

## **Supplementary Material to ‘A South African perspective on the 2023 IPBES Thematic Assessment Report on Invasive Alien Species and their control’**

Citation of the original article:

Wilson JRU, Faulkner KT, Fernández Winzer L, McCulloch-Jones EJ, van Wilgen BW, Blanchard R, Carbutt C, Dechoum MS, Foxcroft LC, Greve M, Hui C, Ivey P, Kgope B, Kumschick S, le Roux PC, Masehela TS, Measey J, Miza S, Mogapi T, Mpikanisi F, Mulaudzi L, Nelukalo K, Nnzeru L, Nsikani MM, Pattison Z, Rahlao SJ, Richardson DM, Robinson TB, Shackleton RT, Tererai F, Tshidada N, Tshikhudo PP, Tshivhandekano I, Wanjau K, Ziller SR, Zengeya TA (2025) A South African perspective on the 2023 IPBES Thematic Assessment Report on Invasive Alien Species and their control. *African Biodiversity & Conservation* 55. doi:10.38201/abc.v55.9

The article and this supplementary material can be found at:

<https://www.abcjournal.org/index.php/abc/article/view/531>

This supplementary material is archived at: <http://dx.doi.org/10.5281/zenodo.17543246>

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## Supplementary Table S1. IPBES IAS Assessment experts and countries of affiliation

As experts<sup>1</sup> can have multiple countries of affiliation, the total in the table is greater than the total number of experts. 25 experts listed South Africa as an affiliation: co-chairs (0/3); coordinating lead authors (2/14): Melodie A. McGeoch, Sebataolo J. Rahlao; lead authors (3/69): Ryan Blanchard, Llewellyn C. Foxcroft, Olaf L.F. Weyl; contributing authors (17/199 + 3 also listed under other roles): Bianca Hagen, Bruce R. Ellender, Cang Hui, Clinton Carbutt, Colleen T. Downs, David M. Richardson, Johannes J. le Roux, John Measey, Julie A. Coetzee, Llewellyn C. Foxcroft, Luis R. Pertierra, Ndivhuwo Shivambu, Philip Ivey, Ross T. Shackleton, Ryan Wasserman, Sabrina Kumschick, Sean M. Marr, Tinyiko Cavin Shivambu, Tsungai A. Zengeya, Zarah Pattison; and review editors (3/12): Cang Hui, David M. Richardson, John R. Wilson. By comparison, 9 experts listed other African countries as an affiliation.

Country	Number of experts with that affiliation
UK	39
USA	35
Australia	28
Germany	25
South Africa	25
Argentina	18
Italy	17
Switzerland	15
New Zealand	13
Canada	12
Ecuador	11
Spain	11
Brazil	9
Portugal	9
France	8
Netherlands	8
India	7
Austria	6
Chile	6
Czech Republic	5
Japan	5
China	4
Cyprus	4
Norway	4
Denmark	3
Estonia	3
Greece	3
Iran	3
Mexico	3
Turkey	3

Country	Number of experts with that affiliation
Armenia	2
Belgium	2
Fiji	2
Finland	2
Ghana	2
Kenya	2
Nepal	2
Panama	2
Tanzania	2
Venezuela	2
Belarus	1
Bolivia	1
Cameroon	1
Canada	1
Colombia	1
Costa Rica	1
Ireland	1
Israel	1
Lesotho	1
Poland	1
Republic of Korea	1
Romania	1
Russian Federation	1
Senegal	1
Slovenia	1
Sri Lanka	1
Uganda	1
Uruguay	1
Zimbabwe	1

<sup>1</sup> IPBES does not call contributing authors 'experts' and the term 'authors' is preferred to describe all roles (though review editors are of course not authors). For simplicity we use the term expert to refer to all those involved and authors to refer to those responsible for content. Members of the Technical Support Unit (based in Japan) were not included here, though they all played critical roles in the production of the IPBES IAS Assessment

**Supplementary Table S2.** The key message paragraphs from the IPBES IAS Assessment and the corresponding South African situation

The key message paragraphs are taken verbatim from the IAS Assessment (IPBES 2023) and split into sections that warrant separate responses. The degree of resonance for South Africa was evaluated as one of five values (completely agree, largely agree, somewhat similar, different and not applicable) with one of four levels of confidence [well established, established but incomplete, unresolved and inconclusive (IPBES 2018)]. See Table 1 in the paper for further details of the method of scoring. See Table 2 in the paper for the scoring of the key messages themselves. The focus is on mainland South Africa and the immediate offshore environment (including islands).

	Paragraph	Available information for RSA	RSA References
A1	More than 37 000 established alien species have been introduced by human activities across all regions and biomes of Earth ...	Over 3 500 alien species are present outside of captivity or cultivation. Alien taxa have been recorded in all biomes, all but one water management area, and in all in-shore marine ecoregions. No alien taxa have been recorded in offshore marine ecoregions. The degree of establishment for these taxa is not systematically recorded yet.	Zengeya et al. (2023)
A1	..., with new alien species presently being recorded at an unprecedented rate of approximately 200 annually.	Three new alien species have been recorded per year, but this is likely an underestimate of the number of introductions. This number does not include those legally introduced for which the risk has been assessed and found to be acceptably low.  The global figure used in the IPBES IAS Assessment (200 per year) is across all combinations of countries and alien species. As such it is hard to directly compare this to the rate for South Africa.	Faulkner (2023)
A1	Studies with evidence of negative impacts exist for more than 3 500 of these species, which are categorized as invasive alien species.	Over 1 000 taxa are categorised as invasive, but only 36 taxa have been formally evaluated for their environmental impact (using the IUCN's Environmental Impact Classification for Alien Taxa methodology). The economic impact for only 71 taxa has been documented.	Van Wilgen et al. (2022b), Zengeya et al. (2023)
A1	The proportion of established alien species known to be invasive varies among taxonomic groups, ranging from 6 per cent of all alien plants to 22 per cent of all alien invertebrates.	About a third of the alien species found outside cultivation or captivity in South Africa are invasive and these are mostly plants (74%) and terrestrial invertebrates (14%). Estimates are likely to be lower if we also consider all alien species only found in captivity or cultivation. Note the definitions for established and invasive differ between the South African status report and the IPBES IAS Assessment (cf. Box 1 in the paper).	Zengeya et al. (2023)

