaranteed (accomplished by relying on feedback from other fishers as well as own knowledge of local weather and sea conditions) Allows fishers to stay engaged in fishery as fishing is seen as a way of life, not just a job
Change fishing strategy	20%	Implement a long-term or permanent change to the way they fish Change their fishing craft (ski boats to deck boats, outboard motors to inboard diesel engine), which reduces input costs such as fuel, and allows for an increase in range and decrease in maintenance costs. Mainly Mossel Bay fishers engage in this strategy.
Other employment (formal)	14%	Fishers indicate that local employers (such as builders) do not want to hire fishers as they are not reliable (will abandon job as soon as fishing is viable again) Fishers are not permitted by conditions of rights to hold alternative employment
Leave fishery	16%	3 participants had already left fishery 5 indicated they were considering it Indications are the fishers leave when it becomes too difficult to 'make ends meet'
Downscale	11%	Larger boats with outboard motors may go faster and further, but with elevated associated running costs which is a burden to the boat owner/skipper Participants indicated that they opted to buy small boats and motors to counteract the larger costs of larger boats
Migrate (temporarily)	12%	Travel to Cape Town to catch snoek (*Thyrsites atun*) in winter (kob off-season) Mostly crew who engage in this strategy as they can move between management areas Most participants unwilling to engage in this strategy as it is not necessarily financially viable (additional costs of 'second household') Participants also indicate unwillingness to migrate temporarily because of a sense of wanting to be 'home'
Increase effort	12%	Accomplished by targeting slower-growing reef (red) fish in absence of kob

Table 3: Change responses implemented by the fishers from Mossel Bay, Gouritsmond and Witsand: business-oriented fishers

	Role	Town			Strategy									
	Skipper/boat owner/ right's holder	Gouritsmond	Witsand	Mossel Bay	'Ride out the storm'	Increase effort	Decrease effort	Other employment – formal	Other employment – informal	Migrate (temporarily)	Leave fishery	Spousal income	Change fishing strategy	Downscale
Participant 8	•			•	•	•				•		•	•	
Participant 41	•			•	•								•	
Participant 42	•			•	•								•	
Participant 43	•			•	•								•	
Participant 44	•			•	•								•	
Participant 31	•	•						•			•			
Participant 50	•		•		•		•		•			•	•	
Total	7	1	1	5	6	1	1	1	1	1	1	2	6	0

Diversification as a fishing strategy took the form of a change in fishing craft from ski boats to deck boats, as well as a change in target species. Ski boats place constraints on the volume of landed catches, provide no space for ice or refrigeration, and pose operational constraints in terms of sea state and duration of fishing trips. In contrast, the range of deck boats is significantly further and they can operate in rougher weather while extending the duration of trips. However, deck boats are slow, require large capital investment and need a longer window of favourable fishing conditions. Fishers who transitioned to deck boats attributed the decision to high running costs associated with outboard engines normally fitted on ski boats. Deck boats have diesel engines and diesel is subsidised for certain sectors with users able to reclaim value-added tax (VAT). Diesel engines, although more expensive to maintain, require less regular maintenance than outboard motors and users maintained that these engines are less 'temperamental'. In the present economic climate, benefits of using diesel engines far outweighed the risks according to these fishers. Additionally, the change to deck boats resulted in extending fishing activities to habitats such as the Alphard Bank (see Figure 1 in Gammage et al.[29]), previously unexploited by these fishers from Mossel Bay. At the time of the study, only a single linefisher from Mossel Bay still utilised a ski boat, although this boat was also fitted with an inboard diesel engine.

The use of deck boats was not only a form of diversification, but also an example of 'intensification of effort', generally linked to fishing 'harder' on the same stocks in an area.[31] This intensification is depicted through the extension of fishing trips on both temporal and spatial scales, as well as fishing in poor conditions that could increase safety risks. The long-term sustainability of this strategy is questioned as intensified effort may impact the biophysical environment negatively as a result of increased fishing pressure on already fully- or over-exploited stocks.[27,32]

It is not easy to attribute definitive reasons for diversification and restructuring taking place in the Mossel Bay linefishery. Sufficient capital was required for these craft fishers to diversify. The diversification of craft was a business-oriented decision, indicative of the way that the participants approached fishing activities. Participants acknowledged that to keep fishing, their fisheries needed to be managed as a business. Why this business acumen was not evident throughout the study area remains unclear. In terms of Mossel Bay, it may be that competition stemming from the proximity of more industrialised fisheries, notably bottom trawling[33], has forced the linefishery in the area to adopt more structured business practices to secure and maintain viable market share. The relatively advanced state of infrastructure development encountered in Mossel Bay is also important as Mossel Bay is the only town in the research area that has suitable berthing for deck boats. The context and scale of the town appears to have an influence on how fishers choose to manage rights.

It is relevant to view the capacity for informed decision-making and business acumen in the context of South Africa's history of racial segregation and its after-effects. This group of participants comprised white men who likely had had access to secondary school education. Most of these fishers would have had to do compulsory military service upon leaving school, exposing them to other skills and environments. Issues of race, education and gender may play a very important role in how this group can respond to change. However, the analysis of individual life histories and their impacts is not within the scope of this paper. It remains important that the role these histories play in decision-making and in the ability to implement certain strategies be acknowledged and further explored in future.

Apart from the general business acumen displayed by this group, the remaining ski-boat operator intensified his effort by targeting slow-growing, high-value reef fish through spending every available moment at sea. He also displayed contradictory characteristics in terms of his willingness to work with others. To a certain extent, this participant was a 'lone wolf', as his work ethic and intensity of effort set him apart from most participants. He did not overtly display cooperation with other fishers to make 'finding the fish' easier and did not appear to benefit from the support of social networks. The ski-boat operator from Mossel Bay also adapted his fishing methods by utilising a technique called *riemhou* that 'involves the skipper keeping the boat positioned directly above the swimming shoal while it feeds on the edge of the reef'[34(p.12)]. This method requires great skill and is becoming increasingly popular amongst younger skippers. Opponents to the method feel that continuously running engines chase the fish away. However, this strategy remained highly successful, albeit costlier, for those fishers utilising the method.

While all the Mossel Bay deck-boat fishers adapted in the longer term, they did not appear to have alternative future strategies in place. This absence came to the fore when voicing concerns over the outcome of the medium-term fishing rights allocation process of 2013 (FRAP 2013)

that was ongoing during the research period. This highlights that even when adaptation has taken place, the constant system flux requires that fishers remain dynamic and proactive in their responses.

It is unclear how many fishers remain active in Gouritsmond. The Gouritsmond participant for this study was no longer involved in commercial fishing as he had surrendered his fishing right. Instead, this participant opted to diversify outside the fishery by operating fishing charters and other businesses such as accommodation letting through capitalising on seasonal tourism. This diversification of economic activities in order to establish a steady stream of alternative income sources[14] is in direct contrast to the diversification displayed by other participants in this group. The decision to exit the fishery is an affirmation of this participant's business acumen. He was previously a successful farmer and engaged in commercial line fishing as a form of retirement. Gouritsmond, relatively close (46 km) to Mossel Bay, is a small holiday town with few permanent residents and considerably less competition from other commercial fishers in the immediate vicinity. The proximity to the larger urban area also allows for convenience in a quiet, rural town setting whilst offering alternative business opportunities upon which to capitalise.

The sole commercial linefisher in Witsand implemented several measures that allowed him to continue to earn an income primarily from fishing. Apart from spousal support and livelihood diversification in the form of activities like helping farmers chase baboons off farms, the Witsand fisher was set apart from all study participants in the way that he managed his fishing right allocation. This participant created a closed corporation (cc) in which his crew were named shareholders with a profit share agreement in place. The cc bore the cost of 'boat rental', maintenance and other expenses. Profits after salaries, were paid out periodically. This approach ensured that a monthly stipend was available to the crew members as part of the profit-share agreement during the off-season. This strategy allowed the fisher to manage his fishery as a responsible business. Apart from procedural and administrative problems encountered with FRAP 2013, the Witsand participant scored well and retained his right. It should be noted that the crew resided outside of the study area and thus their views were not included in this analysis.

Witsand has a strong fishing history and, unlike the other towns in the research area, fishing has always been the primary livelihood activity, whereas in Still Bay, Melkhoutfontein and Vermaaklikheid, the primary livelihood activity has been agriculture.[33] The participant from Witsand is a descendant of one of the town's original fishers and took up commercial fishing in the mid-1990s after spending his early career in formal employment. The experience gained from this earlier employment, coupled with his strong fishing heritage, likely played a central role in his continued trade as a fisher. Opportunities to diversify outside the fishery while remaining in Witsand were rare because of the small size and holiday resort nature of the town, and most fishers had been forced to move away to pursue alternative livelihood opportunities.

Household- and community-level decisions regarding investments reduced dependence on external initiatives (e.g. fish buyers and their marketing networks); stronger contacts with local decision-making are important when examining why different communities respond differently to the same stressors. The fishers of Mossel Bay, in contrast to many other fishers in the region, appeared to be a relatively tight-knit group involved in local and national associations and displayed some teamwork. This was also true for the participant from Witsand – being the sole commercial fisher in the town at the time of the research, he chose to network closely with some of the Mossel Bay fishers. As these two towns are geographically quite far apart (156 km by road) the like-mindedness within this group facilitated this cooperation, which can be viewed as a contributor to their success.

Still Bay and Melkhoutfontein: The coping fishers

The second group of participants comprised fishers from Melkhoutfontein and Still Bay. Still Bay is a middle- to upper-income town with predominantly white residents, both historically and currently, while Melkhoutfontein is a middle- to low-income town with predominantly Coloured residents, both historically and currently. Still Bay provides most of the livelihood diversification opportunities for both towns. Although social and economic conditions in these two towns are very different, the fisheries are intrinsically linked as they utilise the same facilities, sell to the same suppliers and have displayed a similar developmental trajectory.[33] Participants experienced impacts of stressors differently between the two towns where the capacity to respond was influenced by factors such as access to capital, knowledge base (education level) and alternative skill sets.[35,36]

Strategies employed by this group fell into the following categories: diversification outside the fishery, riding out the storm and decreasing effort (Table 4). Fishers were faced with infrastructure constraints when considering alternative options in terms of diversification within the fishery. Still Bay has no available berthing for deck boats and limited facilities for processing, storage and distribution of fish. The fishers from this group used strategies that relied on other skill sets, as well as spousal support and reliance on government grants for those who qualified. Decision-making was largely driven by the availability of capital and human resources.

It is possible to identify two subgroups within the coping fishers. The first subgroup is fishers who had alternative income sources (such as a pension, investment income, rental income, more formal secondary livelihood activities), as well as access to larger amounts of capital through financing, sale of businesses, (early) retirement and/or severance pay. This income provided a certain amount of financial security when fishing-derived income was insufficient. Almost half of the participants indicated that they had previously engaged in other full-time economic activities before taking up commercial fishing and thus had alternative skill sets. Skill sets included repairing boats and outboard motors, panel beating and spray painting services, renting out accommodation, subsistence farming, bee-keeping and operation of boat charters. Such activities can generate decent amounts of income in contrast to informal, less-skilled employment. Access to alternative sources of income allowed these fishers to effectively 'ride out the storm' as they did not find it necessary to implement long-term responses, even if they had the resources to do so at their disposal. For example, this subgroup of fishers opted to keep on using petrol outboard motors as opposed to diesel inboard engines despite objecting to rising petrol costs.

The second subgroup comprised participants who were primarily fishers for most of their working lives. This group did not have, nor had ever had, access to large amounts of capital and had limited access to stable alternative income sources, forcing many to take up unskilled, informal and temporary employment. Opportunities for these fishers were generally low paying and unsustainable over the long term and included activities such as gardening, painting, construction work and temporary employment within other fishing sectors. These fishers therefore tended to engage in a 'hand-to-mouth' existence. Within this subgroup there were fishers who attempted to plan and save money for unforeseen circumstances, but limited access to pre-existing financial capital or skilled opportunities constrained possibilities to diversify livelihoods. This highlights that strategies can be inhibited by financial resources and poorer fishers tend to find themselves unable to adapt to changes even if they wish to do so.

The coping fishers group displayed an immense amount of optimism when viewing the future of the industry, although the presence of alternative strategies indicated that the fishery was not able to singularly support their livelihoods at that time. This behaviour rests on fishers' supposition that fishing will always remain their primary source of income and fishers explicitly stated that they did not wish to do anything but fish. The long-term sustainability of this strategy must be called into question as many of these fishers' livelihoods were only secured when a consistent and substantial income could be derived from fishing.

As a result of the consistently poor kob catches, even fishers with contingency funds and plans had depleted their financial reserves and indicated that it was becoming increasingly difficult to fund trips to sea. They subsequently decreased their effort and carefully selected days on which to go fishing, which were dependent on the probability of a good catch.

Table 4: Change responses implemented by the fishers from Still Bay and Melkhoutfontein: coping fishers

	Role				Town		Strategy									
	Skipper/boat owner/right's holder	Crew member	Associated industry	Partner/spouse	Melkhoutfontein	Still Bay	'Ride out the storm'	Increase effort	Decrease effort	Other employment – formal	Other employment – informal	Migrate (temporarily)	Leave fishery	Spousal income	Change fishing strategy	Downscale
Participant 1	•				•		•		•		•			•		•
Participant 4				•		•	•		•					•		
Participant 5	•					•	•				•	•	•			
Participant 6	•					•	•		•		•		•	•		
Participant 7	•				•		•					•	•	•		•
Participant 9		•			•		•				•			•		
Participant 12			•			•										
Participant 13			•			•										
Participant 14			•			•	•	•			•					
Participant 15			•			•	•	•			•					
Participant 32	•					•						•				
Participant 33	•					•	•		•			•		•		•
Participant 34		•				•	•		•	•						•
Participant 35			•			•		•	•						•	
Participant 36				•		•										
Participant 37			•			•	•				•				•	•
Participant 38			•		•		•				•		•	•		
Participant 39		•			•		•		•		•			•		
Participant 40		•			•		•		•		•			•		
Participant 45			•			•										
Participant 46			•			•	•				•		•	•		•
Participant 47	•					•	•		•		•					
Participant 48	•					•	•		•		•	•		•	•	
Participant 49	•					•	•		•		•				•	
Total	9	4	9	2	6	18	18	3	11	1	14	5	5	11	4	6

Although fishers targeted less lucrative fish in the absence of kob, this option could result in higher fishing costs. Many fishers resorted to borrowing money from other fishers and/or intermediaries who buy the catch.[29]

The 'coping' group displayed less business acumen than the business-orientated fishers. As fishing-derived income declined, many of these coping fishers may not have been financially secure to comply with requirements that bear financial stipulations. Consequently, most rights holders in this group did not score well in terms of the balancing and evaluation criteria (see Gammage et al.[29]) set out by FRAP 2013. The failure to secure a right is a cataclysmic event forcing fishers to either diversify outside the fishery or continue fishing commercially (albeit illegally) or recreationally. Notwithstanding shortcomings in previous and current rights allocation processes, much of the uncertainty and ensuing risk could be avoided if fishers were in a position (in terms of access to capital and skills) in which they could comply with the criteria. The inability to manage rights optimally had made these fishers more vulnerable to changes on multiple scales, as they were not only unable to sustain themselves and their crew in the 'off season', but risks posed by policy and regulatory requirements were also exacerbated.

Vermaaklikheid: The reacting fishers

Situated on the banks of the Duivenhoks River, Vermaaklikheid consists predominately of holiday houses surrounded by agricultural land. All participants from this area were from the Coloured community and reside on what is known as 'the Koppie' (small hill in Afrikaans). The participants hailed from a primarily subsistence fishing community that previously fished in the Duivenhoks River and from the shore at Puntjie (located on the east bank of the Duivenhoks River mouth). At the time of the study, fishing activities were limited to acting as crew for three small-scale commercial boats that operated in the area.

Strategies employed to deal with change can be broadly characterised as: livelihood diversification, riding out the storm and restructuring (Table 5). However, opportunities for diversification and restructuring were severely constrained by social and environmental stressors, resulting in a 'hand-to-mouth' existence for this group. While some of the constraints emanated from the rural nature of the town that gave rise to infrastructure challenges, prevailing economic and social conditions (poverty and low education) played a central role.

A large amount of hopelessness was expressed by Vermaaklikheid participants when considering present and future situations. Participants felt powerless to solve their problems at both community and individual levels and expressed hope for some external intervention to resolve challenges. Responses were generally very emotive, which influences how communities can plan when subjected to multiple hardships by undermining their ability to adapt to and/or cope with stressors that seem to be less 'blameworthy' but more quantitatively important.[12]

Vermaaklikheid is geographically isolated and only accessible by two gravel roads that connect to Riversdale (34.3 km) and Still Bay (43.1 km). At the time of the study, there was no public transport servicing the community whilst only one community member from the Koppie owned a vehicle. Although this community member provided a transport service to Riversdale, it was nevertheless costly for participants who did not have a steady income. The need to travel to Riversdale was a practical one as there was only one informal shop in the area which charged exorbitant prices for basic food items. Women tended to take responsibility for the procurement of basic foodstuffs and other goods with a spirit of cooperation between them to surmount practical challenges.

Table 5: Change responses implemented by the fishers from Vermaaklikheid: reacting fishers

	Role			Strategy									
	Skipper/boat owner/right's holder	Crew member	Partner/spouse	'Ride out the storm'	Increase effort	Decrease effort	Other employment – formal	Other employment – informal	Migrate (temporarily)	Leave fishery	Spousal income	Change fishing strategy	Downscale
Participant 2		•		•	•		•				•		
Participant 3			•										
Participant 10			•	•	•			•				•	
Participant 11	•									•			
Participant 16	•			•				•					
Participant 17	•			•				•			•		
Participant 18		•		•				•			•		
Participant 19		•		•				•			•		
Participant 20		•		•				•			•		
Participant 21		•		•				•			•		
Participant 22		•		•				•			•		
Participant 23		•		•				•			•		
Participant 24		•		•				•			•		
Participant 25		•		•				•			•		
Participant 26			•	•				•			•		
Participant 27			•	•			•	•					
Participant 28			•	•			•	•					
Participant 29			•	•			•	•					
Participant 30			•	•			•	•					
Total	3	9	7	17	2	0	5	16	0	1	11	1	0

This cooperation was evident in the way that they shared transport costs, took turns to do shopping and generally helped each other – making this one of the most important coping strategies displayed by this community.[5,9,12]

Participants observed that the transformation of the area from productive farms to holiday houses and non-crop farms had resulted in the systematic reduction of employment opportunities. As agricultural activities and associated employment decreased, fishing became an increasingly important livelihood strategy. Participants indicated that farmers previously allowed employees to plant small vegetable patches and/or gardens on their land to improve overall food security. Importantly, while government provided housing to eligible communities in Vermaaklikheid, members held no communal land on which to implement projects such as a community garden. One ex-fisher, with the assistance of the Department of Agriculture, Forestry and Fisheries and the Department of Trade and Industry, engaged in subsistence chicken farming as part of a programme in which beneficiaries were trained and given a 'starter kit' of chicks. This participant could undertake chicken farming as he owned a smallholding in the area. Importantly, he did not leave the fishery by choice, but eventually gave up after experiencing practical challenges related to the rights application process.