	Paragraph	Available information for RSA	RSA References
A1	Twenty per cent of all impacts are reported from islands.	Major impacts have been observed on South Africa's offshore and inshore islands. For example, Robben Island has many invasives, which have transformed the habitat (e.g., cats have impacted penguins and wattles transformed the landscape). Other islands have rabbits and mice, but these have not been formally assessed for impact. South Africa has few islands, and most offshore islands are only recently separated from the mainland and so few carry unique species. The situation on the Prince Edward Islands is distinct.	Fernández Winzer et al. (2023, 2025), Weller et al. (2014)
A1	A disproportionate number of documented negative impacts have been reported in terrestrial realms, especially in temperate and boreal forests and woodlands and cultivated areas (including agricultural land).  &  About one quarter of documented negative impacts have been reported from aquatic realms, especially from inland surface waters/waterbodies and shelf ecosystems.	Trees and freshwater fishes, in particular, have 'Major' negative impacts on people and nature across the country. Significant impacts are also seen along the coast, particularly in the intertidal zone. No alien species were recorded on shelf ecosystems and so no impacts were recorded.  Almost all monetary costs are noted for the terrestrial environment, with only 1% of costs reported for the aquatic realm.	McCulloch-Jones et al. (2024), Robinson et al. (2020), Zengeya and Wilson (2023)
A1	In addition to their impacts on nature, about 16 per cent of invasive alien species have negative impacts on nature's contributions to people, and about 7 per cent on good quality of life.	Impacts have not been evaluated as per the IPBES framing of impacts on 'nature's contributions to people' and 'good quality of life'. Moreover, the impacts of invasions on agricultural and human health have not been systematically collated to date and lists of invasive taxa in such ecosystems are not as yet integrated with lists of species that pose threats to the environment, biodiversity or ecosystem services.	None
A2	Invasive alien species have contributed solely or alongside other drivers to 60 per cent of recorded global extinctions, and are the only driver in 16 per cent of the documented global animal and plant extinctions.	Invasive plants have been implicated in ~20% of plant extinctions in South Africa (7 out of 33) (although not as the main driver). Invasive fishes have been implicated in the extirpation of several freshwater fishes.	Chakona et al. (2022), Van der Colff et al. (2023)

	Paragraph	Available information for RSA	RSA References
A2	Biotic homogenization, whereby biological communities around the world become more similar, is a major negative impact of invasive alien species, with consequences for the structure and functioning of ecosystems.	With the global movement of alien species, many previously unique ecosystems in South Africa now have similar species compositions to analogous climatic regions elsewhere in the world (e.g., Mediterranean-type ecosystems). Some alien plant species occur across the country, but different assemblages of alien plants occur in different parts of the country: fynbos-specific invaders, grassland-specific invaders, moist-subtropical invaders and semi-arid invaders.	Richardson et al. (2020b)
A2	Changes in the properties of ecosystems, such as soil and water characteristics, account for more than a quarter of documented impacts.	Not evaluated as a percentage of documented impacts. There have been notable impacts on nutrient cycling, significant changes to hydrology, and effects recorded on the intensity and frequency of wildfires.	Van Wilgen et al. (2022b), Zengeya and Wilson (2023)
A2	The magnitude and types of impacts vary for different invasive alien species and across ecosystems and regions.	The impacts of only 36 alien species have been assessed formally, but these species have impacts that vary in their magnitude ('Minimal Concern' to 'Massive') and mechanism (including competition, disease transmission, changes to ecosystem functioning, and parasitism).	Zengeya and Wilson (2023)
A2	The majority of documented global extinctions attributed mainly to invasive alien species have occurred on islands (90 per cent), and local extinctions account for 9 per cent of documented impacts of invasive alien species on islands.	With few islands, impacts are much more prominent on the mainland. The situation on the Prince Edward Islands is distinct.	Fernández Winzer et al. (2023, 2025)
A2	Some areas, despite being protected for nature conservation or being remote, are also vulnerable to the negative impacts of invasive alien species.	All protected areas for which there are data have alien species, with the area invaded ranging from minor to extensive.	Zengeya and Wilson (2023)
A3	In 2019, global annual costs of biological invasions were estimated to exceed US\$ 423 billion.	<p>The IPBES IAS Assessment global estimate incorporates both damage and management costs, which comprise modelled (historical or current cost projections) and observed estimates (actual incurred costs). These costs have been separately reported for South Africa.</p> <p>The observed annual cost of management is ZAR 150M (2022 values); the modelled annual cost of management is ZAR 3.6B; and the modelled annual cost of damage is: ZAR 1–10B. There was insufficient data to get an estimate of the observed annual cost of damage.</p>	McCulloch-Jones et al. (2024)