In this area, subsistence fishing as a livelihood strategy was curtailed by the removal of access to the Duivenhoks River. Fences were erected to demarcate farm boundaries which blocked pedestrian access to the coast, further impeding community access to traditional fishing spots. Skippers operating in the area provided an opportunity for employment as crew, although not without constraints. Fishers were forced to either launch boats in the river and proceed to sea through the river mouth or travel to Still Bay via road. Neither of these options was viable as travelling an excess of 80 km by road per day contributed to input costs and the poor condition of access roads posed safety risks. The option to launch in the river was only viable in favourable weather conditions; however, viable sea days were perceived by participants to be decreasing. The high unemployment rate in this community implied that available crew members exceeded requirements. Notably, not all crew were traditional fishers, but in the absence of alternative employment opportunities in Vermaaklikheid, crewing remained a popular and potentially lucrative activity.

Participants diversified outside the fishery by engaging in informal economic activities such as alien vegetation clearing and garden services. Harvested wood from these activities was sold to holidaymakers and residents which, in periods of high demand, could be a lucrative undertaking. This strategy had mixed success as landowners did not necessarily invite the woodcutters onto the land. Problems included the fire risk posed by the remaining wood and responsibility for removing leftover vegetation reverting to the landowner. Woodcutters disagreed and felt that they were doing the landowner a favour as alien vegetation would have had to be cleared.[37] Gardening and caretaker opportunities were rare, as many houses were holiday houses and owners were weary of letting strangers work on their property in their absence.

Conversations with the community on the Koppie revealed deep-seated mistrust existing along racial lines. This mistrust is not surprising as the lingering legacy of South Africa's political past is more prominently felt and seen in rural areas – an experience echoed by numerous communities across South Africa.[38,39] Distrust results in a failure to engage in conflict resolution and the implementation of community-focused change response strategies such as coping or adaptation to change. Concern was also raised around low education levels in this community. Coupled with the remoteness of the town, lack of education is a major contributing factor to poverty and can limit livelihood options.[38] One resident (also a participant) recognised this problem and used her expertise to start an independent community school. This venture received no support from government and was funded by an organisation based in the USA. This example highlights that community support from local structures was limited and, apart from private citizens who offered donations or initiatives, there was little support from external institutions and structures.

In the consideration of future options, participants expressed an unwillingness to migrate, albeit temporarily or permanently, because of their connection to the place, which outweighed livelihood struggles endured. Participants noted that migration to larger urban areas did not necessarily guarantee employment or improved living conditions. Any out-migration can fracture communities, break networks and transform relationships, which can subsequently alter the mood of the community when social relations are changed.[9] Instead, it is preferable that communities and households rather be encouraged to maintain diverse livelihood portfolios that include the development of subsistence activities,[12,40] which in this case also appeared unattainable.

Comparison between groups

The three groups of fishers presented in this paper all displayed varying levels of resilience. This resilience can have both positive and negative consequences for individuals and communities. Whilst the presence of resilience can lead to the creation of opportunities and innovation within a system, too much resilience may have negative consequences as systems continually return to the original (and at times unsustainable) state once stressors abate.[19,36]

The business-oriented group had already adapted over the long term and any resilience displayed by them was in the context of strategies implemented. While this group displayed resilience, these large and permanent diversification measures that had already been implemented may make it very difficult for these fishers to respond dynamically to further stressors and/or shocks. Although the group's overall resilience after recent diversification may not be very strong, it is important to note that the individuals in this group displayed a fair amount of resilience as they could sustain their livelihoods through their fishing activities, despite adversity.

To understand the notable difference in strategies implemented by fishers from the different groups in which social and economic conditions and levels were similar or the same, it is important to consider the life histories and social contexts of the inhabitants of the different towns. Historically, the fishers from the towns that form the 'coping group' and 'reacting group' were not exclusively fishers and instead engaged in a wide range of activities to secure livelihoods, with fishing being a secondary source of food and income.[33] This is in direct contrast to those from Mossel Bay who had a strong history of commercial and industrialised fishing[33], and Witsand which was originally established as a fishing town[41]. This history has directly contributed to the variation of change response strategies observed in the research area.

The coping group was the most resilient of the groups, as strategies employed by this group were temporary and these fishers reverted to fishing as the main livelihood income only when conditions were conducive for fishing. Fishers from the coping group highlighted barriers to proposed future alternatives, which is in direct contrast to the optimism displayed when discussing the viability of fishing as a long-term livelihood strategy. This reticence may be indicative of general resistance to permanent long-term change (i.e. adaptation) and if the current status quo is maintained, it will become increasingly difficult to transform the current, resilient system to a state that is more appropriate and suitable.[19,42-44]

The resistance to change displayed by the coping group must also be viewed in the context of the systematic marginalisation of commercial linefishers that has resulted in the creation of a long-existing policy 'grey area'. The implementation of the *Marine Living Resources Act* and ensuing regulatory climate (see Gammage[30]) has steadily closed this policy gap. Once the Small-scale Fisheries Policy (No 274 of 2012) has been fully implemented, current rights holders will be forced to choose between staying in the commercial fishery which will require compliance with regulations where a business-oriented approach is necessary, or alternatively becoming part of a community right, thereby effectively forcing a long-term adaptive change.

In contrast to the business-oriented group, diversification options and opportunities for the fishers of both the coping and reacting groups are limited by geography, infrastructure and economics. Many of the coping

fishers from Still Bay who have left the fishery have subsequently left the geographical area. The same is not true for Melkhoutfontein-based fishers, as they did not necessarily have the financial means to leave the area. The inability to access capital and resources needed to diversify, whether within or outside the fishery, is a large stumbling block when considering responses to change by all groups on all temporal scales. Furthermore, although better access to financial capital will enable fishers to implement more sustainable and long-term adaptive strategies, it is the social capital and knowledge held by the fishers that will allow them to recognise the need to adapt. The recognition of a problem and the ability to forecast and evaluate change is not only the first step in building resilience, but also the most important one.[19] Although the fishers of the coping group displayed a large amount of resilience, their responses indicate that decision-making in terms of the need to change was not part of a cognitive and deliberate decision-making process. This lack of deliberateness is in direct contrast to the business-oriented group who had mostly made very deliberate decisions to diversify within the fishery (especially in terms of craft).

The fishers in Vermaaklikheid were the least resilient group. Challenges brought about by the inability to access capital had resulted in the reacting group of fishers who would have liked to apply for rights, being unable to buy boats and equipment needed to comply with evaluation criteria used to allocate rights.[29] This situation is in direct contrast to the two other groups whose access to capital had provided the opportunity to diversify within and outside the fishery to varying degrees. In the case of the reacting group, this lack of funds restricted access to the fishery overall. However, the reacting group would most likely benefit from the implementation of the new Small-scale Fisheries Policy. Whilst there are limitations and concerns with the implementation of the policy,[45] successful implementation and management of the policy should benefit fishers in both Melkhoutfontein and Vermaaklikheid in terms of food security and social-ecological resilience.

Conclusion

We have highlighted change response strategies employed by participants in the commercial linefishery in the southern Cape to ensure and maintain sustainable livelihoods. These analyses provide insights into the varying levels of resilience displayed by the three broad groupings identified, as well as the costs and benefits of these different response types. The analyses offer a detailed description of strategies that are implemented, as well as some valuable insights into the decision-making processes. This discussion is by no means complete as a thorough evaluation with a focus on the reasoning in decision-making will provide much more insight into the rationale used by the fishers. An insight that emerges from these discussions with participants is that both cognitive and reflexive decision-making processes are shaped by individual and communities' experience of past and present environments. The practical implications of actions are not always the overriding concern in decision-making, which underscores the importance of culture and belief systems. There is also a recognition that the severity of the challenges experienced with policy and regulatory processes may be exacerbated by a strong resistance to change.

The insights gained from this research have rendered qualitative information that serves to provide insight into the daily lives of these groups of fishers – anchored in their own perspective. However, there is a lack of appropriately scaled quantitative data required to provide insight into, amongst others, household income, supply chains and networks, education levels, employment status – all of which are crucial in developing an understanding of economic forces that give rise to environmental degradation whilst undermining sustainability.[46] Whilst this research aimed to contribute towards understanding the current reacting, coping and adaptive strategies employed in fishing communities in the southern Cape, the interactions of these drivers and inter-relationships between the various strategies require better understanding. Understanding gained within this fishery system provides important insights into a system that has not been well described in the past, highlighting many knowledge gaps that need to be addressed by conducting further context-specific research at small scales. Following this study researchers will be in a better position to explore viable strategies for the future of these fishing communities through action research as a basis for regionally appropriate management recommendations.

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References

1. Jarre A, Ragaller SM, Hutchings L. Long-term, ecosystem-scale changes in the southern Benguela marine pelagic social-ecological system: Interaction of natural and human. Ecol Soc. 2013;18(4), Art. #55, 15 pages. http://dx.doi.org/10.5751/ES-05917-180455
2. Ommer RE, Perry RI, Murray G, Neis B. Social-ecological dynamism, knowledge, and sustainable coastal marine fisheries. Curr Opin Environ Sustain. 2012;4(3):316–322. http://dx.doi.org/10.1016/j.cosust.2012.05.010
3. Isaacs M, Hara M, Raakjær J. Has reforming South African fisheries contributed to wealth redistribution and poverty alleviation? Ocean Coast Manag. 2007;50(5–6):301–313. http://dx.doi.org/10.1016/j.ocecoaman.2006.11.002
4. Van Sittert L. 'Those who cannot remember the past are condemned to repeat it': Comparing fisheries reforms in South Africa. Mar Policy. 2002;26(4):295–305. https://doi.org/10.1016/S0308-597X(02)00012-X
5. Bennett NJ, Dearden P, Peredo AM. Vulnerability to multiple stressors in coastal communities: A study of the Andaman coast of Thailand. Clim Dev. 2015;7(2):37–41. http://dx.doi.org/10.1080/17565529.2014.886993
6. Bunce M, Brown K, Rosendo S. Policy misfits, climate change and cross-scale vulnerability in coastal Africa: How development projects undermine resilience. Environ Sci Policy. 2010;13(6):485–497. http://dx.doi.org/10.1016/j.envsci.2010.06.003
7. Leichenko RM, O'Brien K. Environmental change and globalisation: Double exposures. New York: Oxford University Press; 2008.
8. O'Brien KL, Leichenko RM. Double exposure: Assessing the impacts of climate change within the context of economic globalization. Glob Environ Chang. 2000;10:221–232. http://dx.doi.org/10.1016/S0959-3780(00)00021-2
9. Ommer RE, and the Coasts under stress team. Coasts under stress: Restructuring and social-ecological health. Montreal and Kingston: McGill-Queen's University Press; 2007.
10. Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J. Social-ecological resilience to coastal disasters. Science. 2005;309(5737):1036–1039. http://dx.doi.org/10.1126/science.1112122
11. Cinner J, Fuentes MMPB, Randriamahazo H. Exploring social resilience in Madagascar's marine protected areas. Ecol Soc. 2009;14(1), Art. #41, 20 pages. Available from: http://www.ecologyandsociety.org/vol14/iss1/art41/
12. Bennett NJ, Dearden P, Murray G, Kadfak A. The capacity to adapt?: Communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. Ecol Soc. 2014;9(2), Art. #5, 20 pages. http://dx.doi.org/10.5751/ES-06315-190205
13. Marschke MJ, Berkes F. Exploring strategies that build livelihood resilience: A case from Cambodia. Ecol Soc. 2006;11(1), Art. #42, 16 pages. Available from: http://www.ecologyandsociety.org/vol11/iss1/art42/
14. De Haan L, Zoomers A. Development geography at the crossroads of livelihood and globalisation. Tijdschr voor Econ en Soc Geogr. 2003;94(3):350–362. https://doi.org/10.1111/1467-9663.00262
15. Taylor PJ. A materialist framework for political geography. Trans Inst Br Geogr. 1982;7(1):15–34. http://dx.doi.org/10.2307/621909

16. De Haan L, Zoomers A. Exploring the frontier of livelihoods research. Dev Change. 2005;36(1):27–47. http://dx.doi.org/10.1111/j.0012-155X.2005.00401.x

17. Kirkby J, O'Keefe P, Howorth C. Introduction: Rethinking environment and development in Africa and Asia. Land Degrad Dev. 2001;12(3):195–203. http://dx.doi.org/10.1002/ldr.431

18. Berkes F, Colding J, Folke C, editors. Navigating social-ecological systems: Building resilience for complexity and change. New York: Cambridge University Press; 2003.

19. Folke C. Resilience: The emergence of a perspective for social–ecological systems analyses. Glob Environ Chang. 2006;16(3):253–267. http://dx.doi.org/10.1016/j.gloenvcha.2006.04.002

20. Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B. Resilience and sustainable development: Building adaptive capacity in a world of transformations. Ambio. 2002;31(5):437–440. http://dx.doi.org/10.1579/0044-7447-31.5.437

21. Cinner JE, Folke C, Daw T, Hicks CC. Responding to change: Using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. Glob Environ Chang. 2011;21(1):7–12. http://dx.doi.org/ 10.1016/j.gloenvcha.2010.09.001

22. Cinner JE, McClanahan TR, Graham NAJ, Daw TM, Maina J, Stead SM, et al. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Glob Environ Chang. 2012;22(1):12–20. http://dx.doi.org/10.1016/j.gloenvcha.2011.09.018

23. Benguela Current Commission. Benguela Current Commission [homepage on the Internet]. c2013 [cited 2016 Jul 15]. Available from: http://www.benguelacc.org/index.php/en/about/the-bclme

24. Hutchings L, Van der Lingen CD, Shannon LJ, Crawford RJM, Verheye HMS, Bartholomae CH, et al. The Benguela Current: An ecosystem of four components. Prog Oceanogr. 2009;83(1–4):15–32. http://dx.doi.org/10.1016/j.pocean.2009.07.046

25. Jarre A, Hutchings L, Kirkman S, Kreiner A, Tchipalanga P, Kainge P, et al. Synthesis: Climate effects on biodiversity, abundance and distribution of marine organisms in the Benguela. Fish Oceanogr. 2015;24(Suppl 1):122–149. http://dx.doi.org/10.1111/fog.12086

26. Griffiths MH. Long-term trends in catch and effort of commercial linefish off South Africa's Cape Province: Snapshots of the 20th century. S Afr J Mar Sci. 2000;22(1):81–110. http://dx.doi.org/10.2989/025776100784125663

27. Blamey LK, Shannon LJ, Bolton JJ, Crawford RM, Dufois F, Evers-King H, et al. Ecosystem change in the southern Benguela and the underlying processes. J Mar Syst. 2015;144:9–29. http://dx.doi.org/10.1016/j.jmarsys.2014.11.006

28. Adger WN. Vulnerability. Glob Environ Chang. 2006;16(3):268–281. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006

29. Gammage LC, Jarre A, Mather C. A case study from the southern Cape linefishery 1: The difficulty of fishing in a changing world. S Afr J Sci. 2017;113(5/6), Art. #2016-0252, 8 pages. http://dx.doi.org/10.17159/sajs.2017/20160252

30. Gammage LC. Considering one's option when the fish leave: a case study of the traditional commercial linefishery of the Southern Cape [master's dissertation]. Cape Town: University of Cape Town; 2015. Available from: https://open.uct.ac.za/handle/11427/15479

31. Perry RI, Ommer RE, Barange M, Jentoft S, Neis B, Sumaila UR. Marine social-ecological responses to environmental change and the impacts of globalization. Fish Fisheries. 2011;12(4):427–450. http://dx.doi.org/10.1111/j.1467-2979.2010.00402.x

32. Winker H, Kerwath SE, Attwood CG. Report on age-structured stock assessments and the simulation of the impacts of various fisheries management options for the South African linefishery. Report no. LSWG II. Pretoria: Department of Agriculture, Forestry and Fisheries; 2014.

33. Visser N. The origins of the present: Economic conflicts in the fisheries of the South African south east coast, circa 1910 – 1950. Marit Stud. 2015;14(1):9. http://dx.doi.org/10.1186/s40152-015-0029-6

34. Duggan GL, Green LJF, Jarre A. "Thinking like a fish": Adaptive strategies for coping with vulnerability and variability emerging from a relational engagement with kob. Marit Stud. 2014;4(13):1–21. http://dx.doi.org/10.1186/2212-9790-13-4

35. Coulthard S. Adapting to environmental change in artisanal fisheries – Insights from a south Indian lagoon. Glob Environ Chang. 2008;18(3):479–489. http://dx.doi.org/10.1016/j.gloenvcha.2011.01.003

36. Smit B, Wandel J. Adaptation, adaptive capacity and vulnerability. Glob Environ Chang. 2006;16(3):282–292. http://dx.doi.org/10.1016/j.gloenvcha.2006.03.008

37. South African Department of Environmental Affairs. Working for Water (WfW) programme [homepage on the Internet]. No date [cited 2016 Aug 01]. Available from: https://www.environment.gov.za/projectsprogrammes/wfw

38. Isaacs M. Small-scale fisheries reform: Expectations, hopes and dreams of 'a better life for all'. Mar Policy. 2006;30(1):51–59. http://dx.doi.org/10.1016/j.marpol.2005.06.010

39. Sowman M. Subsistence and small-scale fisheries in South Africa: A ten-year review. Mar Policy. 2006;30(1):60–73. https://dx.doi.org/10.1016/j.marpol.2005.06.014

40. Ellis F, Allison E. Livelihood diversification and natural resource access. Norwich: Overseas Development Group, University of East Anglia; 2004.

41. Welcome to the Overberg.co.za [homepage on the Internet]. No date [cited 2016 Aug 01]. Available from: http://www.overberg.co.za/content/view/142/27/

42. Walker B, Meyers JA. Thresholds in ecological and social–ecological systems: A developing database. Ecol Soc. 2004;9(2), Art. #3, 16 pages. http://www.ecologyandsociety.org/vol9/iss2/art3/

43. Gunderson L, Holling C, editors. Panarchy: Understanding transformations in human and natural systems. Washington: Island Press; 2002.

44. Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. Catastrophic shifts in ecosystems. Nature. 2001;413(10):591–596. https://dx.doi.org/10.1038/35098000

45. Sowman M, Sunde J, Raemaekers S, Schultz O. Fishing for equality: Policy for poverty alleviation for South Africa's small-scale fisheries. Mar Policy. 2014;46:31–42. http://dx.doi.org/10.1016/j.marpol.2013.12.005

46. Sowman M, Scott D, Green LJF, Hara MM, Hauck M, Kirsten K, et al. Shallow waters: Social science research in South Africa's marine environment. Afr J Mar Sci. 2013;35(3):385–402. http://dx.doi.org/10.2989/1814232X.2013.836134

The medical device development landscape in South Africa: Institutions, sectors and collaboration

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A characterisation of the medical device development landscape in South Africa would be beneficial for future policy developments that encourage locally developed devices to address local healthcare needs. The landscape was explored through a bibliometric analysis (2000–2013) of relevant scientific papers using co-authorship as an indicator of collaboration. Collaborating institutions thus found were divided into four sectors: academia (A); healthcare (H); industry (I); and science and support (S). A collaboration network was drawn to show the links between the institutions and analysed using network analysis metrics. Centrality measures identified seven dominant local institutions from three sectors. Group densities were used to quantify the extent of collaboration: the A sector collaborated the most extensively both within and between sectors; local collaborations were more prevalent than international collaborations. Translational collaborations (AHI, HIS or AHIS) are considered to be pivotal in fostering medical device innovation that is both relevant and likely to be commercialised. Few such collaborations were found, suggesting room for increased collaboration of these types in South Africa.

Significance:

- Results could inform the development of strategies and policies to promote certain types of medical device development.
- Further studies could identify drivers and barriers to successful medical device development in South Africa.

Introduction

Medical device innovation requires contributions from multiple disciplines, as well as collaboration and knowledge transfer across sectors. The three main sectors identified as playing a role in medical device development are academia (in the form of higher education institutions), healthcare and industry.[1-3]

The knowledge base, resources and roles vary considerably across these sectors. Academic institutions often possess specialised instrumentation and equipment; are responsible for local education and training at all tertiary levels; and add to the stock of codified knowledge through publications, patents, and software and hardware prototypes.[4] The healthcare sector best understands the patients' needs; and has access to currently available medical devices and knowledge about their shortcomings within the local context. Industry has knowledge of, and access to, current technologies used in the manufacture and development of medical devices; and is responsible for making the devices accessible to the general public.

Collaboration between organisations from the different sectors is a key component of innovation in the medical field.[5] The benefits of academia–healthcare collaborations include increased awareness of technologies used in clinical practice and clinical input into research projects. Industry–academia collaboration increases the problem-solving capacity of industry by enabling access to university equipment and specialised knowledge.[4] Universities benefit from this collaboration through awareness of current technologies used in industry[6] and access to new funding opportunities[7].

Of particular interest for medical device innovation are so-called translational collaborations – defined here as collaborations between all three sectors (academia, healthcare and industry) considered essential to the biomedical innovation system[1,8] – which enable biomedical discoveries to translate into clinical practice.[2] Translation is possible as a result of the different, yet complementary, perspectives and social capital[5] provided by each collaborator.

Collaborations between organisations can be visualised using network graphics. Such networks have been developed using co-authorship of scientific publications as a proxy for collaboration between individual researchers, their affiliated institutions and the countries in which they are based.[3,9-15] These networks provide a way to ascertain the extent and nature of collaboration between different categories of organisation.

The main aim of this paper was to characterise the broad medical device development landscape, particularly with regard to collaboration, in South Africa. This characterisation was accomplished using a bibliometric network analysis of scientific publications to generate a collaboration network. The network was then used to: identify the institutions active in the field and to which sectors they belong; determine the dominant institutions (and sectors); quantify the extent of intra- and cross-sector collaboration; investigate the presence of foreign influence; and explore the prevalence of various collaboration types, with a particular focus on translational collaborations.

Co-authorship as a proxy for scientific collaboration

Scientific collaboration is a fundamental aspect of research activity, which generates knowledge flows between different groups of partners.[16] It is driven by globalisation and the emergence of new communication technologies, which make it possible for different institutions to work together.[17,18] Through collaboration, institutions complement their expertise, share available resources and create social networks, which often result in the integration of knowledge, efforts and capabilities as well as enhancement of productivity.[19] Scientific collaboration can be

measured by co-authorship – which is one of the most tangible and well-documented forms of partnership.[20,21] As scientific collaboration evolves, the focus is shifting from authors to the different institutions involved, with a trend, since the 1960s, towards interdisciplinarity.[22]

In analysing scientific collaboration networks, centrality measures (which include degree, betweenness and closeness centrality)[23], can be used to identify dominant institutions which have greater influence within the network. Each centrality measure uses a different definition of the 'centre' of action in the network, although all of them analyse patterns of relations in the network.[24] Degree centrality uses the number of direct contacts of an actor as an indicator of the quality of their interconnectedness.[25,26] Usually institutions or nodes with a higher degree are more central to the structure and tend to have a greater ability to influence others.[25] Betweenness centrality measures the influence of an individual over information flow between others[27]; those with high betweenness have the potential to influence others near them in a network through both direct and indirect pathways.[28] Thus an actor with high betweenness centrality can potentially influence the spread of information through the network, by facilitating, hindering, or even altering the communication between others.[29] Closeness centrality gives a measure of how well connected an actor is by considering the shortest paths between them and the other actors[23], thereby quantifying how long the information takes to spread from a given actor to others in the network. As such, the extent of the influence of the actor over the entire network can be investigated.[30,31]

Lander[3] suggests that, for biomedical research and development, academia is the key network sector, followed by healthcare and government organisations, with the industry sector playing a weaker role. This ranking is further supported by the findings of Chimhundu et al.[32] who showed that universities and healthcare facilities were the dominant sectors in cross-sector collaboration for cardiovascular medical device development in South Africa. Nonetheless, collaboration between all three sectors is essential within the biomedical innovation system to facilitate the translation of resources.[2,8] Globally, medical research has high degrees of 'extramural domestic' collaboration between different institutions in the same country.[33] In African countries, collaboration in the medical field is characterised by the dominance of international institutions, with collaboration driven by foreign funding.[34] The economic and/or political dependence of a country or geopolitical region and the presence of special equipment that is shared in large multinational projects, influences the degree of co-operation.[35] In a study on cardiovascular device development in South Africa, foreign institutions were found to play a role in connecting local institutions that would otherwise have remained isolated.[32]

Method

Regulatory control of medical devices has necessitated a single definition that would allow for their inherent diversity. Such a definition was proposed by the Global Harmonization Task Force (GHTF)[36], a consortium formed in 1992 consisting of regulatory authorities and representatives from the medical device industry, now known as the International Medical Device Regulators Forum. The GHTF definition of a medical device has been widely accepted and is as follows[37]:

> *A medical device is any instrument, apparatus, implement, machine, appliance, implant, in vitro reagent or calibrator, software, material or other similar or related article that does not achieve its primary intended action in or on the human body solely by pharmacological, immunological or metabolic means and that is intended for human beings for:*
>
> - *the diagnosis, prevention, monitoring, treatment or alleviation of disease;*
> - *the diagnosis, monitoring, treatment, alleviation of, or compensation for an injury;*
> - *the investigation, replacement, modification, or support of the anatomy or of a physiological process;*
> - *supporting or sustaining life;*
> - *controlling conception;*
> - *disinfecting medical devices; and*
> - *providing information for medical or diagnostic purposes by means of in vitro examination of specimens derived from the human body.*

Publication search methodology

Because medical devices incorporate numerous technologies, it is difficult to define a search based on device types. Consequently, the publication search was structured around the three sectors – academia, healthcare and industry – known to be crucial elements of biomedical innovation.[1,2]

A list was generated of South African institutions involved in medical device development (see Supplementary table 1). The list consisted of 23 universities that were in existence in South Africa at the end of 2013, 10 academic hospitals, and a set of companies known to be active in the medical device field. The list of companies comprised those registered as part of the MDMSA (Medical Device Manufacturers South Africa) – an umbrella corporation for companies in South Africa that manufacture medical devices; MDMSA had 15 members when the search was executed. The list was further expanded with select members of SAMED (South African Medical Device Industry Association) – an association overseeing medical device policies, innovation, ethical principles and practices within South Africa. From the list of 121 SAMED members, 17 companies were selected according to their location (based in South Africa) and their engagement in product development.

Table 1 outlines the search method employed using both websites and search engines. This exploratory search was intended to generate a broad overview of the South African medical device development landscape that would allow key players to be identified and aspects of collaboration to be investigated.

Filtering the search results

Articles published between January 2000 and December 2013 were retained. Individual publications were manually scrutinised to determine whether their content was related to medical device development, and either accepted or rejected according to the following criteria: publication type, affiliation and indicators of medical device development.

Publication type

Journal or conference proceeding publications were retained, as were articles published on the Research Space (https://researchspace.csir.co.za/dspace/) of the Council for Scientific and Industrial Research (CSIR). The CSIR is a government commissioned science council that provides an online archive of all their research; such outputs were considered to be of similar credibility to publications in conference proceedings. Other research-related documentation (e.g. magazine articles, internal reports) was excluded.

Affiliation

At least one co-author was required to be affiliated with a South African institution.

Indicators of medical device development

Publications were required to explicitly mention a medical device (as determined by the GHTF definition), and to relay information that would aid the (further) development of said device.

Publications that discussed the use of medical devices to examine medical conditions, and did not aid the development of the device, were excluded. Typically such publications mentioned the device only in the methods section. Review papers were excluded as they do not contribute directly to device development. Animal studies that did not contribute to device development intended for human use, were excluded.

Publications that presented non-medical technological advances without making a direct link to healthcare and a prospective medical device were excluded. However, if the focus of the publication was on the non-medical technology and a medical device was discussed as an application, then the publication was included. The publication of Booysen et al.[38] serves

Table 1: Search methodology for finding medical devices developed in South Africa (2000–2013)

	Universities
1.	The existence of a Faculty of Engineering and/or a Faculty of Health Sciences or Medical School was determined for each of the 23 universities[a] from their websites.
2.	Provided either, or both, of these faculties existed, the presence of a biomedical engineering department or grouping within the faculties was determined.
3.	Any biomedical engineering department websites, thus found, were searched for publication lists typically provided as evidence of departmental or staff research activities.
4.	*PubMed*[b] was used to search for university publications using the following key words and filters:
	Search phrase: 'medical devices South Africa'
	Publication date: selected to be from 1 January 2000 to 31 December 2013
	Species: only medical devices developed for human application were considered
	Language: only papers written in English were assessed
	Text availability: only papers for which we had full-text access were considered so as to ensure accurate classification of the paper as being on medical device development, based on its full content
	Hospitals
1.	The 10 hospital[a] websites were searched for listings of research activities.
2.	The hospital names were used as search terms in *Google Scholar* and *PubMed*, using the same search criteria as in the university search. In the case of hospitals that are known under multiple names, all names were used as search terms.
	Companies
1.	The 32 company[a] websites were searched for listings of company and staff research activities.
2.	Staff research activities were further investigated through *Google* searches of relevant staff members.
3.	If steps (1) and (2) yielded no publications, an additional *Google Scholar* search was performed for either the company name or an abbreviation thereof.

[a]*Individual institutions are listed in Supplementary table 1.*

[b]PubMed *was developed by the US National Centre for Biotechnology Information at the US National Institute of Health; it contains biomedical literature from over 25 000 journals and includes MEDLINE.*

as an example: advancements in rapid prototyping technology are discussed with reference to a secure airway clamp case study.

Device development was also understood to mean novel applications of existing devices. For example, Saleh et al.[39] proposed using MRI to diagnose ventricular wall remodelling, while Bosanquet and John[40] discussed a method to extract patterns in EEG recordings during exercise-fatigue experiments. Although MRI and EEG devices are not new, the applications presented were; in addition, when considering the GHTF definition[37], both papers presented the development of 'software intended for the investigation of a physiological process'.

Only synthetic implants, grafts and/or replacements were considered to be acceptable. Biological samples (for instance vein grafts used in heart bypass surgery) were excluded.

Extracting collaboration data

A list was extracted of the institutions with which co-authors were affiliated. Four sectors were identified:

1. Academia (A): higher education institutions involved in academic research for the development of medical devices; predominantly consisting of universities, polytechnics and colleges.
2. Healthcare (H): clinics, hospitals and medical facilities whose primary function is patient care; essential for identifying healthcare needs.
3. Industry (I): companies, firms, organisations and individuals involved in medical device development for purposes of commercialisation.
4. Science and support (S): any organisation, not belonging to one of the other sectors, that contributes to, or utilises, the scientific body of knowledge through research, education and training, clinical services and/or community services. This includes science councils, other research facilities, non-government organisations (NGOs), non-profit organisations (NPOs) and designated special interest groups.

Science councils and facilities concentrate on performing social, scientific and technological research in accordance with their commission by the South African government under the *Scientific Research Council Act 46 of 1988*. NGOs and NPOs may serve as a source of research and information and offer assistance and educational opportunities. Special interest groups are recognised as such by the South African Medical Association, and promote the practice and study of a particular field of medicine.

The institutions were further assessed by applying the following filters:

- Departmental affiliations were omitted and only the affiliation with the parent institution was retained. An exception to this rule was in the case of academic hospitals. For instance an author affiliated with Onderstepoort Veterinary Academic Hospital (OVAH), which is associated with the University of Pretoria (UP), was recorded as having a H sector affiliation. If the author was jointly affiliated with a UP department, a second A sector affiliation was recorded.
- Private hospitals belonging to a larger conglomerate (e.g. MediClinic, Life Health and Netcare) were still considered as individual hospitals. This was thought to better reflect collaboration at the institutional level.
- Branches of large multinationals in different locations were considered separately, e.g. Siemens Healthcare (Atlanta, GA, USA), versus Siemens Medical Solutions (Baltimore, MD, USA).

After filtering, the country in which each institution was based was recorded.

Collaboration network generation and analysis

A collaboration network was generated and analysed using UCINET (version 6.474)[41] and *NetDraw* (version 2.131)[42]. Within such networks, each institution is represented by a network node, while edges (ties between nodes) represent publications on which the institutions collaborated. Edge thickness was weighted according to the number of collaborative publications; edges were undirected, as collaboration is a reciprocal relationship.

NetDraw's spring-embedding graph layout algorithm was used to draw the network, followed by manual manipulation of node positions as necessary to ensure labels were legible. The size, shape and colour of the nodes were used to highlight features of interest, namely

connectedness to other institutions, sector classification and institutional location, respectively.

Structural analysis

The following centrality measures[24,43] were used to identify the central nodes (i.e. dominant institutions):

- Degree: The number of connections or edges that a node has to other nodes.
- Betweenness: The number of times a node falls on the geodesic distance between all pairs of nodes in the network, normalised with respect to the maximum possible betweenness a node could have.
- Closeness: Calculated for a node (N_n) by dividing the number of remaining nodes in the network ($n-1$) by the sum of all distances between node N_n and each of the remaining nodes. Closeness values were calculated for the largest component within the network.[27]

The centrality measures were normalised using the number of nodes present in the network.[44-46]

Collaboration analysis

Network density measures the speed of information diffusion among nodes[24] and is defined as the sum of edges present in a network between groups of nodes, divided by the maximum number of edges that could possibly exist between the nodes. When calculated for different groups within a network, density provides insight into the exchange of information within and between the groups. In this paper, group densities are used to evaluate the extent of collaboration at both the sectoral and international levels.

Additionally, the various types of sectoral collaboration and their prevalence within the network were considered. For instance, if a publication has two co-authors, one affiliated with a university (sector A) and the other with a company (sector I), the publication represents an AI type of cross-sectoral collaboration. Translational collaborations include three possible groupings of the four sectors: AHI, HIS and AHIS. Each sector contributes different, yet complementary, resources. Typically, the A sector provides a research/development component, the H sector may be responsible for identifying the patient needs to be addressed, and the I sector may be responsible for getting the product to market. Recalling that in this study, the S sector has similar resources to those of the A sector, translational collaborations are consequently considered to comprise the A and/or the S sector, in combination with the H and I sectors.

Limitations of the data set

The data set presented in this paper has three inherent shortcomings. First, even though bibliometric studies often make use of co-authorship as an indicator of collaboration, co-authorship can at best only be considered a partial indicator as not all collaborations are formally acknowledged through a co-authorship.[47] This is especially true at the micro-level, when considering individual collaborators; however, the problem is lessened when considering collaborations at the macro-level (i.e. the institutional level). Second, because of the exploratory nature of the publication search, not all relevant publications would have been found. However, by the very nature of medical devices, conducting an exhaustive search would not be practicable. Third, the type of publications considered (namely journal articles and conference proceedings) are the preferred output for the A sector. The other three sectors would not necessarily use these forums to document their medical device development activities. As such the data set may be biased towards activity within the A sector.

The data set was considered suitable for an initial investigation into collaboration activities and the parties involved.

Results and discussion

After filtering the search results, a total of 171 publications remained, comprising 781 authors affiliated with 116 institutions from the four sectors (45 A; 36 H; 21 I; 14 S).

Collaboration network

Figure 1 shows the collaboration network for institutions (nodes) found to be active in medical device development during the period 2000–2013. Both local (South African) and foreign (international) institutions are shown; node colour is used to differentiate between the two locations. Furthermore, node shape is used to represent the sector to which each institution belongs (A, diamond; H, circle; I, square; S, triangle), while node size is scaled according to the node degree. Abbreviations used for the institution names are listed in Supplementary tables 2–5.