	Paragraph	Available information for RSA	RSA References
A3	The vast majority of global costs (92%) accrue from the negative impacts of invasive alien species on nature's contributions to people or on good quality of life, while only 8 per cent of that sum is related to management expenditures of biological invasions.	Of the total observed costs, 85% were due to negative impacts and 15% related to management expenditure.	McCulloch-Jones et al. (2024)
A3	The benefits to people that some invasive alien species provide do not mitigate or undo their negative impacts, which include harm to human health (such as disease transmission), livelihoods, water security and food security ...	For many species, benefits are seen in the short term, but negative impacts are felt elsewhere and later in time; with invasions often becoming a net negative.	Shackleton et al. (2007), Van Wilgen and Richardson (2014), Weyl et al. (2017), Zengeya et al. (2017)
A3	... with reduction in food supply being by far the most frequently reported impact (more than 66%).	Invasive plants can reduce the carrying capacity of rangelands for livestock production at a farm scale by 75%. In South Africa, invasive plants are estimated to reduce the value of livestock production by ZAR 340M, this could increase as the invasions spread. The overall cost to agriculture has not been estimated.	O'Connor and Van Wilgen (2020), Yapi et al. (2018)
A4	People with the greatest direct dependence on nature, including those involved in gender- and age-specific activities, such as fishing or weeding, may be disproportionately affected by invasive alien species.	Although a spatial correlation has been shown between income levels and the presence of invasive plants, there is no clear evidence for disproportionate impacts. By contrast, there is clear evidence that those who directly depend on nature in South Africa often utilise invasive species.	Ellender and Weyl (2014), Reynolds et al. (2020), Shackleton et al. (2007)
A4	More than 2 300 invasive alien species are found on lands managed, used and/or owned by Indigenous Peoples across all regions of Earth, threatening their quality of life and often leading to general feelings of despair, sadness and stress.	The number of invasive species found on 'lands managed, used and/or owned by Indigenous Peoples' has not been specifically evaluated. Research on the impacts of invasions in communal land areas in South Africa has found that people benefit (in the short term) from some invasive species; this has not yet been mapped. Please note that the terminology used in South Africa is often different from the IPBES terminology (cf. Box 4 in the paper).	De Neergaard et al. (2005), Shackleton et al. (2007), Shackleton and Shackleton (2018), Wootton and Shackleton (2023), Yapi et al. (2018)

	Paragraph	Available information for RSA	RSA References
A4	Indigenous Peoples and local communities, ethnic minorities, migrants, and poor rural and urban communities are disproportionately impacted by invasive alien vector-borne diseases.	Relatively high densities of alien disease vectors (e.g., rodents) in rural areas and urban informal settlements put people in these areas at risk of contracting zoonotic diseases. The Department of Health and various municipalities have initiated vector control, especially relating to rodents and mosquitoes. Most of this research, however, is from the perspective of health rather than the environment or social science.	Bastos et al. (2011), Jassat et al. (2013), Lebelo (2020)
A4	Biological invasions negatively affect the autonomy, rights and cultural identities of Indigenous Peoples and local communities through the loss of traditional livelihoods and knowledge, reduced mobility and access to land, and increased labour to manage the invasive alien species.	The definitions used in South Africa are not always the same as those used by IPBES (Box 4). Nonetheless comparable issues have been evaluated in some cases. Evidence of such negative impacts are available from across Africa, particularly for subsistence agriculture.	Yapi et al. (2018)
A4	Impact reports by some Indigenous Peoples and local communities document 92 per cent negative impacts and 8 per cent positive impacts on nature caused by invasive alien species.	There are examples of both positive and negative impacts, but the relative proportion has not been estimated. Current information is rather patchy. Both are needed to increase the number of studies and for a method to summarise information.	See references in other sections.
A5	Up to 2020, only partial progress was made towards international goals and targets (e.g., Aichi Biodiversity Target 9 and Sustainable Development Goal Target 15.8).	South Africa has made significant progress towards reporting on biological invasions, as well as developing the indicators needed to do so.	Wilson et al. (2018), Zengeya and Wilson (2023)
A5	While most countries have targets related to the management of biological invasions within their national biodiversity strategies and action plans, effective policies are often lacking or inadequately implemented.	A national strategy and action plan is under development. A national target for 2030 to respond to our obligations under the KM-GBF of the CBD is also under development.  The National Environmental Management: Biodiversity Act of 2004 and the Alien and Invasive Species Regulations along with other legislation guide management activities, as does South Africa's National Biodiversity Strategy and Action Plan 2014–2025. However, coordination is lacking and the extent of interventions vary.	Lukey and Hall (2020), Wilson and Kumschick (2024)