The collaboration network provides a first step in characterising the medical device development landscape in South Africa. Of the 116 institutions, 56 are local and 60 are foreign. These institutions can be further broken down to the sectoral level: A(11 local, 34 foreign); H(24 local, 12 foreign); I(10 local, 11 foreign); and S(11 local, 3 foreign).

Comparing the proportion of institutions (both local and foreign) within each sector (A-39%; H-31%; I-18%; S-12%) against those found by Lander[3] for the infection and immunity network in Canada (university-37%; hospital-23%; government-18%; firm-14%; NGO-8%) echoes the dominance of the academia sector. However, more healthcare institutions were present in the South African landscape, while the industry sector proportions are similar. The government and NGO sectors identified by Lander[3] are similar in nature to the institutions belonging to the S sector of this study. More institutions from these sectors were present in the network in Canada than in South Africa.

In the academia sector, nearly half (11/23) of the South African universities were found to be active in medical device development. These local institutions, however, were far outnumbered by the foreign institutions. Foreign universities therefore make a substantial intellectual contribution to medical device development activity in South Africa, although their role cannot be determined from the current analysis. However, the network does show that the foreign nodes have low degree, which would imply low influence for the individual nodes.

Far more local than foreign healthcare institutions are present in the network. Such local collaborations are critical if medical device development is to target local healthcare needs; however, further analysis would be required to ascertain if there is alignment between the types of devices being developed and the healthcare needs.

Dominant institutions

The dominant institutions within the network were identified by calculating three centrality measures (degree, closeness and betweenness) and listing the 10 highest ranking nodes for each measure (Table 2). These measures indicate different ways in which institutions exhibit dominance in the network. Nodes with high degree have a greater ability to influence others, while high betweenness measures the institution's ability to spread information through the network, and closeness indicates which nodes could potentially facilitate the efficient spread of knowledge in the network.

According to Goh et al.[48], a network typically constitutes a small number of influential individuals and many peripheral actors. The findings in Table 2 agree with this observation. Seven local nodes are common to all three centrality measures: UCT (University of Cape Town), GSH (Groote Schuur Hospital), SUN (Stellenbosch University), UP (University of Pretoria), WITS (University of the Witwatersrand), TH (Tygerberg Hospital) and NHLS (National Health Laboratory Services). The order in which these institutes appear varies for each measure, although UCT is consistently the highest ranked node, while GSH and SUN share the second and third highest rankings. Four of the seven institutions are from the A sector, two from the H sector and one from the S sector. It should also be noted that both of the H sector institutions are academic hospitals. This dominance exhibited by the A and H sectors is consistent with the findings of Lander[3].

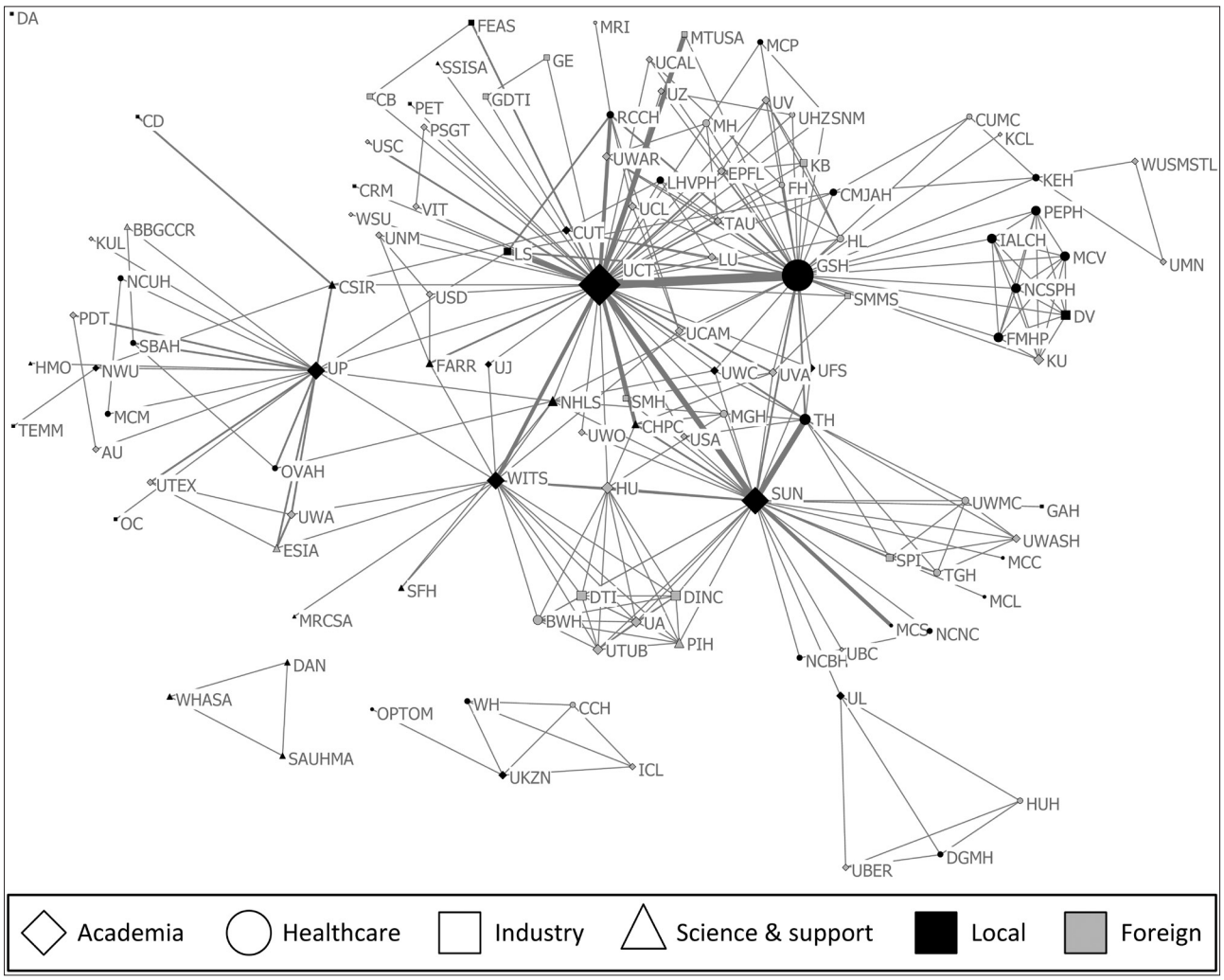


Figure 1: Collaboration network of institutions generated using all relevant publications found during the period 2000–2013. Node size scaled according to node degree. Edge thickness weighted according to number of publications co-authored. Institution names and abbreviations are listed in Supplementary tables 2–5.

Table 2: Ten highest ranking nodes for the normalised centrality measures: degree, closeness and betweenness

Rank	Degree centrality			Closeness[a] centrality			Betweenness centrality		
	Institution	Sector	Value	Institution	Sector	Value	Institution	Sector	Value
1	UCT	A	0.461	UCT	A	0.642	UCT	A	0.432
2	GSH	H	0.348	GSH	H	0.552	SUN	A	0.247
3	SUN	A	0.278	SUN	A	0.538	GSH	H	0.235
4	UP	A	0.165	NHLS	S	0.502	UP	A	0.182
5	WITS	A	0.157	WITS	A	0.495	WITS	A	0.088
6	HU*	A	0.096	TH	H	0.473	UL	A	0.047
7	TH	H	0.096	UP	A	0.469	NHLS	S	0.041
8	NHLS	S	0.078	UWC	A	0.461	KEH	H	0.032
9	Six institutions[b]		0.070	UVA*	A	0.459	CSIR	S	0.027
10				UFS	A	0.455	TH	H	0.022

*A, academia; H, healthcare; I, industry; S, science and support; *foreign institutions.*

Institution names and abbreviations are listed in Supplementary tables 2–5.

[a]*Closeness calculated for the largest component comprising 107 of the total 116 institutions.*

[b]*The six institutions with equal degree were: BWH*(H); DINC*(I); UTUB*(A); DTI*(I); UA*(A); PIH*(S).*

Universities are seen to form hubs that facilitate the exchange of information within the network; they are typically well connected and are considered to be influential in the development of medical devices. Because of their position in the network, universities have the potential to help establish new collaborations with other institutions in the network.

The industry sector is absent from Table 2, except for two foreign organisations. This finding may be as a result of the bias inherent in the network, namely that journal article publication is not imperative for industry. However, it could also indicate that local industry is not a dominant figure in medical device innovation within South Africa. Further investigation, possibly through patent analysis, could produce more insight. Another possible explanation of the low industry presence in the South African co-publication landscape could be that the academic research being generated is not finding a market. Lander and Atkinson-Grosjean[2] described a number of translational pathways necessary for biomedical innovation, one of which was the commercial pathway which characterised movement between academia and the marketplace, typically facilitated by the I sector. Further analysis would be needed to investigate the extent of this pathway in South Africa.

Sectoral and international collaboration

Extent of collaboration

Table 3 shows the group densities (ρ) that were calculated for the four sectors. Within-group densities lie on the diagonal of the table, are shown in bold, and represent intra-sectoral collaboration. The remaining entries in the table are the between-group densities, which represent cross-sectoral collaboration. The table is symmetric, because of the reciprocal nature of collaboration in the network. The sum of edge weights ($\sum ew$) used to calculate the densities is also shown in the table; these values indicate the number of edges present in the network, taking into account the weight of the edges, which connect all the nodes belonging to the various sectors. For instance, the summed weight of all edges in the network that connect institutions from the A sector to those of the H sector is 114.

Considering only intra-sectoral collaboration, from highest density to lowest we can rank the sectors as follows: A, H, S, I. The fact that universities are seen to collaborate extensively with one another (the density of 0.088 seen for AA collaboration is the highest in the entire table), is to be expected. Low intra-sector collaboration within the I sector (ρ=0.014; one of the lowest values in the entire table) is evident, perhaps because local companies perceive little commercial gain in II collaboration. The relatively high density seen for the H sector (ρ=0.065) could stem from the fact that many of the hospitals in the network are academic hospitals and may reflect university research practices.

With regard to cross-sectoral collaboration, the three highest ranking collaboration types are AH (ρ=0.070; $\sum ew$=114), AS (ρ=0.063; $\sum ew$=40) and AI (ρ=0.049; $\sum ew$=46), while the two lowest ranking collaboration types are IS (ρ=0.014; $\sum ew$=4) and HS (ρ=0.012; $\sum ew$=6).

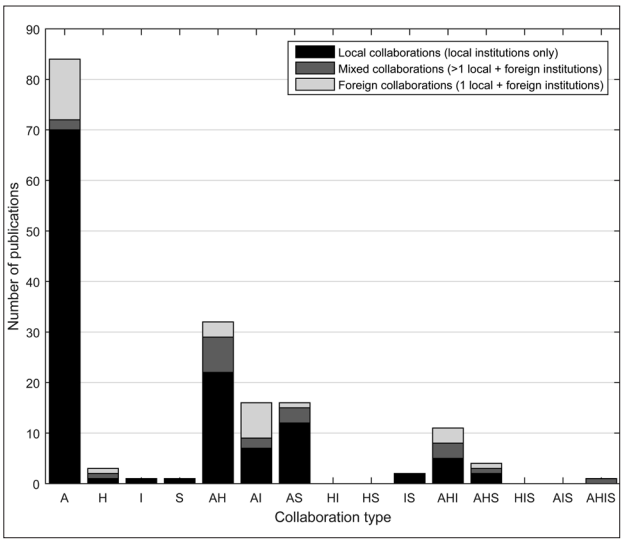
AH has the highest cross-sectoral collaboration density – a finding in agreement with that of Chimhundu et al.[32] for cardiovascular devices. The next highest cross-sector density was found for AS collaborations, even though the S sector (14 institutions) is considerably smaller than the H sector (36 institutions). When comparing AS and AI, even though AS has the higher ρ value, the $\sum ew$ value is lower than that of AI. This result is explained by the fact that there are fewer S sector (14) than I sector (21) institutions. What these observations indicate, is that small sectors like the S sector can still be extensively involved in collaboration activities, and conversely, that larger sectors do not necessarily engage in more instances of collaboration.

The A sector is seen to collaborate extensively both intra- and cross-sectorally as it is present in the highest ranking collaboration types for both cases, and is seen to readily collaborate with all other sectors. Interestingly, the S sector is found to be present in one of the highest ranking cross-sectoral collaboration types (AS), as well as the two lowest (IS and HS).

A similar analysis was carried out to investigate the extent of international collaboration, the results of which are also shown in Table 3. Local only (*l-l*) collaboration is shown in bold text, while local-foreign (*l-f*) collaboration is shown in normal text. The number of local institutions in the network is about the same as the number of foreign institutions (56 and 60 respectively). Nonetheless the *l-l* density is almost three times greater than that of the *l-f* collaborations. Even though foreign institutions do have a presence in the South African medical device development landscape, local institutions collaborate far more extensively with one another than with foreign institutions.

Collaboration type prevalence

Publications were sorted according to the type of sectoral collaboration each represented. The number of publications thus found was further divided to show collaborations that involved only local institutions; mixed collaborations with more than one local institution and additional foreign involvement; and, foreign collaborations (a single local institution collaborating with foreign institutions). The proportions of the local, mixed and foreign collaborations are indicated in Figure 2.



A, academia; H, healthcare; I, industry; S, science and support.

Figure 2: Number of publications during the period 2000–2013 classified according to sectoral collaboration.

Table 3: Quantitative measures of within-group (bold text; intra-sectoral or local) and between-group (normal text; cross-sectoral or international) collaboration

	A		H		I		S			Local	
	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$		ρ	$\sum ew$
A	**0.088**	**174**	0.070	114	0.049	46	0.063	40	Local	**0.116**	**356**
H	0.070	114	**0.065**	**82**	0.032	24	0.012	6	Foreign	0.041	138
I	0.049	46	0.032	24	**0.014**	**6**	0.014	4			
S	0.063	40	0.012	6	0.014	4	**0.044**	**8**			

ρ, density; ∑ew, sum of edge weights; A, academia; H, healthcare; I, industry; S, science and support.

Even though the number of foreign institutions (60) present in the network is slightly greater than the number of local institutions (56), 123 of the total 171 publications (72%) were found to represent local collaboration. This proportion far exceeded the 20 publications (12%) representing mixed collaboration and 28 publications (16%) showing foreign collaboration. Thus local institutions collaborate far more locally than internationally. This observation is in agreement with the findings of Sooryamoorthy[49] who investigated partnership trends evident in South African medical research (1975–2005). Sooryamoorthy[49] showed that out of 5642 medical research publications, only 20.6% involved international partnerships in which at least one co-author was affiliated with an institution from a foreign country.

In Figure 2, translational collaboration types are represented by the columns labelled AHI, HIS and AHIS. Of these three collaboration types, AHI was the most active, HIS had no publications, and AHIS only had mixed collaborations. The low number of publications (7%; 12 out of 171) involving translational collaborations may be indicative of the biomedical innovation chain in South Africa not fully utilising the pathways presented by Lander and Atkinson-Grosjean[2]. Even though there is evidence of medical device development activity and cross-sectoral collaboration occurring locally within the country, the lack of translational collaborations could indicate that the devices being developed may not be relying on evidence of healthcare needs from the H sector, or are not reaching the market (lack of I sector involvement). However, the fact that there are institutions from the various sectors engaging in medical device development, means that collaborative opportunities exist. A study by Chinchilla-Rodríguez et al.[50] investigating medical research collaboration in Latin America and the Caribbean (2003–2007) showed that through the implementation of policies to promote desired intra-regional collaboration, the growth of select collaboration types can indeed be fostered.

Summary and conclusion

We examined the South African medical device development landscape for the period 2000–2013. Through a bibliometric analysis in which co-authorship on scientific papers was interpreted as an indicator of collaboration, a collaboration network of the medical device development field was produced. Four sectors – academia, healthcare, industry, and science and support – were identified as being active in device development. The dominant institutions within the network were identified according to their influence on other institutions, their ability to quickly disseminate information through the network, and their ability to broker the exchange of information between institutions. Of these, seven local institutions, from three of the four sectors (4-A, 2-H, 1-S), were found to be the most dominant. The three highest-ranking dominant institutions were the University of Cape Town (UCT), Groote Schuur Hospital (GSH) and Stellenbosch University (SUN).

Collaboration activities at the sectoral level were investigated. With regard to intra-sector collaboration, the A sector collaborated the most, followed by the H sector and then the S sector.

About the same number of local and foreign institutions (56 and 60, respectively) were present in the network. The local institutions, however, were seen to collaborate far more with each other (72% of all collaborations) than with international institutions (28%).

There were far fewer translational collaborations – involving at least three different sectors (A or S, H and I) – present in the South African medical device field, compared with intra-sectoral collaborations, or cross-sectoral collaborations involving two different sectors. Thus there is room for increased translational collaboration within South Africa, potentially for greater health impact. Policies structured to help engender more cross-sector interaction could benefit medical device development, by creating opportunities for more translational collaborations.

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Authors' contributions

T.S.D. was the project leader and was responsible for funding acquisition. K.d.J., C.C. and T.S.D. were responsible for conceptualisation and developed the bibliometric and network analysis methodology employed. K.d.J. oversaw the data collection and analysis. K.d.J. and C.C. were responsible for data curation. T.S. developed the theoretical framework. K.d.J. wrote the initial draft of the manuscript. C.C., T.S. and T.S.D. contributed to the interpretation of results and reviewed and edited the manuscript.

References

1. Hicks D, Katz JS. Hospitals: The hidden research system. Sci Public Policy. 1996;23(5):297–304. https://doi.org/10.1093/spp/23.5.297
2. Lander B, Atkinson-Grosjean J. Translational science and the hidden research system in universities and academic hospitals: A case study. Soc Sci Med. 2011;72(4):537–544. https://doi.org/10.1016/j.socscimed.2010.11.019
3. Lander B. Sectoral collaboration in biomedical research and development. Scientometrics. 2013;94(1):343–357. https://doi.org/10.1007/s11192-012-0776-8
4. Lester RK. Universities, innovation, and the competitiveness of local economies: A summary report from the Local Innovation Systems Project – Phase I. Working Paper 05-010 [document on the Internet]. c2005 [cited 2016 Jul 13]. Cambridge, MA: Industrial Performance Center, Massachusetts Institute of Technology. Available from: http://web.mit.edu/lis/papers/LIS05-010.pdf
5. Lander B. The role of institutions and capital in intersectoral collaboration: Infection and immunity research and development collaboration in Vancouver. Rev Policy Res. 2014;31(5):390–407. https://doi.org/10.1111/ropr.12086
6. Fries RC, Glave SA, Radick MK. The benefits of industry–university interaction. In: Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); 2008 August 20–25; Vancouver, Canada. IEEE; 2008. p. 1598–1601. https://doi.org/10.1109/IEMBS.2008.4649477
7. Douglas TS. Drivers and restrainers of relevance in graduate BME education – A South African study. In: Proceedings of the 34th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); 2012 August 28 – September 01; San Diego, CA, USA. IEEE; 2012; p. 5054–5057. https://doi.org/10.1109/EMBC.2012.6347129
8. The Academy of Medical Sciences FORUM. Academia, industry and the NHS: Collaboration and innovation – Meeting report. c2010 [cited 2014 Nov 27]. Available from: http://www.acmedsci.ac.uk/viewFile/publicationDownloads/Collabor.pdf
9. Breschi S, Catalini C. Tracing the links between science and technology: An exploratory analysis of scientists' and inventors' networks. Res Policy. 2010;39(1):14–26. https://doi.org/10.1016/j.respol.2009.11.004
10. Meyer M, Bhattacharya S. Commonalities and differences between scholarly and technical collaboration. Scientometrics. 2004;61(3):443–456. https://doi.org/10.1023/B:SCIE.0000045120.04489.80
11. Abbasi A, Altmann J. On the correlation between research performance and social network analysis measures applied to research collaboration networks. In: Proceedings of the 2011 44th Hawaii International Conference on System Sciences (HICSS); 2011 January 4–7; Kauai, HI, USA. IEEE; 2011. p. 1–10. https://doi.org/10.1109/HICSS.2011.325
12. Gazni A, Sugimoto CR, Didegah F. Mapping world scientific collaboration: Authors, institutions, and countries. J Am Soc Inf Sci Tec. 2012;63(2):323–335. https://doi.org/10.1002/asi.21688
13. Ding Y. Scientific collaboration and endorsement: Network analysis of coauthorship and citation networks. J Informetr. 2011;5(1):187–203. https://doi.org/10.1016/j.joi.2010.10.008

14. Newman M. Scientific collaboration networks I: Network construction and fundamental results. Phys Rev E. 2001;64(1), Art. #016131, 8 pages. https://doi.org/10.1103/PhysRevE.64.016131

15. Ramlogan R, Mina A, Tampubolon G, Metcalfe JS. Networks of knowledge: The distributed nature of medical innovation. Scientometrics. 2007;70(2):459–489. https://doi.org/10.1007/s11192-007-0212-7

16. Abramo G, D'Angelo CA, Solazzi M. Are researchers that collaborate more at the international level top performers? An investigation on the Italian university system. J Informetr. 2011;5(1):204–213. https://doi.org/10.1016/j.joi.2010.11.002

17. Hoekman J, Frenken K, Tijssen RJ. Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. Res Policy. 2010;39(5):662–673. https://doi.org/10.1016/j.respol.2010.01.012

18. Ynalvez MA, Shrum WM. Professional networks, scientific collaboration, and publication productivity in resource-constrained research institutions in a developing country. Res Policy. 2011;40(2):204–216. https://doi.org/10.1016/j.respol.2010.10.004

19. Powell WW, Koput KW, Smith-Doerr L. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Admin Sci Quart. 1996;41(1):116–145. https://doi.org/10.2307/2393988

20. Franceschet M, Costantini A. The effect of scholar collaboration on impact and quality of academic papers. J Informetr. 2010;4(4):540–553. https://doi.org/10.1016/j.joi.2010.06.003

21. Glänzel W, Schubert A. Double effort = double impact? A critical view at international co-authorship in chemistry. Scientometrics. 2001;50(2):199–214. http://dx.doi.org/10.1023/A:1010561321723

22. Qin J. An investigation of research collaboration in the sciences through the philosophical transactions 1901–1991. Scientometrics. 1994;29(2):219–238. https://doi.org/10.1007/BF02017974

23. Yan E, Ding Y. Applying centrality measures to impact analysis: A coauthorship network analysis. J Am Soc Inf Sci Tec. 2009;60(10):2107–2118. https://doi.org/10.1002/asi.21128

24. Hanneman RA, Riddle M. Introduction to social network methods. Riverside, CA: University of California; 2005.

25. Landherr A, Friedl B, Heidemann J. A critical review of centrality measures in social networks. Bus Inf Syst Eng. 2010;2(6):371–385. https://doi.org/10.1007/s12599-010-0127-3

26. Valente TW, Coronges K, Lakon C, Costenbader E. How correlated are network centrality measures? Connect (Tor). 2008;28(1):16–26.

27. Opsahl T, Agneessens F, Skvoretz J. Node centrality in weighted networks: Generalizing degree and shortest paths. Soc Networks. 2010;32(3):245–251. https://doi.org/10.1016/j.socnet.2010.03.006

28. Abbasi A, Hossain L, Leydesdorff L. Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks. J Informetr. 2012;6(3):403–412. https://doi.org/10.1016/j.joi.2012.01.002

29. Dolev S, Elovici Y, Puzis R. Routing betweenness centrality. J Acm. 2010;57(4):1–27. https://doi.org/10.1145/1734213.1734219

30. Okamoto K, Chen W, Li XY. Ranking of closeness centrality for large-scale social networks. In: Preparata FP, Wu X, Yin J, editors. Frontiers in algorithmics. Lecture notes in computer science volume 5059. Berlin: Springer; 2008. p. 186–195. https://doi.org/10.1007/978-3-540-69311-6

31. Wehmuth K, Ziviani A. DACCER: Distributed Assessment of the Closeness CEntrality Ranking in complex networks. Comput Netw. 2013;57(13):2536–2548. https://doi.org/10.1016/j.comnet.2013.05.001

32. Chimhundu C, De Jager K, Douglas T. Sectoral collaboration networks for cardiovascular medical device development in South Africa. Scientometrics. 2015;105(3):1721–1741. https://doi.org/10.1007/s11192-015-1743-y

33. Thijs B, Glänzel W. A structural analysis of collaboration between European research institutes. Res Evaluat. 2010;19(1):55–65. https://doi.org/10.3152/095820210X492486

34. Pouris A, Ho YS. Research emphasis and collaboration in Africa. Scientometrics. 2013;98(3):2169–2184. https://doi.org/10.1007/s11192-013-1156-8

35. Glänzel W, Schubert A. Analysing scientific networks through co-authorship. In: Moed HF, Glänzel W, Schmoch U, editors, Handbook of quantitative science and technology research. Dordrecht: Springer Netherlands; 2005. p. 257–276. https://doi.org/10.1007/1-4020-2755-9_12

36. Global Harmonization Task Force Study Group 1. Information document concerning the definition of the term "medical device". c2005 [cited 2014 Jul 07]. Available from: http://www.imdrf.org/docs/ghtf/final/sg1/technical-docs/ghtf-sg1-n29r16-2005-definition-medical-device-050520.pdf

37. World Health Organization (WHO). Medical devices: Managing the mismatch: An outcome of the priority medical devices project. Geneva: WHO; 2010. Available from: http://apps.who.int/iris/ bitstream/10665/44407/1/9789241564045_eng.pdf

38. Booysen G, De Beer D, Truscott M, Combrinck J, Mosimanyane D. Combining additive fabrication and conventional machining technologies to develop a hybrid tooling approach. In: Proceedings of the 21st International DAAAM Symposium volume 21. Vienna: DAAAM International; 2010. p. 1563–1564. Available from: http://www.daaam.info/Downloads/Pdfs/proceedings/proceedings_2010/24988_Annals_1_head.pdf

39. Saleh MG, Sharp SK, Alhamud A, Spottiswoode BS, Van der Kouwe AJW, Davies NH, et al. Long-term left ventricular remodelling in rat model of nonreperfused myocardial infarction: Sequential MR imaging using a 3T clinical scanner. J Biomed Biotechnol. 2012;2012, Art. #504037, 10 pages. https://doi.org/10.1155/2012/504037

40. Bosanquet D, John L. A method for investigating alpha band phase synchronization in the cortex during a fatiguing muscle contraction using EEG. In: The 2006 International Conference on Scientific Computing (CSC). USA. 2006. Available from: https://www.semanticscholar.org/paper/A-Method-For-Investigating-Alpha-Band-Phase-Bosanquet-John/b6b6a00a836a21f6af7c3480d5ed6c3f57934d0a

41. Borgatti SP, Everett MG, Freeman LC. Ucinet for Windows: Software for social network analysis. Harvard, MA: Analytic Technologies; 2002. Available from: https://sites.google.com/site/ ucinetsoftware/home

42. Borgatti SP. NetDraw software for network visualization. Lexington, KY: Analytic Technologies; 2002. Available from: https://sites.google.com/site/netdrawsoftware/home

43. De Prato G, Nepelski D. Global technological collaboration network: Network analysis of international co-inventions. J Technol Transf. 2014;39(3):358–375. https://doi.org/10.1007/s10961-012-9285-4

44. Abbasi A, Altmann J, Hossain L. Identifying the effects of co-authorship networks on the performance of scholars: A correlation and regression analysis of performance measures and social network analysis measures. J Informetr. 2011;5(4):594–607. https://doi.org/10.1016/j.joi.2011.05.007

45. Cimenler O, Reeves KA, Skvoretz J. A regression analysis of researchers' social network metrics on their citation performance in a college of engineering. J Informetr. 2014;8(3):667–682. https://doi.org/10.1016/j.joi.2014.06.004

46. Rodriguez Miramontes J, Gonzalez-Brambila CN. The effects of external collaboration on research output in engineering. Scientometrics. 2016;109(2):661–675. https://doi.org/10.1007/s11192-016-2054-7

47. Laudel G. What do we measure by co-authorships? Res Evaluat. 2002;11(1):3–15. https://doi.org/10.3152/147154402781776961

48. Goh KI, Oh E, Jeong H, Kahng B, Kim D. Classification of scale-free networks. Proc Natl Acad Sci USA. 2002;99(20):12583–12588. https://doi.org/10.1073/pnas.202301299

49. Sooryamoorthy R. Medical research in South Africa: A scientometric analysis of trends, patterns, productivity and partnership. Scientometrics. 2010;84(3):863–885. https://doi.org/10.1007/s11192-010-0169-9

50. Chinchilla-Rodríguez Z, Benavent-Pérez M, De Moya-Anegón F, Miguel S. International collaboration in medical research in Latin America and the Caribbean (2003–2007). J Am Soc Inf Sci Tec. 2012;63(11):2223–2238. https://doi.org/10.1002/asi.22669

Stable isotope ($\delta^{13}C$) profiling of xylitol and sugar in South Africa

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Xylitol is an alternative sweetener to sucrose, glucose and fructose, and is available under a number of brands in South Africa. Carbon stable isotope values ($\delta^{13}C$) of a selection of commercially available xylitol products ($n=28$) were analysed and compared with sugar samples ($n=29$). Sugarcane (C_4) and beet sugar (C_3) derived sugar samples aligned with published values of source, although two samples that indicated a sugarcane origin suggested a beet sugar origin. Control corn-derived samples defined a stepwise xylose to xylitol discrimination of +0.7‰. The distinction between C_3- and C_4-derived xylitol was less clear with three samples difficult to define (range = -14.8 to -17.1‰). The values for a suite of xylitol samples (-22.3‰ to -19.7‰; $n=8$) that aligned closely with a suspected C_3-derived xylose, were ~8‰ more positive than known birch isotope values. Some xylitol samples may thus represent (1) a mixture of C_3- and C_4-derived products, (2) derivation from a CAM species source or (3) different processing techniques in which the discrimination values of xylose from corn, and xylose from birch, may differ because of the respective chemical processing techniques. No samples that claimed a birch bark origin were within the range of samples suggested to be corn derived (i.e. -13.0‰ to -9.7‰, $n=16$). We suggest that the threshold values provided are relatively robust for defining the origins of xylitol and sugar, and can be used in determining the authenticity and claims of suppliers and producers.

Significance:

- Stable isotope ($\delta^{13}C$) profiles of commercially available xylitol and sugar products in South Africa will enable the determination of authenticity.

Introduction

Sucrose or 'table sugar', together with its disaccharide constituents – fructose and glucose – are important in the global economy as the major sweeteners of food and beverages.[1-5] The intake of free sugars modifies both energy intake and body weight, and has been shown to be harmful by fuelling the development of obesity.[1-3] Added sugars in processed foods and beverages are linked to the development of diabetes, obesity and metabolic syndrome.[6,7] A positive behavioural response to these health risks, especially healthy eating and increased physical activity is important.[2,8-10] The intake of alternative sweeteners (artificial and non-nutritive) may reduce these health risks[9,11] and consequently the alternative sweetener market has increased in recent times[5,12].

Xylitol (D-erythro-pentitol), a reduced-calorie sweetener, is a five-carbon sugar alcohol or polyol ($C_5H_{12}O_5$), also known as wood or birch sugar[10,13], that occurs naturally in small quantities in a variety of plants[9,14-16], fruits and vegetables[4,17-19] and is even produced in the human body[10]. It has been used as a sweetening agent in food since the 1960s[20,21], in chewing gums, mints, sweets and toothpaste and also as a sugar substitute in confectionery and drinks[4,18]. Evidence suggests that it may prevent dental caries[15], ear and upper respiratory tract infections[4,18], the development of obesity[22], and can be safely consumed by sufferers of diabetes type I and II, as it has the capacity to stabilise blood sugar levels[4,22]. In comparison with other alternative sweeteners, xylitol is similar in sweetness to sucrose with a lower calorie content (2.4 vs 4.0 cal/g).[16,22]

On an industrial scale, xylitol is currently produced by chemical reduction of xylose (D-xylose), traditionally derived from the bark of birch trees (*Betula pendula*) and other hardwoods.[4,23,24] More recently, corncobs (*Zea mays*)[25], sugarcane bagasse, and wheat, sorghum and rice straw[26-28] have been used as sources of xylose; in China, xylitol production from corncob reached 50 000 tons in 2008[25,29]. Production from corncob is favoured as it is less expensive than production from birch.[30] Alternative methodologies to produce xylitol utilise yeasts (e.g. *Candida* sp.), bacteria and fungi.[4,17,31,32] The annual demand for xylitol is over 100 000 tons worldwide, with a selling price of USD4–5/kg and an economic value of up to USD537 million per year.[4,25,33] Asia produces 50% of the world's total xylitol, with the balance produced in Europe, the USA and Australia.[25] The largest producer of xylitol in the world has production plants in Finland, the USA and China.[25,34]

Food adulteration (or fraud) occurs when external substances are added to a food product and it is economically motivated when added or substituted (with lower-valued ones) to increase a product's value or to reduce production costs.[35-38] This has the overall negative effect of raising health concerns, reducing consumer confidence, and decreasing the sale of authentic products.[36] Stable isotope analysis is one method to identify food adulteration, where the botanical origin, geographical origin, and specific farming regime or production system of a product can potentially be determined.[35,36,38] Stable isotope analysis has been successfully utilised to detect the adulteration of honey with cheaper sugars[37,39-41] and olive oil with pomace oil[42], and CO_2 in apple cider (C_3) with a C_4 carbon isotope value may suggest the incorporation of C_4 sugars[43].

The fundamental variation in the ratios of stable carbon isotopes in terrestrial food webs stems from differences in the photosynthetic pathways of plants.[44-48] The majority of plants utilise the Calvin cycle (C_3) and have tissues with a mean $\delta^{13}C$ value of approximately -26.5‰. The $\delta^{13}C$ values of plants relying upon the Hatch-Slack pathway (C_4) – mainly tropical grasses including maize (corn), millet and sugarcane – are much higher, with a mean stable

isotope value of approximately -12.5‰. Plants utilising a third pathway, crassulacean acid metabolism (CAM), present intermediate $\delta^{13}C$ values ranging from -27‰ to -12‰.[49] The $^{13}C/^{12}C$ isotope ratio can thus be used to identify a product's botanical origin.[38]

In South Africa, xylitol is available from local retailers, supermarkets and health stores, with a number of brands available to the public. Xylitol is one of the more recent alternatives to sugar (sucrose, fructose, glucose) and claims on the origins of products vary, from those indicating a birch bark or corn origin, to those for which the source is unknown or not disclosed. The aim of this study was to isotopically profile xylitol products available in South Africa, in an attempt to define their likely origin: from C_3 (e.g. birch bark) or C_4 (e.g. corn) plants. For comparison, we analysed sugar samples that were expected to reflect distinct origins from either sugarcane *Saccharum* spp. (C_4) or sugar beet *Beta vulgaris* (C_3). By doing so we attempt to present a critical assessment of these commercially available sweeteners that adds to consumer transparency and the integrity of food products currently available on the South African market.

Materials and methods

Samples

Samples of xylitol products ($n=28$; including duplicates for two brands) available in South Africa were purchased from various retailers (January 2015 – November 2016), mostly in the Gauteng Province. Information was collected from each product regarding (1) country of origin and (2) claimed source (if disclosed). Of the 28 samples, 10 disclosed the source on the packaging. Anonymity of the selected brands is assured through assigned control numbers to each sample. In all instances we assumed products to be 100% xylitol, as indicated by the packaging.

To understand the relationship between xylose and xylitol we sourced two laboratory xylose samples, a sample of xylose from a Chinese supplier and derived xylitol (from the supplier of one of the brands for which we sourced repeat samples). To understand the likely source species we compared them to published isotope values of corn and birch – the two most common sources of xylitol. In addition, we measured the carbon isotope value of a birch bark and a birch leaf sample collected on the University of the Witwatersrand east campus (in Johannesburg) in December 2016.

We obtained additional sugar (fructose, glucose and sucrose) samples as controls ($n=29$) because South African table sugar (sucrose) is mainly derived from sugarcane (C_4) and European sugar from sugar beet (C_3). Some of these samples also included laboratory samples ($n=8$), of which three samples were indicated to be derived from *Agave* (a CAM photosynthesiser) and two samples were indicated to be derived from coconut, *Cocos nucifera*.