	Paragraph	Available information for RSA	RSA References
A5	Eighty-three per cent of countries do not have national legislation or regulations directed specifically toward the prevention and control of invasive alien species.	National legislation addressing alien plants has been in place since 1983, and since 2014 addressing all alien taxa. Regulatory lists are in place and have been updated every few years. Different legislation is in place to address different aspects of the problem (e.g., agriculture and biodiversity); these aspects are not well aligned.	Kumschick et al. (2020a), Lukey and Hall (2020), Wilson and Kumschick (2024)
A5	Policy relevant to biological invasions is also fragmented within countries and across sectors.	Various national policies address biodiversity and plant health, but there is no integrated single policy on biological invasions.	Lukey and Hall (2020)
A5	To date, capacity to respond to biological invasions has varied widely across regions, with nearly half of all countries (45%) not investing in management of invasive alien species (SDG indicator 15.8.1).	Approximately ZAR 320 million (adjusted to 2020 values) has been spent by the government annually (1998–2020), largely on managing plant invasions, although the annual expenditure has declined recently. This figure does not include biosecurity and investment by private companies, though other evidence shows that significant interventions are in place (notably the Cape Town Water Fund). Volunteer groups are making substantial inputs.	Jubase et al. (2021a), Stafford et al. (2019), Turpie et al. (2019), Van Rensburg et al. (2017), Van Wilgen et al. (2022a)
A5	Differences in perception, including conflicting interests and values, of the importance and urgency of the threat of invasive alien species, coupled with lack of awareness of the need for a collective and coordinated response, as well as gaps in data and knowledge, can hinder the management of invasive alien species.	The management of conflict-generating species has been particularly challenging and management interventions have often required trade-offs that aim to preserve benefits while limiting negative impacts. Stakeholder engagement around the management of cacti invasions has helped build shared understanding in South Africa.	Novoa et al. (2017), Zengeya et al. (2017)
A5	Economic development policies and those aiming to manage other drivers of change sometimes facilitate biological invasions.	<p>Actions to improve water security have resulted in biological invasions through inter-basin water transfer schemes. Relatively new policies such as the promotion of aquaculture as a source of food and South Africa as a destination for the maintenance of oil and gas infrastructure could facilitate new introductions, while future climate change mitigation and adaptation strategies (e.g., carbon sequestration projects) similarly pose a threat.</p> <p>Biofuels/biomass to stimulate rural development could also create invasions (e.g., <i>Jatropha</i> and bamboo).</p>	Faulkner et al. (2020), Richardson and Blanchard (2011), Van Wilgen et al. (2023b)



	Paragraph	Available information for RSA	RSA References
A5	Demographic drivers also facilitate the introduction and spread of invasive alien species while acknowledging that drivers differ across regions and level of impact.	People have immigrated to South Africa from different regions at different times bringing plants and animals from their home regions to serve various purposes. Trade in alien species (such as pets) is focused in highly populated areas, and alien species richness (at least for birds and plants) is highest around urban areas.	Faulkner et al. (2020), Mantintsilili et al. (2022), Measey et al. (2020), Shivambu et al. (2021), Shivambu et al. (2022), Zengeya and Wilson (2023)
A5	The lack of border biosecurity (such as inspections undertaken by quarantine officers of commodities, goods and people) in one country weakens the efficacy of such measures in other countries.	Most African countries have a low capacity to prevent the introduction of alien species. The spread of alien species between African countries represents an important and possibly increasing threat to South Africa's biosecurity. Agreements such as the African Continental Free Trade Agreement will facilitate biological invasions especially considering that neighbouring jurisdictions do not apply biosecurity interventions pre-port and at-port to the same extent as South Africa.	Early et al. (2016), Faulkner et al. (2017)
B1	Many invasive alien species have been intentionally introduced outside their natural range around the world for their perceived benefits without consideration or knowledge of their negative impacts ...	Most terrestrial and freshwater alien species introduced to South Africa have been intentionally introduced. These include hundreds of plant taxa for ornamental/horticultural, forestry and agricultural purposes, and animals for fishing or as pets.	Faulkner et al. (2016), Faulkner et al. (2020)
B1	..., but there have also been many unintentional introductions, including as contaminants of traded goods and stowaways in shipments.	Many alien organisms have been accidentally introduced, particularly with imported plants, animals or their products, and through shipping. The relative importance of accidental introductions has increased over time.	Faulkner et al. (2020), Faulkner et al. (2016)
B1	Indirect drivers of change, particularly those associated with economic activities, of which international trade is the most important, are increasingly facilitating transport and introduction, the early stages of biological invasion.	The first known introductions were intentional, with plants and animals being introduced to serve specific purposes (economic, aesthetic, resource related), but as South Africa's trade and transport increased and expanded geographically, and technologies changed, introduction pathways became diverse, with accidental introductions beginning to play a more important role.	Faulkner et al. (2020)

	Paragraph	Available information for RSA	RSA References
B1	Direct drivers, particularly land- and sea-use change and climate change, are increasingly important later in the biological invasion process, facilitating the establishment and spread of invasive alien species ...	Riparian corridors often act as pathways for the spread of invasive plants.	Esler et al. (2008)
B1	... with fragmented ecosystems being more vulnerable to invasive alien species.	In South Africa, the upper reaches of freshwater catchments are often separated from lower reaches due to steep gradients. As a result, upper catchments often contain unique faunas that are highly sensitive. In terrestrial systems, there is no clear evidence from South Africa that we are aware of that fragmented ecosystems are more vulnerable. There are, however, plenty of examples that pristine ecosystems can be readily invaded (e.g., the Fynbos is readily invaded by alien trees).	Van Wilgen et al. (2016), Weyl et al. (2020)
B1	Transport and utility infrastructures in terrestrial and aquatic environments can create corridors that facilitate the spread of invasive alien species, including into remote, undisturbed and protected areas.	Infrastructure built to improve water security that links previously isolated river catchments has facilitated the spread of many fish species into rivers where they previously did not occur. These native-alien populations have had Major impacts on biodiversity. Port developments near marine protected areas have facilitated marine introductions. There is some evidence that railways might act as conduits for spread.	Ellender and Weyl (2014), Mararakanye et al. (2017), Nelufule et al. (2022), Peters et al. (2017), Ramoejane et al. (2020)
B1	For some invasive alien species, the spread is immediate, but others only begin to spread long after first introduction meaning that currently observed threats of invasive alien species can lead to underestimation of the magnitude of the future impact. Invasive alien species may increase in numbers after a long period at low density as a result of changes in interactions with other species, for example as a result of the introduction of a missing dispersal agent or the removal of a competitor.	The concept of invasion debt has been clarified and quantified for Australian acacias in South Africa. Examples of lag phases in South Africa include: <i>Banksia ericifolia</i> becoming invasive upon the imposition of the natural fire regime, and the Pacific oyster <i>Magallana gigas</i> spreading and establishing outside of culture operations in response to warm events 30 years post-introduction.	Geerts et al. (2013), Robinson et al. (2005), Rouget et al. (2016)