To assess the likely mixing of xylitol from different sources, in which the different sources may contain different size xylitol crystals, we selected three samples (X1, X3, X7) and separated them into $>500\,\mu$m or $<500\,\mu$m constituents (Labotec™, Star Screens, Booysens, Johannesburg, South Africa, sieve conforms to SABS197-ISO9002 specifications) for stable isotope analysis. A 28–33 g amount of each sample was separated into the different constituent size classes and prepared for isotope analysis.

Sample preparation for $\delta^{13}C$ analyses

Duplicate subsamples (0.4–0.5 mg) of all xylitol, xylose and sugar samples were weighed into tin cups (pre-cleaned in toluene) for analysis. For every four samples we weighed a gelatine (Merck) laboratory working standard (0.2, 0.4, 0.6 mg). Standards were of variable mass in order to determine if there was any sample size effect. The samples were combusted at 1020 °C on an EA1112 Elemental Analyser coupled to a DeltaV Plus stable light isotope mass spectrometer by a Conflo IV interface (all equipment supplied by Thermo Scientific, Bremen, Germany). These analyses were performed in the Mammal Research Institute stable light isotope laboratory at the University of Pretoria. Precision on the standard analyses was 0.11‰ and no sample size effect was noted. The stable isotopic values are expressed in delta (δ) notation in parts per thousand (per mille, ‰), relative to the international standard Vienna PeeDee belemnite (VPDB).

Results

The $\delta^{13}C$ values of the 28 branded xylitol samples ranged from -26.5‰ to -9.7‰ (Figure 1). The xylitol sample (X33) sourced from a Chinese supplier was 0.7‰ more positive than the xylose (Xy33=-11.5‰) from which it was derived (Figure 1). Fourteen xylitol values were more positive than the corn average of -12.4‰[48,50-53] (within 2.7‰), and two xylitol values were more negative but within 0.6‰.The two laboratory xylose samples had $\delta^{13}C$ values (-21.5‰ and -22.3‰) concomitant with eight xylitol samples (-22.3‰ to -19.7‰) (Figure 1). Three xylitol samples (-13.7‰, -15.2‰, -17.1‰) appeared unassociated with either of these apparent endpoints and a single xylitol sample (X14=-26.5‰) was 2.0‰ more positive than the mean birch isotope value (-28.5‰)[54-58] derived from the literature (Figure 1). The locally sampled birch bark and leaves measured -27.0‰ and -25.5‰, respectively. Seven samples (X14,X11=-20.4‰, X27=-20.2‰, X28=-20.0‰, X26=-19.9‰, X15=-15.2‰, X5=-13.7‰) had birch bark as the origin indicated on the package; with X26–X28 being the samples sourced from Finland. The packages of three xylitol samples indicated that they were corncob derived (X29=-11.0‰, X20=-10.7‰, X30=-10.5‰). For the three samples tested (X1, X3, X7), the isotope values of the different separated particle size classes ($<$ or $>500\,\mu$m) were similar (Table 1).

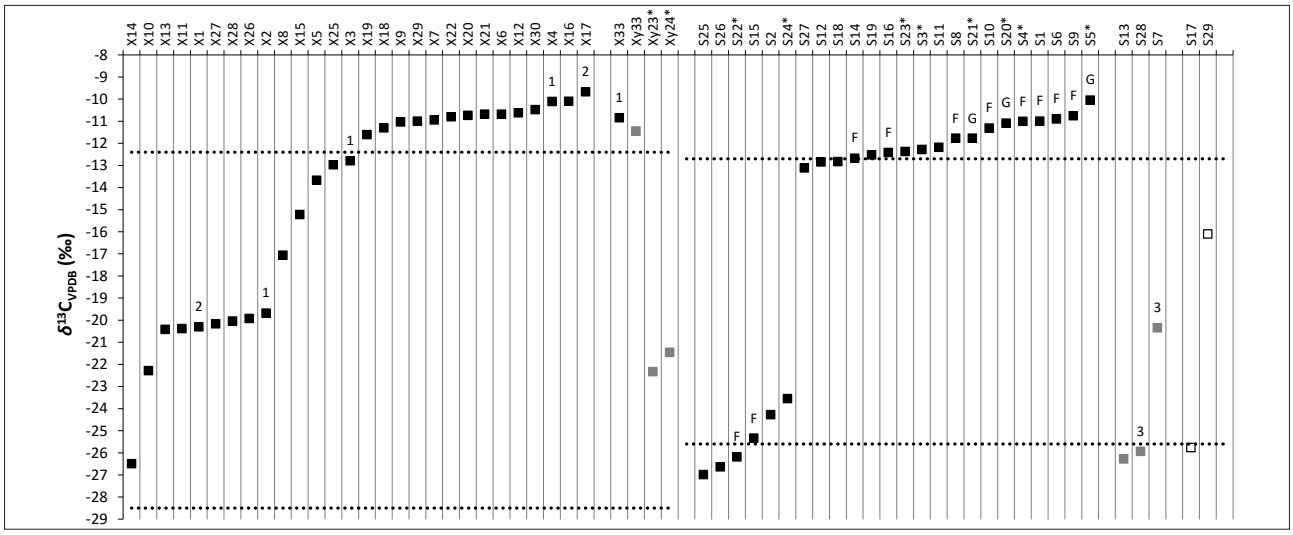
The sugar samples were clearly separated into two clusters: those C_4 derived (range: -13.1‰ to -10.0‰, $n=18$; cf. mean literature cane value of -12.7‰[41,48]), and those C_3 derived (range: -27.0‰ to -23.5‰, $n=6$; cf. mean sugar beet value of -25.6‰[41,59]). Three of the four C_3 commercially available sugar samples were sourced from Europe (one from the UK and two from Finland), i.e. they were of sugar beet origin. Two of the C_3 samples were indicated to be sugarcane derived (laboratory sucrose sample S24=-23.5‰ and fructose sample S15=-25.3‰). The samples that indicated an *Agave* origin (CAM) had a range of values (-26.3‰, -25.9‰, -20.3‰), and the two samples (S17 and S29) indicating a coconut blossom origin had contrasting values (-25.8‰ and -16.1‰, respectively; Figure 1).

Discussion

The hexose sugars sampled in this study suggest that stable isotope analysis is able to clearly define the origin of C_3- and C_4-derived sugars, with $\delta^{13}C$ values ranging from 27.0‰ to -23.5‰ and -13.1‰ to -10.0‰, respectively. These values in turn align, respectively, with the published $\delta^{13}C$ values for sugarcane and beet sugar. Sugars derived from *Agave* (a CAM photosynthesiser) yielded expected intermediate isotope values, but this finding does not affect the analysis, as CAM plants are not routinely used for xylitol production.

The xylitol isotope values are less clear. Because the chemical processes involved in the production of xylitol may vary, and are more complex than those for sugar production, we cannot be sure that stable isotopes unambiguously link source and product. In one of the manufacturing processes, xylose in hemicellulosic hydrolysate fractions is converted to xylitol by a chemical catalytic reaction,[24] but other processes may be used and it is unclear if different chemical processes are the reason for the range of values observed. If the processing method is discounted, then the variation in isotope signatures in commercially available xylitol in South Africa may indicate many different sources.

To understand the isotopic relationship between xylitol and its precursor, namely xylose, we sourced xylose and the derivative xylitol from a Chinese manufacturer (and the supplier of one of the brands sampled). In this assessment, we found very little difference between the two samples (xylitol ‰ = xylose + 0.7 ‰), suggesting that 14 samples, with $\delta^{13}C$ values ranging from -13.0‰ to -9.7‰, are most likely derived from corn (or some other C_4 plant). In support of this conclusion is a mean corn value of -12.4‰ reported in the literature. If this $\delta^{13}C$ discrimination from xylose to xylitol is minimal for C_4-derived xylitol, it is difficult to align the group of eight xylitol samples (-22.3‰ to -19.7‰) to a C_3 origin if the mean published birch (-28.5‰) and the local birch (mean=-26.3‰) values are significantly more negative than the xylitol samples claimed to be derived from birch.



Dotted lines indicate endpoints for (1) xylitol; mean maize (corn) Zea mays *$\delta^{13}C$=-12.4‰, includes seeds and cob values[48,50-53], mean birch* Betula pendula *$\delta^{13}C$=-28.5‰, includes leaves and wood[54-58] and (2) sugar; mean sugarcane* Sacharrum *spp. $\delta^{13}C$=-12.7‰[41,48], mean sugar beet* Beta vulgaris *$\delta^{13}C$=-25.6‰[41,59].*

**indicates laboratory samples.*

For xylitol samples: Xy indicates xylose samples (grey markers), similar numbers indicate same brand name.

For sugar samples: sucrose unless indicated; F, fructose; G, glucose. Grey sugar markers indicate Agave *(CAM photosynthesiser) derived sugars; similar numbers indicate same brand name; open sugar markers indicate sugar samples derived from coconut blossom.*

Figure 1: The $\delta^{13}C$ values of 29 xylitol, 3 xylose and 29 sugar samples. See Supplementary tables 1 and 2 for isotope values of samples presented in the figure, and values and references for calculated mean endpoint values for xylitol and sugar.

Table 1: $\delta^{13}C$ values of different xylitol granule size components (>500 μm and <500 μm), with proportions (%) of each size category indicated

Sample	Combined	>500 μm		<500 μm	
	$\delta^{13}C_{VPDB}$ (‰)	%	$\delta^{13}C_{VPDB}$ (‰)	%	$\delta^{13}C_{VPDB}$ (‰)
X1	**-20.3**	54.7	**-19.9**	45.3	**-19.8**
X3	**-13.3**	91.0	**-12.8**	9.0	**-12.4**
X7	**-10.7**	95.9	**-10.8**	4.1	**-10.8**

However, two forms of evidence suggest that these samples are birch authentic; first, three of the samples (within 0.3‰ of each other) are from Finland and we suggest that we are less likely to observe any adulteration in the country in which this process was developed, and second, two xylose values (albeit laboratory samples) that are similar to these samples lend support to the fact that they may be pure C_3 derived (in the same way that we recognise a close isotopic link between C_4 xylose and the derived xylitol in the factory control). The different discrimination values between xylose (and xylitol) and the plants from which they are thought to be derived, i.e. C_3 or C_4, may be a consequence of different chemical processes, and this remains to be investigated further. If not, then an entire suite of available C_3 xylitol products may be consistently adulterated with C_4 xylitol.

Only one sample (X14) was within 2.0‰ of the published values for birch. This sample warranted further investigation and for this and a number of other products, contact with the supplier was made to obtain further insight on their products. It was ascertained that xylitol in the product X5 was supplied by the packager of X15. Also, X15's supplier supplied the xylitol in X14, but further communication revealed that X14 had been withdrawn from the market because of suspected mistrust with X15. Because X14 was 'suspicious', one of us (C.S.) tasted it. The lack of a subtle cooling effect in the mouth (a characteristic of xylitol)[5] and an aftertaste reminiscent of other sweeteners (e.g. stevia) added basis to the idea that we were dealing with a likely adulterated food product. Analysing the contents of all samples is beyond the scope of this study, but given this outcome, it is an investigation that should be undertaken.

Two brands are represented more than once (Figure 1), and in each case the within-product isotope values are different; which may be explained by a change in supplier.

To test the possibility that sample contents may comprise mixed origins we analysed samples separated by size (< or >500 μm; n=3 samples). For each (although the proportions of each size class were different between products), we found no difference in the isotope values of the two fractions. This analysis included one sample for which the source (C3 or C4) was not clear. This finding suggests, at least at this scale, that the sample was not derived from separate sources.

In 36% (n=10) of xylitol samples, the country of origin was not disclosed on the packaging, and information regarding the origin and source was sometimes vague, e.g. 'fibrous parts of plant', or lacking. The *South African Foodstuffs, Cosmetics and Disinfectants Act* (*Act no. 54 of 1972)*, which includes regulations on the labelling and advertising of foods (Government Gazette No 37695, May 2014), prescribes numerous requirements that do not appear on a number of the products. These inconsistencies, in what appear to be standard labelling requirements, may result in consumers being mis- or uninformed regarding the products they are purchasing. Xylitol available in South Africa is not produced locally but, to the best of our knowledge, imported. In China, the waste biomass available after preparing corncobs (C_4) for the food industry provides a substrate for xylitol production[25,29], yet negative perceptions regarding the source (and country) of certain products may persist for consumers. In the USA, hydrosylate from birch trees (C_3) is utilised as a substrate for xylitol production[25] and it is also potentially produced from other hardwood (C_3) species[26]. Even though xylitol produced from birch may appeal to a discerning market, although it may be more expensive, there is no other major difference between birch-sourced and corn-sourced xylitol. Therefore, both information that is provided and a lack of information, can be misleading for the consumer.

Xylitol is traded all over the world. South Africa is simply one example of an importer vulnerable to adulteration and/or misinformation originating at either the source or locally; making this work of both national and international relevance. The carbon isotope data prima facie suggest that most xylitol samples represent origins suggesting either a C_3 or a C_4 source. For four samples, we question a single C_3 or C_4 source (intermediate isotope values; X8, X15, X5), or authenticity as xylitol

(X14). However, other reasons may explain these findings, including that: (1) the samples represent both C_3 and C_4 origins (mixture of different products; although this was not apparent in the three samples for which we measured the isotope value of different size granules), (2) different processing techniques result in fractionation processes that result in isotope values of the product not aligned with the source (we suggest that this is unlikely because the wide range of isotope values obtained would then suggest many processing techniques), (3) the isotope values of the samples do align with the source, but it is rather the source that (for whatever reason) does not have a clearly distinguishable C_3 or C_4 signature, (4) these intermediate products represent xylitol with a CAM origin (although in no sample was this disclosed, and we are not aware of any xylitol derived from a CAM species), or (5) adulteration with non-xylitol additives (e.g. flow agents, other artificial sweeteners like stevia or erythritol) affected the final $\delta^{13}C$ of the marketed product. Because marketers are not obliged to disclose the origins or methods of processing, the intention is thus not to challenge the authenticity of those marketing these products, but rather to challenge the information (or lack thereof) in the marketing process. Stable isotope analyses may be a suitable method to distinguish the origin of commercially available xylitol, especially when this is not clearly stated on the packaging or label. This study thus provides information that may be used to profile C_3- or C_4-derived sugar and xylitol products, and to lay a foundation for further investigations regarding these products in the food market. However, a priori information may be required regarding chemical processes that present source-product variation in isotope signatures, before conclusive origins (i.e. C_3 or C_4) can be defined, and before any isotope interpretation can be applied in a forensic assessment.

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Authors' contributions

C.S. conceived the project; E.L. and C.S. collected and prepared samples; S.W. analysed samples; all authors contributed to data interpretation and the write-up.

References

1. Bray G, Popkin B. Dietary sugar and body weight: Have we reached a crisis in the epidemic of obesity and diabetes? Diabetes Care. 2014;37:950–956. https://doi.org/10.2337/dc13-2085
2. Temple N, Steyn N. Sugar and health: A food-based dietary guideline for South Africa. S Afr J Clin Nutr. 2013;26:S100–S104.
3. Schmid M. Sugar and spice yet today everything is not so nice. Revista Alimentos Hoy. 2012;21:3–6.
4. Rehman S, Mushtaq Z, Zahoor T, Jamil A, Murtaza M. Xylitol: A review on bioproduction, application, health benefits, and related safety issues. Crit Rev Food Sci Nutr. 2015;55:1514–1528. https://doi.org/10.1080/10408398.2012.702288
5. Grembecka M. Sugar alcohols as sugar substitutes in food industry. In: Mérillon J-M, Ramawat KG, editors. Sweeteners: Pharmacology, biotechnology, and applications. Zug: Springer International Publishing; 2016. p. 1–27. https://doi.org/10.1007/978-3-319-26478-3_23-1
6. DiNicolantonio JJ, O'Keefe JH, Lucan SC. Added fructose: A principal driver of type 2 diabetes mellitus and its consequences. Mayo Clinic Proc. 2015;90(3):372–381. https://doi.org/10.1016/j.mayocp.2014.12.019
7. Malik VS, Popkin BM, Bray GA, Després J-P, Hu FB. Sugar-sweetened beverages, obesity, type 2 diabetes mellitus, and cardiovascular disease risk. Circulation. 2010;121(11):1356–1364. https://doi.org/10.1161/CIRCULATIONAHA.109.876185
8. Wing RR, Goldstein MG, Acton KJ, Birch LL, Jakicic JM, Sallis JF Jr, et al. Behavioral science research in diabetes: Lifestyle changes related to obesity, eating behavior, and physical activity. Diabetes Care. 2001;24(1):117–123. https://doi.org/10.2337/diacare.24.1.117
9. Chattopadhyay S, Raychaudhuri U, Chakraborty R. Artificial sweeteners – A review. J Food Sci Technol. 2014;51:611–621. https://doi.org/10.1007/s13197-011-0571-1
10. Grembecka M. Sugar alcohols – Their role in the modern world of sweeteners: A review. Eur Food Res Technol. 2015;241(1):1–14. https://doi.org/10.1007/s00217-015-2437-7
11. Martä N, Funes L, Saura D, Micol V. An update on alternative sweeteners. Agrofood Industry Hi-tech. 2008;19:8–10.
12. Ruprecht W. The historical development of the consumption of sweeteners – A learning approach. J Evol Econ. 2005;15(3):247–272. https://doi.org/10.1007/s00191-005-0253-0
13. O'Brien Nabors L, editor. Alternative sweeteners. 4th ed. Boca Raton, FL: CRC Press; 2012.
14. Mäkinen KK, Söderling EVA. A quantitative study of mannitol, sorbitol, xylitol, and xylose in wild berries and commercial fruits. J Food Sci. 1980;45(2):367–371. https://doi.org/10.1111/j.1365-2621.1980.tb02616.x
15. Mäkinen K. Sugar alcohol sweeteners as alternatives to sugar with special consideration of xylitol. Med Prin Pract. 2011;20:303–320. https://doi.org/10.1159/000324534
16. Rehman S, Murtaza MA, Mushtaq Z. Xylitol as sweetener. In: Merillon J-M, Ramawat KG, editors. Sweeteners: Pharmacology, biotechnology, and applications. Zug: Springer International Publishing; 2016. p. 1–21. https://doi.org/10.1007/978-3-319-26478-3_30-1
17. Da Silva S, Chandel A. D-Xylitol. Fermentative production, application and commercialization. Berlin: Springer-Verlag; 2012.
18. Granström T, Izumori K, Leisola M. A rare sugar xylitol. Part I: The biochemistry and biosynthesis of xylitol. Appl Microbiol Biotechnol. 2007;74:277–281. https://doi.org/10.1007/s00253-006-0761-3
19. Rehman S, Nadeem M, Ahmad F, Mushtaq Z. Biotechnological production of xylitol from banana peel and its impact on physicochemical properties of rusks. J Agric Sci Technol. 2013;15(4):747–756.
20. Hyvönen L, Törmä R. Examination of sugars, sugar alcohols, and artificial sweeteners as substitutes for sucrose in strawberry sam. Keeping quality tests. J Food Sci. 1983;48(1):186–192. https://doi.org/10.1111/j.1365-2621.1983.tb14820.x
21. Olinger P, Pepper T. Xylitol. In: O'Brien Nabors L, editor. Alternative sweeteners. 4th ed. Boca Raton, FL: CRC Press; 2012. p. 349–378.
22. Mussatto S. D-Xylitol. Fermentative production, application and commercialization. In: Silva S, Chandel A, editors. Application of xylitol in food formulations and benefits for health. Berlin: Springer-Verlag; 2012. p. 309–324. https://doi.org/10.1007/978-3-642-31887-0_14
23. Rao RS, Jyothi CP, Prakasham RS, Sarma PN, Rao LV. Xylitol production from corn fiber and sugarcane bagasse hydrolysates by *Candida tropicalis*. Bioresour Technol. 2006;97(15):1974–1978. https://doi.org/10.1016/j.biortech.2005.08.015
24. Usvalampi A. Microbial production of xylitol, l-xylulose and l-xylose [doctoral dissertation]. Helsinki: Aalto University; 2013.
25. Ravella S, Gallagher J, Fish S, Prakasham R. Overview on commercial production of xylitol: Economic analysis and market trends. In: Da Silva S, Chandel A, editors. D-Xylitol fermentative production, application and commercialization. Berlin: Springer-Verlag; 2012. p. 291–308. https://doi.org/10.1007/978-3-642-31887-0_13
26. Gírio FM, Carvalheiro F, Duarte LC. Deconstruction of the hemicellulose fraction from lignocellulosic materials into simple sugars. In: Silva SS, Chandel AK, editors. D-Xylitol. Berlin: Springer-Verlag; 2012. p. 3–37. https://doi.org/10.1007/978-3-642-31887-0_1
27. Carvalho W, Santos J, Canilha L, Silva S, Perego P, Converti A. Xylitol production from sugarcane bagasse hydrolysate: Metabolic behaviour of *Candida guilliermondii* cells entrapped in Ca-alginate. Biochem Eng J. 2005;25(1):25–31. https://doi.org/10.1016/j.bej.2005.03.006
28. Camargo D, Sene L, Variz DILS, Felipe MdGdA. Xylitol bioproduction in hemicellulosic hydrolysate obtained from sorghum forage biomass. Appl Biochem Biotechnol. 2015;175(8):3628–3642. https://doi.org/10.1007/s12010-015-1531-4