	Paragraph	Available information for RSA	RSA References
B2	The number of alien species has been rising continuously for centuries in all regions ...	New alien species are introduced every year. The rate of introduction (~ 3 per year) has not changed dramatically recently. Gaps in data and the way the estimates are calculated mean that certainty in these rates is low.	Faulkner (2023)
B2	..., and the global economic costs of invasive alien species have quadrupled every decade since 1970.	There are very few estimates of the costs of damage due to biological invasions, but there are estimates of money spent on management. In South Africa, spending remained relatively stable from the 1970s to the 1990s at around ZAR 10 million (in 2022 values) per year, increasing thereafter to over ZAR 250 million per year, declining dramatically recently.	McCulloch-Jones et al. (2024)
B2	Even without the introduction of new species, already established alien species given the opportunity, may continue to expand their geographic ranges into new countries, regions and ecosystems, including remote environments.	It has taken several centuries for invasive plants to reach most of their climatically suitable locations at a broad-scale in South Africa (quarter-degree grid cells). Between 2000 and 2016 the cumulative range occupied by all invasive plants at the resolution of a quarter-degree grid-cell increased by 50%.  It is expected that the spread of invasive species between South Africa and neighbouring countries, and Africa more generally, will continue.	Faulkner et al. (2017), Henderson and Wilson (2017), Rouget et al. (2004), Wilson et al. (2007)
B2	Under a 'business-as-usual' scenario, which assumes that trends of drivers will continue as observed in the past, by 2050 the total number of alien species globally is expected to be about one-third higher than in 2005.	Not evaluated specifically and quantitatively for South Africa, though it is expected that the number of alien species will continue to rise.	Faulkner et al. (2020), Wilson et al. (2020)
B2	However, the number of alien species worldwide is expected to increase faster than predicted under the business-as-usual scenario.	Climate change adaptation and mitigation strategies are likely to lead to the introduction of new alien species for new purposes (e.g., carbon sequestration and biofuel projects, and managed relocations) and to new accidental introductions (e.g., through new inter-basin water transfer schemes to improve water security). There is no explicit expectation that these drivers will increase invasion rates though, and several important historical pathways of introduction are no longer active.	Van Wilgen et al. (2023b)

	Paragraph	Available information for RSA	RSA References
B3	The causal links between indirect and direct drivers imply that ongoing and future amplification of these drivers will increase the frequency and extent of biological invasions and the impacts of invasive alien species, which, in some cases, may exacerbate the impacts of other drivers.	Internationally there have been perspective papers exploring these issues, but little that is specific to South Africa.	To our knowledge there has been no general perspective paper on this topic for RSA
B3	At a global scale, the number of invasive alien species and their negative impacts are likely to increase due to the amplification of multiple drivers including but not limited to demographic, economic and land-use and sea-use change while noting regional variation.	Not evaluated except through some scenario planning. There could be issues in future however, for example, the drive to plant more trees in Africa might end up stimulating invasions.	Bond et al. (2019), Chapman et al. (2001), Parr et al. (2024), Wilson et al. (2020)
B3	Additionally, climate change will further exacerbate the establishment of some invasive alien species and will be a major cause of future establishment and spread.	Partly analysed, noting some invasions are predicted to decline in range and abundance. Populations of cool-adapted invasive fish (e.g., <i>Salmo trutta</i> ) could decline due to warming of headwater streams, leaving an empty niche and creating opportunities for warm-adapted invasive fish species ( <i>Micropterus</i> species or <i>Oreochromis mossambicus</i> ) to invade.	Van Wilgen et al. (2023b), Weyl et al. (2020)
B3	Delays in the response of invasive alien species to drivers of change may result in a long legacy of future biological invasions due to past and present amplification of drivers.	This is a component of the invasion debt concept that has been estimated for Australian acacias in South Africa. It is also noted that control costs often rise sharply over time if no action is taken. Evidence has shown that over time invasions cross abiotic and biotic thresholds such that restoration becomes more difficult (and in some cases impossible).	Gaertner et al. (2012b), Marais et al. (2004), Rouget et al. (2016)
B4	Climate change interacting with land- and sea-use change is predicted to profoundly shape and amplify the future threat from invasive alien species.	Based on models, scenarios and experiences elsewhere it is likely there will be significant interactions between climate change and biological invasions. Theoretically, it makes sense but is not strongly supported by South African specific studies.	Iponga et al. (2009), Van Wilgen et al. (2023b)

	Paragraph	Available information for RSA	RSA References
B4	Interactions among climate change, land-use change and invasive alien species can alter and intensify natural disturbance regimes, such as wildfires.	<p>The destructive wildfires in Knysna in 2018 were exacerbated by plant invasions (15% more fuel was burnt in invaded areas than uninvaded areas, increasing the severity of fires and making containment measures ineffective).</p> <p>Strong evidence of damage to soils leading to erosion.</p> <p>Invasive plants have been implicated in worsening flood damage and destabilisation of riverbanks.</p>	Esler et al. (2008), Kraaij et al. (2018), Van Wilgen and Richardson (1985), Van Wilgen and Scott (2001)
B4	Variations in human perceptions and values add yet another level of complexity, as sociocultural drivers interact with other indirect drivers and influence direct drivers.	Various stakeholder groups have different perceptions of alien taxa with some extracting significant value from them while others see large negative impacts. This variation in perception and values present significant challenges for management. This has been studied in various contexts, noting there are often specific challenges in urban areas.	Gaertner et al. (2016), Jubase et al. (2021b), Potgieter et al. (2019), Shackleton et al. (2020), Van Wilgen (2012), Zengeya et al. (2017)
B4	Such interactions may lead to unprecedented numbers of invasive alien species, with the consequent amplification of their impacts.	See the three rows above, noting these interactions can be considered through the concept of invasion debt.	Rouget et al. (2016)
C1	There are decision-making frameworks and tools for inclusively identifying and supporting management goals related to (a) management of pathways of introduction and spread of invasive alien species; ...	Many introduction pathways are managed, particularly those related to intentional introductions and those related to accidental introductions that pose a threat to agriculture or animal and human health. There are, however, gaps in management (e.g., ballast water and biofouling). Pathways of spread are managed for specific species that pose a threat to agriculture and animal health.	Van Wilgen et al. (2023a)
C1	...(b) management of target invasive alien species at either local or landscape scales; ...	A substantial majority of management expenditure is spent to control selected plant taxa with Major impacts. 44% of management expenditure over the last 6 decades has focussed on <i>Acacia</i> , <i>Chromolaena odorata</i> , <i>Eucalyptus</i> , <i>Lantana camara</i> , <i>Neltuma</i> and <i>Pinus</i> . The effectiveness of control operations is not regularly monitored, but a few studies at local scales have reported reductions in alien plant cover.	Van Wilgen et al. (2022a)
C1	... and (c) site-based or ecosystem-based management.	Some work has been done on prioritisation and management at sites [e.g., management unit control plans (MUCPs)].	Forsyth et al. (2012)

	Paragraph	Available information for RSA	RSA References
C1	There are many sources of accessible literature and information, tools, and ...	There are a variety of data sources and databases though the last review of them was a decade ago.	Faulkner et al. (2015)
C1	... novel and emerging technologies, including biotechnology, bioinformatics, eDNA, remote sensing and data analytics, for supporting the management of biological invasions.	There are several initiatives to use new technologies to monitor and manage biological invasions, e.g., remote sensing and eDNA, but there has been little tangible progress in terms of monitoring to date.  There are various initiatives to improve data flow.	Zengeya and Wilson (2023)
C1	Consideration of both potential benefits and risks of the management of biological invasions can improve outcomes. A risk assessment and a risk management framework in line with a precautionary approach, as appropriate, can be effective to guide management actions, including the use of novel and emerging and environmentally sound technologies.	The Risk Analysis for Alien Taxa (RAAT) framework developed for South Africa considers the risks and benefits of alien taxa. A precautionary approach is applied as appropriate. Decisions are made by the governmental Risk Analysis Review Committee, which considers evidence from reports produced using the RAAT and other sources of input. Similar processes are in place to regulate the release of biocontrol agents.	Ivey et al. (2021), Kumschick et al. (2020b), Wilson and Kumschick (2024)
C1	The success of any management programme depends on the availability of adequate, sustained resources, ...	The government has provided substantial funding over the past 30 years through its Working for Water Programme, but its effectiveness is compromised by year-to-year fluctuations and funding cycles (annual or every three years), so management does not always occur when it is most appropriate. More recently, these funds have declined significantly.	Van Wilgen and Wannenburgh (2016), Van Wilgen et al. (2022a)
C1	... including for building capacity, which is sometimes lacking, especially in some developing countries.	Various research institutions have a strong focus on developing scientists, with funding available to conduct fundamental and applied research.	Richardson et al. (2020a)
C1	Multi-stakeholder engagement, including risk communication and context-specific application, can improve public acceptability and adoption of new tools and technologies for managing biological invasions.	Frameworks to aid stakeholder engagement have been developed. A programme is in place to promote engagement among stakeholders in the case of biocontrol and biomass use of <i>Neltuma</i> spp. invasions in the Northern Cape.	Ivey et al. (2024), Novoa et al. (2018)