29. Cheng K-K, Zhang J-A, Chavez E, Li J-P. Integrated production of xylitol and ethanol using corncob. Appl Microbiol Biotechnol. 2010;87:411–417. https://doi.org/10.1007/s00253-010-2612-5

30. Parthasarathy G. Cheaper production of xylitol [article on the Internet]. c2015 [cited 2015 May 07]. Available from: www.industrysourcing.com/article/cheaper-production-xylitol

31. Mohamad NL, Mustapa Kamal SM, Mokhtar MN. Xylitol biological production: A review of recent studies. Food Rev Int. 2015;31(1):74–89. https://doi.org/10.1080/87559129.2014.961077

32. Lachke AH, Jeffries TW. Levels of enzymes of the pentose phosphate pathway in *Pachysolen tannophilus* Y-2460 and selected mutants. Enzyme Microb Tech. 1986;8(6):353–359. https://doi.org/10.1016/0141-0229(86)90135-3

33. Prakasham R, Sreenivas Rao R, Hobbs P. Current trends in biotechnological production of xylitol and future prospects. Curr Trends Biotechnol Pharm. 2009;3:8–36.

34. Franceschin G, Sudiro M, Ingram T, Smirnova I, Brunner G, Bertucco A. Conversion of rye straw into fuel and xylitol: A technical and economical assessment based on experimental data. Chem Eng Res Des. 2011;89(6):631–640. https://doi.org/10.1016/j.cherd.2010.11.001

35. Moore J, Spink J, Lipp M. Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010. J Food Sci. 2012;77:R118–R126. https://doi.org/10.1111/j.1750-3841.2012.02657.x

36. Wei Y. Analytical techniques in food authentication. Paper presented at: 6th Asian Conference on Food and Nutrition Safety; 2012 November 26–28; Singapore, Singapore.

37. Mehryar L, Esmaiili M. Honey and honey adulteration: A review. Paper presented at: 11th International Congress on Engineering and Food; 2011 May 22–26; Athens, Greece.

38. Rossmann A. Determination of stable isotopes ratios in food analysis. Food Rev Int. 2001;17(3):347–381. https://doi.org/10.1081/FRI-100104704

39. Kelly S. Using stable isotopes ratio mass spectrometry (IRMS) in food authentication and traceability. In: Lees M, editor. Food authenticity and traceability. Cambridge, UK: Woodhead Publishing Limited; 2003. p. 156–181. https://doi.org/10.1533/9781855737181.1.156

40. Padovan G, De Jong D, Rodrigues L, Marchini J. Detection of adulteration of commercial honey samples by the $^{13}C/^{12}C$ isotopic ratio. Food Chem. 2003;82(4):633–636. https://doi.org/10.1016/S0308-8146(02)00504-6

41. González-Martín I, Marqués-Macías E, Sánchez-Sánchez J, González-Rivera B. Detection of honey adulteration with beet sugar using stable isotope methodology. Food Chem. 1998;61(3):281–286. https://doi.org/10.1016/S0308-8146(97)00101-5

42. Angerosa F, Camera L, Cumitini S, Gleixner G, Reniero F. Carbon stable isotopes and olive oil adulteration with pomace oil. J Agric Food Chem. 1997;45(8):3044–3048. https://doi.org/10.1021/jf960993d

43. Cabañero AI, Rupérez M. Carbon isotopic characterization of cider CO_2 by isotope ratio mass spectrometry: A tool for quality and authenticity assessment. Rapid Commun Mass Sp. 2012;26(16):1753–1760. https://doi.org/10.1002/rcm.6281

44. Hobson KA. Tracing origin and migration of wildlife using stable isotopes: A review. Oecologia. 1999;120:314–326. https://doi.org/10.1007/s004420050865

45. O'Leary MH. Carbon isotope fractionations in plants. Phytochemistry. 1981;20:553–567. https://doi.org/10.1016/0031-9422(81)85134-5

46. Vogel J, Fuls A, Ellis R. The geographical distribution of Kranz grasses in South Africa. S Afr J Sci. 1978;74:209–215.

47. Farquhar G, Ehleringer J, Hubick K. Carbon isotope discrimination and photosynthesis. Annu Rev Plant Physiol Plant Mol Biol. 1989;40:503–537. https://doi.org/10.1146/annurev.pp.40.060189.002443

48. Smith B, Epstein S. Two categories of $^{13}C/^{12}C$ ratios for higher plants. Plant Physiol. 1971;47:380–384. https://doi.org/10.1104/pp.47.3.380

49. Finucane B, Agurto PM, Isbell WH. Human and animal diet at Conchopata, Peru: Stable isotope evidence for maize agriculture and animal management practices during the Middle Horizon. J Archaeol Sci. 2006;33(12):1766–1776. https://doi.org/10.1016/j.jas.2006.03.012

50. DeNiro MJ, Hastorf CA. Alteration of $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios of plant matter during the initial stages of diagenesis: Studies utilizing archaeological specimens from Peru. Geochim Cosmochim Acta. 1985;49:97–115. https://doi.org/10.1016/0016-7037(85)90194-2

51. Greer AL, Horton TW, Nelson XJ. Simple ways to calculate stable isotope discrimination factors and convert between tissue types. Methods Ecol Evol. 2015;6:1341–1348. https://doi.org/10.1111/2041-210X.12421

52. Keegan WF, DeNiro MJ. Stable carbon- and nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. Am Antiquity. 1988;53(2):17. https://doi.org/10.2307/281022

53. González-Martín I, González-Pérez C, Hernández-Méndez J, Marqués-Macías E, Sanz-Poveda F. Use of isotope analysis to characterize meat from Iberian-breed swine. Meat Sci. 1999;52:437–441.

54. Ineson P, Cotrufo MF, Bol R, Harkness DD, Blum H. Quantification of soil carbon inputs under elevated CO_2: C_3 plants in a C_4 soil. Plant Soil. 1995;187(2):345–350. https://doi.org/10.1007/BF00017099

55. Czimczik CI, Preston CM, Schmidt MW, Werner RA, Schulze E-D. Effects of charring on mass, organic carbon, and stable carbon isotope composition of wood. Org Geochem. 2002;33(11):1207–1223. https://doi.org/10.1016/S0146-6380(02)00137-7

56. Saurer M, Maurer S, Matyssek R, Landolt W, Günthardt-Goerg MS, Siegenthaler U. The influence of ozone and nutrition on $\delta^{13}C$ in *Betula pendula*. Oecologia. 1995;103(4):397–406. https://doi.org/10.1007/BF00328677

57. Balesdent J, Girardin C, Mariotti A. Site-related $\delta^{13}C$ of tree leaves and soil organic matter in a temperate forest. Ecology. 1993;74(6):1713–1721. https://doi.org/10.2307/1939930

58. Martin B, Bytnerowicz A, Thorstenson YR. Effects of air pollutants on the composition of stable carbon isotopes, $\delta^{13}C$, of leaves and wood, and on leaf injury. Plant Physiol. 1988;88(1):218–223. https://doi.org/10.1104/pp.88.1.218

59. Jahren AH, Saudek C, Yeung EH, Linda Kao WH, Kraft RA, Caballero B. An isotopic method for quantifying sweeteners derived from corn and sugar cane. Am J Clin Nutr. 2006;84:1380–1384.

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MeerKAT time and frequency reference optical network: Preliminary design analysis

The MeerKAT telescope is a precursor to the Square Kilometre Array, which will rely on optical fibres to link the telescope receivers to a central processor point. The main aspects to consider for the fibre transport are astronomical data transmission as well as timing, monitoring and control. The astronomical data streams from individual dishes to a central building, while the clock signal is distributed from a central point to remote dishes in the telescope array. The MeerKAT telescope, for instance, demands highly accurate and stable clock distribution over up to 12 km of optical fibre to remote dishes. The clock distribution is required for digitisation of astronomical signals. Phase stability is thus critical both for short-term and long-term requirements. In this work, we focused on the short-term stability. Phase noise measurements were performed on optical transmitters used to distribute the clock signals so as to ascertain their contribution to the overall clock jitter of the system. A maximum jitter requirement of 130 fs for a 1.712-GHz clock signal for MeerKAT time and reference is achieved using a distributed feedback laser. We found that with optimised modulation depth, additional passive optical components in the link do not significantly degrade the phase noise response. A distributed feedback laser was proven to be a suitable optical source that will meet the performance and link budget requirements for the MeerKAT telescope.

Significance:

- A distributed feedback laser is recommended for the design of the MeerKAT time and reference system as it is a suitable optical source that will meet the performance and link budget requirements.

Introduction

In the quest to explore our universe, human curiosity has led to the conception of the Square Kilometre Array (SKA). The SKA is a large radio telescope currently under construction. South Africa will host the SKA dish antennas and mid-frequency aperture array antennas while Australia will house the low-frequency aperture array antennas. The different antenna receivers are shown in Figure 1. The different receiver components form an interferometer that provides rejection to systematics that allows the theoretical sensitivity to be realised. Radio astronomy demands a radio-free environment, thus the choice of these remote sites in the southern hemisphere. The instrument is estimated to be completed in 2030 with about 3000 dishes extending to about 3000 km from the core, making it the most sensitive astronomical instrument in the world.[1] The dish distribution and the central site are depicted in Figure 2. The SKA is derived from the total receiver collecting surface area of all receiver components which will amount to one square kilometre.

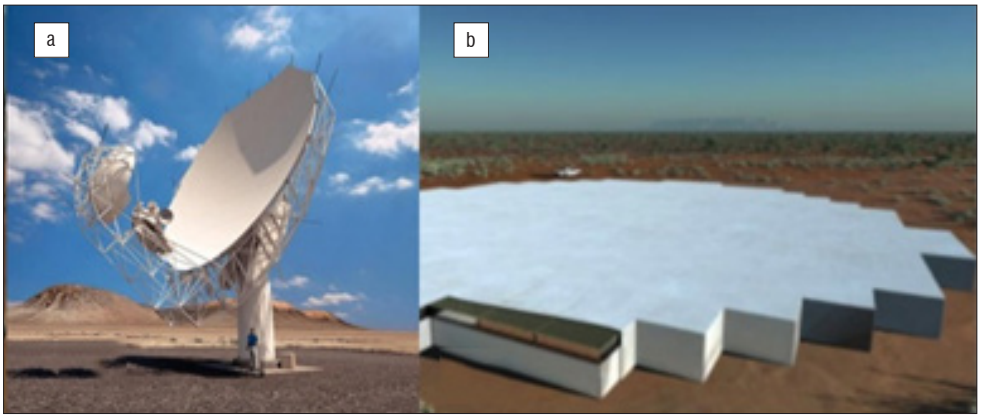
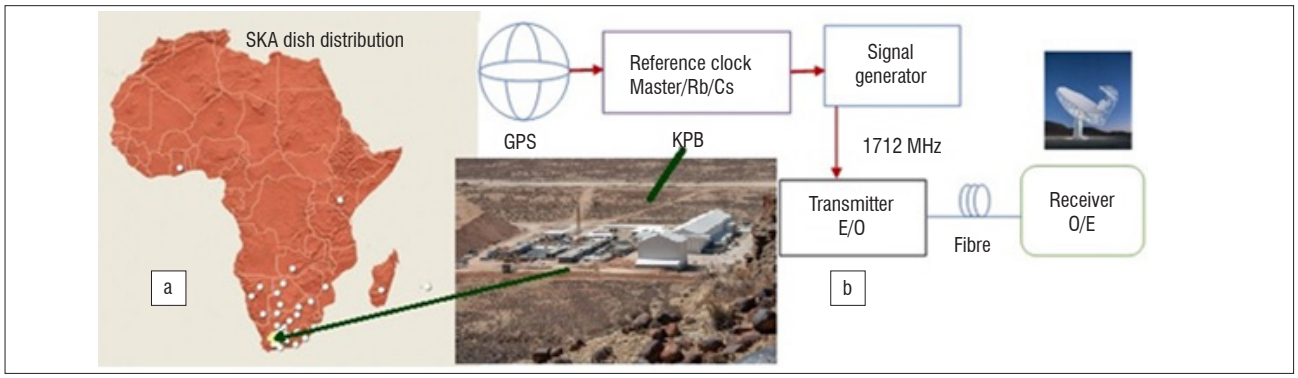


Figure 1: An artist's impression of (a) the MeerKAT dish antenna and (b) the mid-frequency aperture array antenna.[1]

The SKA is being built in stages. Currently operational is a seven-dish prototype known as KAT-7. It is situated at the SKA core site. The MeerKAT telescope is a precursor for the SKA and is a 64-dish mid-frequency receptor currently under construction in the Karoo (Figure 2). Upon completion, it will be the most sensitive radio interferometer in the L-band in the world[1] and the best radio telescope of its kind in the southern hemisphere. MeerKAT is a guide for the later SKA phases. It will be integrated into the mid-frequency component of SKA Phase 1 (SKA 1). A further 133 dishes added to MeerKAT will form SKA 1. MeerKAT should provide lessons for the eventual construction of SKA 1 and SKA 2. The larger SKA 2 will eventually constitute about 3000 dishes extending to other partner countries. All the data from these dishes will be collected and transmitted to a central processing station in the Karoo known as the Karoo Processor Building. MeerKAT science objectives include testing Einstein's theory, a survey of neutral hydrogen and atomic hydrogen, and investigation of galaxies, pulsars and transient radio sources.[1]



E/O, electrical to optical; O/E, optical to electrical

Figure 2: (a) Map of Africa indicating the core Square Kilometre Array (SKA) site and other dish sites on the continent. (b) Potential MeerKAT time and frequency reference system layout.[1]

In addition to data collection via the telescope optical transport, of great essence is the clock signal distribution to remote dishes over optical fibres. A clock signal will be required for generation of a stable reference tone for phase coherence of the dishes; absolute time code for antennae controllers and beam formers; accurate timing ticks and counters for data stamping; operational monitoring and control; stable periodic synchronisation; and running the digitisers.[2] The use of optical fibres in clock distribution has been previously reported.[3,4] Existing telescopes have used optical fibre links for timing and frequency reference distribution. These telescopes include the Expanded Very Large Array (EVLA) in the USA[5], Atacama Large Millimetre Array (ALMA) in Chile[6] and Multi-element Radio Linked Interferometer Network (e-MERLIN) in the UK[7].

In the 64-dish MeerKAT array, for example, a digitiser will be installed on each dish so as to convert the received electromagnetic wave from a radio frequency (RF) into a digital signal. The received radio astronomy signals will be digitised using an analogue digital converter and sent via buried optical link for science processing. The MeerKAT telescope will employ clock frequencies of 1.712 GHz (L-band), 1.088 GHz (UHF band) and 14.5 GHz (X-band) in addition to 1 pulse per second for telescope synchronisation.[2] A clock signal is required to drive analogue digital converters. Therefore, a time and frequency reference system is needed to distribute clock signals to each dish in the array using optical fibres. The main challenge is to have a very stable central clock distributed over an optical fibre. The farthest dish in the MeerKAT array extends to about 12 km from the processing station (see layout in Figure 2b). Clock phase stability is required in the short term and long term. Short-term stability, also known as clock jitter, is needed to control the degradation of the signal-to-noise performance of the digitisation process while long-term stability is vital for applications such as very large baseline interferometry and to provide phase stability between phase calibration observations for standard interferometric imaging. Very large baseline interferometry involves the simultaneous use of various telescopes in different countries and even continents to focus on a particular astronomical object in the sky. The distance of separation between the various receivers requires a very coherent accurate and stable clock. It is because of this that a time and frequency reference system requires a stable clock signal from a hydrogen maser or a rubidium or a caesium source.[2] The intended timing source ought to be enabled for synchronisation with the Global Positioning System (GPS).