	Paragraph	Available information for RSA	RSA References
C2	Prevention can be achieved through pathway management, including strictly enforced import controls, pre-border, border and post-border biosecurity, and measures to address escape from confinement.	The intentional import of alien species and accidental import of agricultural pests and diseases are controlled through pre-border risk analyses and permitting, and for agricultural pests' pre-border treatment. At-border inspections are performed at some ports of entry, and post-border inspections (e.g., of pet shops) for regulated taxa are performed. Illegally imported plants and animals can be confiscated and kept in quarantine. The focus of this management is on regulated species, and there are gaps, especially for marine pathways. The focus in South Africa is largely on reactive management.	Zengeya and Wilson (2023)
C2	Prevention is particularly critical in marine and connected water systems, where most attempts at eradicating or containing invasive alien species have mostly failed.	There has been success at extirpating invasive fishes from discrete water-bodies, but the only evaluation of a marine eradication found that an attempt would likely not be cost effective.	Mabin et al. (2020), Van der Walt et al. (2019)
C2	Prevention has been particularly effective on islands.	South Africa has few large islands. Experiences on the Prince Edward Islands are discussed in Box 2 of the paper.	Fernández Winzer et al. (2023, 2025)
C2	Preparedness includes border surveillance, early detection and rapid response planning, and is critical to reduce rates of establishment.	An incursion response unit has been set up and has mostly focussed on long-established invasions where eradication is potentially feasible.  Botanical gardens have been used as sentinel sites for the detection of pests and pathogens.  There is some surveillance and trapping for agricultural pests at ports of entry and at the borders.	Wilson et al. (2013), Wondafrash et al. (2021)
C2	Horizon scanning and risk analysis can support prevention and preparedness by prioritizing emerging invasive alien species.	Watch lists and a risk analysis framework have been developed specifically for South Africa. A risk analysis is required for the import of a new alien taxon.	Faulkner et al. (2014), Kumschick et al. (2020b), Swart and Robinson (2019)
C2	Sustained and adequate funding, capacity-building, technical and scientific cooperation, transfer of technology, monitoring, relevant and appropriate biosecurity legislation and enforcement, and quarantine and inspection facilities are necessary for effective prevention measures.	Most of the funding, capacity and effort allocated to manage biological invasions is focused on established alien species. Thus, South Africa's capacity to respond proactively to biological invasions is relatively low.	Early et al. (2016), Zengeya and Wilson (2023)

	Paragraph	Available information for RSA	RSA References
C3	Over the last 100 years, 88 per cent of eradication attempts on 998 islands have proven successful, especially for invasive alien vertebrates.	There are a few examples of extirpation of invasive vertebrates from in-shore islands, including rabbits from Robben Island.	Davies et al. (2020b)
C3	Large-scale eradications have been achieved but in many cases are likely to be infeasible.	No examples from South Africa. As a highly connected continental system, large-scale eradications would often require regional collaboration. In general, these are only possible on islands.	None
C3	There are also examples of eradication of invasive alien plants and invertebrates, particularly for those with limited distribution.	A snail species was eradicated from mainland South Africa, several ongoing programmes are underway for plants, and possibly several undocumented cases exist. There are no marine examples.	Wilson et al. (2013)
C3	Adoption of appropriate tools and technologies and involvement of relevant stakeholders underpin and improve the success of eradication programmes.	Several alien fish species have been extirpated from discrete water catchments using either mechanical methods (gill nets, electrofishing and seine netting) or chemical control (use of piscicides such as rotenone).	Davies et al. (2020b), Zengeya and Wilson (2020)
C3	Sustained investment is required for eradication programmes but they are generally more cost-effective than long term and permanent control or the costs incurred through inaction.	ZAR 183 million has been invested between 2006 and 2020 on alien plants that are potential targets for eradication. Additional resources have been invested to eradicate alien pests of agricultural crops. The cost effectiveness of these investments has not been estimated.	Van Wilgen et al. (2020)
C4	Physical control alongside chemical control options in terrestrial and closed water systems are generally only effective at a local scale and can have non-target effects.	The broad-scale impact of herbicide usage in efforts to control invasive plants in South Africa has not been fully evaluated. Working for Water has, however, had projects covering 2.7 million ha, which is ~ 14 % of the estimated invaded area, with some cases demonstrating effective control at landscape scales.	Van Wilgen et al. (2023a), Van Wilgen et al. (2022a)
C4	Biological control can be applied for widely distributed invasive alien species and has been successful in managing some invasive alien plants, invertebrates and, to a lesser extent, plant pathogenic microbes and vertebrates, ...	At least 17 species have been brought under permanent control through biological control and reductions in many other invasions exist. Biological control can also be effectively deployed against invasive plant species with limited distributions.	Olckers (2004), Van Wilgen et al. (2023a), Zachariades et al. (2017)



	Paragraph	Available information for RSA	RSA References
C4	... but it may also have non-target effects if not well regulated. International standards and risk-based regulatory frameworks for biological control have been used in many countries to manage risks, and continue to be successfully applied.	In over a century of classical biological control in South Africa there has been no significant non-target damage. South Africa has processes in place to adhere to international best practice in the field.	Hill et al. (2020), Ivey et al. (2021)
C4	Integrated management, where more than one containment or control option are used, can improve outcomes.	Integrated management has shown positive results; for example, the use of biological control in the landscape in combination with site-based control.	Nsikani et al. (2018), Van Wilgen et al. (2001)
C5	Management outcomes can be improved by the integration of site- and/or ecosystem-based management options that enhance ecosystem function and resilience.	See C4.	See C4
C5	Frequent long-term monitoring of sites ensures early detection of invasive alien species, including re-invasions, and can inform further management actions.	Monitoring is crucial to the management of biological invasions; hence clearing efforts are often accompanied by follow-up treatments aimed at reducing re-invasions.	Nsikani et al. (2017)
C5	In marine and connected water systems, ecosystem restoration has so far proved to be largely ineffective.	No restoration has been attempted in marine or connected water systems in South Africa. There is no evidence that it would be successful.	None
C5	Adaptive management, possibly combining multiple options, will improve management of biological invasions under ongoing climate and land-use change.	There are cases of restoration efforts in the country that have combined multiple options (e.g. biological control, manual removal of target invaders, follow-ups and seed application) leading to enhanced ecosystem recovery through the management of barriers to ecological restoration. Frameworks for adaptive management have been developed.	Foxcroft (2004), Nsikani et al. (2018)
C5	Integrating site and/or ecosystem-based approaches can improve management outcomes of biological invasions and also enhance ecosystem functioning under ongoing climate and land-use change.	The application of biological control in the landscape reduces the reproductive output of invaders and slows their spread. When combined with site-based clearing that is followed-up by restoration, management outcomes have been improved. Similarly, in aquatic environments, biological control of floating aquatic invasive plants promotes ecosystem recovery.	Coetzee et al. (2020), Motitsoe et al. (2020), Nsikani et al. (2018)