In this study, a preliminary design of the timing and frequency distribution suited for MeerKAT typical distance was analysed using a 1712-MHz signal. To ensure short-term and long-term clock stability, different components in the link must be evaluated. The transmitters, optical fibres, splitters and receivers play a vital role in the clock signal degradation and contribute to the overall phase noise of the clock distribution system. The dispersive effects on the clock signal have been estimated on the existing KAT-7 optical fibre network.[8,9] This study focused on optical transmitters as one of the components contributing to the overall degradation of the phase noise performance in an optical fibre link.

Experimental set-up used to investigate phase noise

The experimental set-up used in the study is given in Figure 3. Three different directly modulated lasers and an externally modulated source, all operating at 1550 nm, were used. The directly modulated lasers were a RF fibre link laser, a distributed feedback laser (DFB) and a vertical cavity surface emitting laser (VCSEL). The externally modulated laser was a wavelength division multiplexing (WDM) distributed feedback laser source. A Mach-Zehnder modulator was used to modulate the signal from a WDM laser source. A 1.712-GHz clock from a signal generator with a 10-MHz reference was used to modulate the various light sources. Suitable modulation depths for each light source were selected. In a back-to-back transmission, the clock signal was received using a positive intrinsic negative (PIN) photodiode and the RF output was established using an electrical spectrum analyser. A PIN photodiode with 10-GHz bandwidth and a sensitivity of -19 dBm was used. The RF output on the interference-shielded PIN receiver was established for various optical powers. The clock jitter was obtained for the received signal, integrated over the frequency range of 800 Hz to 10 MHz.

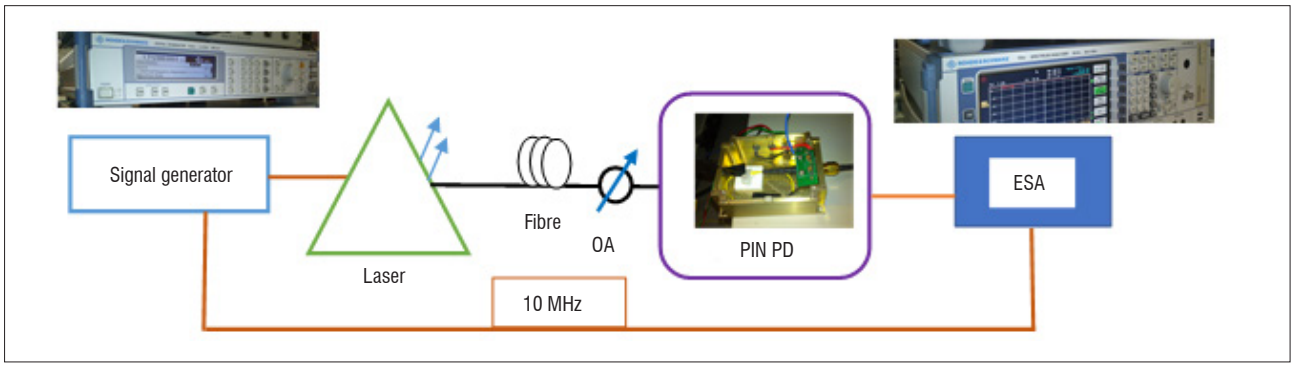
The frequency range is of particular relevance to the MeerKAT telescope because of the correlator's resolution and the filter's cut-off frequency. A frequency of 800 Hz was derived by setting half the narrowest channel resolution of the correlator while 7 MHz was the 10-dB cut-off frequency of the filter used on the digitiser to limit the noise at the analogue digital converter. A 25.3-km ITU-T G.655 fibre and 1x4 splitter were then included in the link and the jitter value was obtained.

Results and discussion

The jitter performance of the entire optical link was evaluated to determine the contribution of the link to the jitter of the source. To do that the phase noise of the source was plotted and compared to the phase noise response of the output signal from the link.

Figure 4a and 4b illustrates a sample of phase noise performance on VCSEL and DFB transmitters, respectively. The regions arise from different sources of laser noise contribution. Random noise predominates very close to the carrier frequency. Random noise is normally very difficult to measure because it is very close to the carrier. Flicker phase noise may be related to the physical resonance mechanism of an oscillator or the choice of parts used for the electronics design of the oscillator, but it is usually added by noisy electronics.[10] The peaks on the noise floor between 10 kHz and 100 kHz in Figure 4a correspond to poor jitter performance on the VCSEL transmitter. Typically, a DFB transmitter bandwidth is about 2 MHz, while that of a VCSEL is about 10 MHz. This difference will cause the phase noise of the VCSEL to be higher than that of a DFB, which will dramatically degrade the system performance.

Appropriate modulation voltages were selected. The optimal RF power level was that required to modulate the laser such that optimal photodiode performance was achieved. The RF output from the various sources is shown in Figure 5a.



ESA, electrical spectrum analyser; OA, optical attenuator; PIN PD, positive intrinsic negative photodiode

Figure 3: Illustration of the set-up used to analyse the phase noise performance.

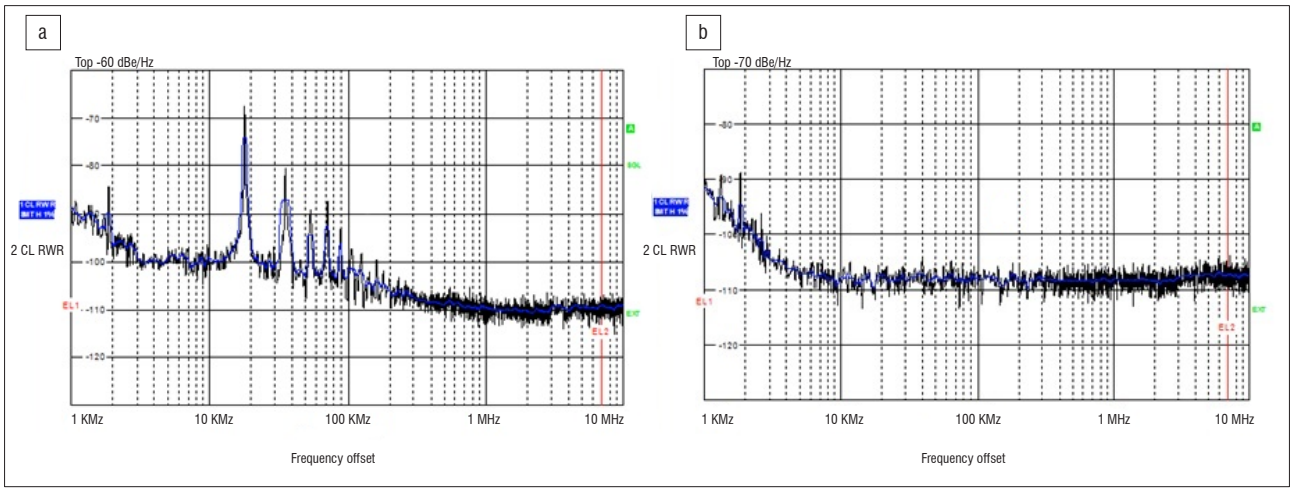


Figure 4: Phase noise of the output signal using (a) a vertical cavity surface emitting laser (VCSEL) and (b) a distributed feedback laser (DFB) transmitter.

The directly modulated lasers show a higher output than that of the externally modulated source. This result is because of the power losses incurred in the external modulation. VCSEL is a low-power device, therefore the optical power range is lower than that of the RF fibre link laser and DFB lasers, and hence the RF output range is lower. The RF fibre link laser and VCSEL give a better RF output response as compared to both the DFB and WDM lasers.

The dotted line in Figure 5b shows the telescope expected jitter threshold of 130 fs. For all the measurements, proper choice of bias voltage and modulation powers were chosen so as to avoid distortions of the received clock signal. The nonlinear operation in electronics is responsible for signal distortions. Higher jitter values were obtained for VCSEL and WDM lasers than with DFB and RF fibre link lasers. VCSEL showed some small deviation over a range of optical power of -20 dBm to -7.5 dBm, but high jitter of about 1.8 ps. The WDM laser gave the highest jitter deviation, extending to about 14 ps at -22.5 dBm of optical power.

DFB and RF fibre link lasers meet the threshold but over different optical power ranges. The DFB laser has the best performance with jitter of less than 130 fs over a range of optical power of -15 dBm to about -3 dBm. The different performance of the various lasers may be attributed to differences in the structural designs, semiconductor material and operating specifications. From Figure 6a, it is noted that the fibre and a splitter reduce the power without altering the RF output trend. The modulation power was maintained at 13 dBm. From Figure 6b, it was established that no significant jitter alteration was contributed by the fibre spool and splitter. The additional passive components merely reduce the optical power without significantly degrading the phase noise. The 25.3-km fibre spool used is double the expected distance of the furthest MeerKAT dish from the Karoo Processor Building. This length is to demonstrate that the same optical transmitter can be employed in the round-trip monitoring while meeting the jitter requirements. Round-trip monitoring is not envisaged in the MeerKAT design, but the demonstration allows for a possible extension if need be. For a 12-km fibre link, more optical power will be available for splitting. With an optical power of about -12 dBm on the receiver, a 1x4 splitter can be employed in the link. This power level is sufficient for the 1.712-GHz clock to drive the digitiser without the need for an amplifier. This finding implies that one laser source can be utilised for four dishes. Therefore, only 16 lasers will be required to serve the 64 dishes, thus reducing the cost significantly.

Conclusion

Timing and synchronisation of the dishes is vital for the functioning of the radio telescope. We have experimentally demonstrated a 1.712-GHz clock transmission over 25 km of optical fibre. To enhance stability, MeerKAT's time and frequency reference system requires the proper choice of laser and appropriate modulation levels. A DFB optical transmitter attained a clock jitter of 130 fs for a 1.712-GHz clock. This laser is thus the preferred candidate that meets the expected performance requirements and link budget for the MeerKAT time and frequency reference system. Passive components reduce the optical power without causing jitter deterioration in the link.

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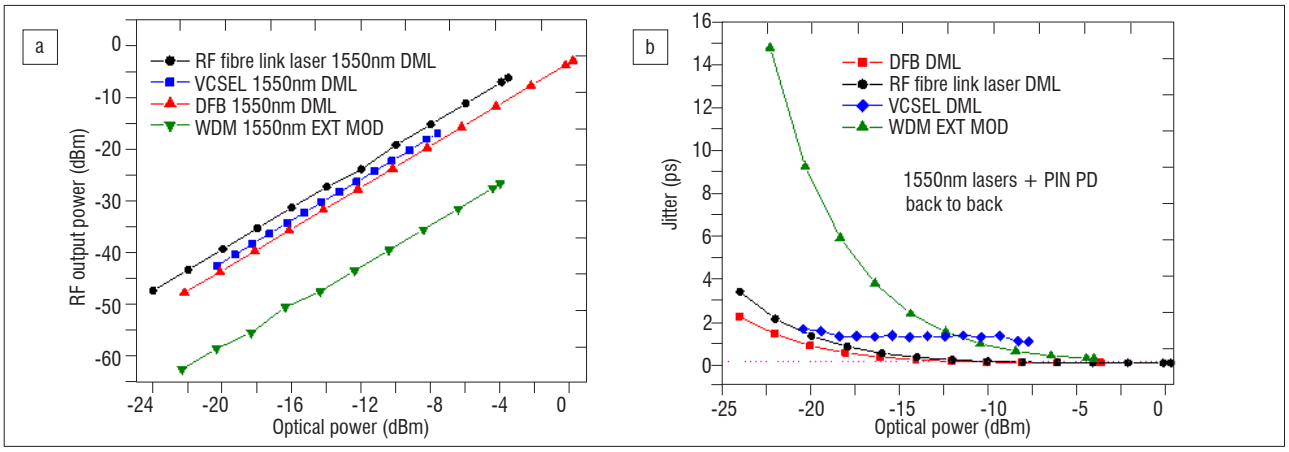
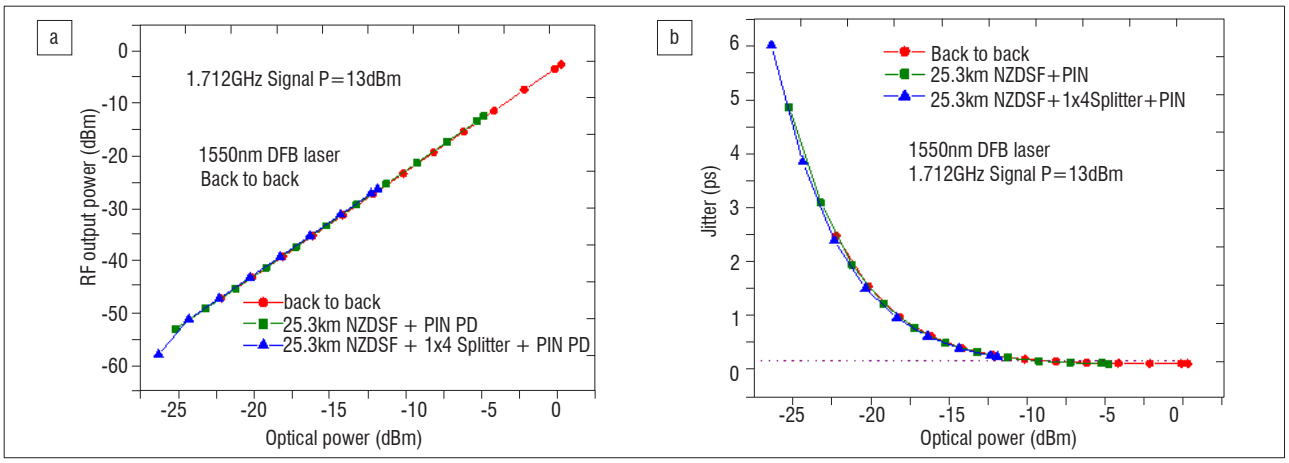


VCSEL, vertical cavity surface emitting laser; DFB, distributed feedback laser; DML, directly modulated laser; WDM, wavelength division multiplexing laser

Figure 5: (a) Radio frequency (RF) output as a function of optical power for different lasers and (b) corresponding jitter measurement variation with optical power.



PIN PD, positive intrinsic negative photodiode; NZDSF, non-zero dispersion-shifted fibre

Figure 6: (a) A distributed feedback (DFB) laser radio frequency (RF) output with additional optical components and (b) jitter measurements over a 25.3-km fibre link with a 1x4 splitter.

Authors' contributions

E.K.R.K. was the lead author; R.R.G.G., S.M. and H.K. collected the data and together with E.K.R.K. performed the experiments; A.W.R.L., T.B.G. and F.K. contributed to the project design and data analysis.

References

1. MeerKAT radio telescope [homepage on the Internet]. c2013 [cited 2016 Aug 09]. Available from: http://www.ska.ac.za/meerkat/
2. Peens-Hough A, Küsel T, Malan S, Kapp F, Esterhuyse W. MeerKAT system preliminary design memo series m0000-0000v1-42 tm revision 1a. 2012. Unpublished internal report.
3. Mullavey AJ, Slagmolen BJJ, Shaddock DA, McClelland DE. Stable transfer of an optical frequency standard via a 4.6 km optical fibre. Opt Exp. 2010;18(5):5213–5320.
4. Baldwin KG, He Y, Hsu M, Wouters M, Gray M, Orr BJ, et al. Analog and all-digital frequency distribution via optical fibre links. In: Proceedings of the Conference on Lasers and Electro-Optics (CLEO) Science and Innovations; 2012 May 6–11; San Jose, CA, USA. OSA Tech Dig. 2012, Art. #CTh4A.2. https://doi.org/10.1364/CLEO_SI.2012.CTh4A.2
5. Durand S, Jackson J, Morris K. Phase coherence of the EVLA radio telescope. In: Stepp LM, editor. SPIE 6267: Ground-based and Airborne Telescopes; 2006 May 24; Orlando, FL, USA. SPIE; 2006. 62673Y. https://doi.org/10.1117/12.667804
6. Shillue W. Fibre distribution of local oscillator for Atacama Large Millimetre Array. In: Proceedings of the Optical Fibre Communication/National Fibre Optic Engineers Conference; 2008 Feb 24–28; San Diego, CA, USA. IEEE; 2008. p.1–3. https://doi.org/10.1109/OFC.2008.4528513
7. McCool R, Bentley M, Argo MK, Spencer R, Garrington S. Transfer of a 1486.3 MHz frequency standard over installed fibre links for local oscillator distribution with a stability of 1 picosecond. In: Proceedings of the European Conference on Optical Communication; 2008 Sep 21–25; Brussels, Belgium. IEEE; 2008. p. 1–2. https://doi.org/10.1109/ECOC.2008.4729488
8. Gibbon TB, Rotich EK, Kourouma HYS, Gamatham RRG, Leitch AWR, Siebrits R, et al. 2013 Fibre-to-the-telescope: MeerKAT, the South African precursor to Square Kilometre Telescope Array (SKA). In: Weiershausen W, Dingel BB, Dutta AK, Srivastava AK, editors. Proceedings of SPIE 9008 Optical Metro Networks and Short-Haul Systems VI 90080P; 2014 Feb 01; San Francisco, CA, USA. SPIE; 2014. https://doi.org/10.1117/12.2049434
9. Rotich Kipnoo EK, Kourouma HYS, Gamatham RR, Leitch AWR, Gibbon TB, Julie R, et al. Characterization of the polarization mode dispersion of single mode fibre in KAT-7 Telescope Array Network, South Africa. In: AFRICON; 2013 Sep 9–12; Pointe-Aux-Piments, Mauritius. IEEE; 2013. p. 1–4. https://doi.org/10.1109/AFRCON.2013.6757860
10. Kester W. Converting oscillator phase noise to time jitter. MT-008 Tutorial. Norwood, MA: Analog Devices Inc.; 2009. Available from: http://www.analog.com/media/en/training-seminars/tutorials/MT-008.pdf.