	Paragraph	Available information for RSA	RSA References
C6	Engaging stakeholders, including the private sector, and Indigenous Peoples and local communities in the collaborative management of biological invasions is important for social acceptability and improving environmental, social and economic outcomes, particularly where there are conflicting perceptions of the value of invasive alien species and the ethics of management options.	Specific approaches and frameworks to engage with stakeholders on the issue of biological invasions were developed by South African stakeholders at a workshop in Cape Town. Collaborative engagement across sectors (including academics, government institutions and private stakeholders) is being undertaken to support the sustainability of biological control programmes in the country.	Ivey et al. (2024), Jubase et al. (2021a), Novoa et al. (2018)
C6	Management actions also benefit from sharing and collaboration across knowledge systems.	There are a variety of active working groups and an annual national symposium on biological invasions and their management. In addition, building collaborative governance initiatives can help to ensure sufficient funding for research and management that is relevant to stakeholders' needs. However, more can be done in South Africa to promote this both within and outside of academia.	Abrahams et al. (2019), Foxcroft et al. (2020), Ivey et al. (2024)
C6	Recognizing Indigenous Peoples' and local communities' knowledge, rights and customary governance systems in accordance with national legislation also helps to improve long-term management.	Management of biological invasions, particularly in communal areas, often takes place in consultation with traditional leadership and authorities. These have not, however, been well documented as far as we are aware. Understanding local perspectives and needs is being considered increasingly by managers and decision-makers and has helped to shape discourses on management and governance [for example, justifying the support for the introduction of more damaging biological control agents for managing invasive <i>Neltuma</i> (prosopis) in the Northern Cape]. In addition, in some areas, local communities are very active in managing their local environments to prevent or limit invasions, this could be a useful leverage point to build collaborative governance moving forward.	Ivey et al. (2024), Jubase et al. (2021a), Shackleton et al. (2007), Shackleton et al. (2015)

	Paragraph	Available information for RSA	RSA References
D1	Strategic actions to prevent the introduction and impact of invasive alien species include: enhancing coordination and collaboration across international and regional mechanisms; developing and adopting effective and achievable national strategies; sharing efforts and commitment and understanding the specific role of all actors; improving policy coherence; broad engagement across all stakeholders and Indigenous Peoples and local communities; resourcing innovation, research and technology; and supporting information systems, infrastructures and data sharing.	<p>These are discussed in turn in Table 3 in the paper.</p> <p>A ‘participatory futuring process’ has been applied with a view to scaling up a range of already successful or promising interventions to transform and improve invasive species management in South Africa.</p>	Van Velden et al. (2023)
D2	International, national and local agencies involved in developing policies for the environment, agriculture, aquaculture, fishing, forestry, horticulture, border control, shipping (including biofouling), tourism, trade (including online trade in animals, plants, and other organisms), community and regional development (including infrastructure), transportation and the health sector can all play a role in developing a coherent approach to managing biological invasions and preventing and controlling invasive alien species.	<p>Various policies and legislation exist, but these are not completely aligned. Other actions (i.e., those not at the border) are not coherent (e.g., different risk analyses systems for different threats).</p> <p>A newly created intra-departmental Alien and Invasive Species Forum was established by the DFFE to facilitate integrated governance across all aspects of biological invasions. The intention is for it to become interdepartmental.</p> <p>There are various provincial working groups and partnerships with various sectors (e.g., the horticultural and forestry industries). These facilitate discussions around regulatory lists published for public consultation, in a few cases while lists are being implemented. There are, however, several unresolved issues (e.g., how to address the risks of horticultural cultivars).</p> <p>The Border Management Authority (BMA) was established as a schedule 3(A) public entity and the third law enforcement agency on 1 April 2023. The BMA is the single authority for the management of South Africa’s borders. The BMA integrates and facilitates the implementation of biosecurity interventions at ports of entry and the Border Law Enforcement area under a single command and control.</p>	Chetty et al. (2024), Wilson and Kumschick (2024), Zengeya and Wilson (2023)

	Paragraph	Available information for RSA	RSA References
D2	Enhancing coordination and collaboration across international and regional mechanisms is one of the key strategic actions for rapid and transformative progress. International and regional partnerships can improve management of biological invasions.	<p>There are partnerships between African countries to monitor for new alien species, these partnerships tend to be industry specific (e.g., the Forest Invasive Species Network for Africa monitors for forestry pests).</p> <p>There are increasing initiatives at the level of the Southern African Development Community (SADC) and there is the potential for an Africa-wide strategy to address biological invasions. However, there is little evidence of on-ground implementation of such initiatives. A greater focus on bottom-up approaches (e.g., through research and management collaboration) might lead to tangible improvements.</p>	To our knowledge there has been no general perspective paper on this topic for RSA
D2	Collaboration and co-development with Indigenous Peoples and local communities can increase the effectiveness of implemented strategies.	<p>The IPBES definitions do not always correspond to definitions used in South Africa, but the sentiment does (cf. Box 4 in the paper).</p> <p>There are various hack groups, spotter networks and farmer groups. Some efforts have gone into translating into local languages. There are also land user incentive programmes.</p> <p>Recently, farm-level management strategies to improve the control of <i>Neltuma</i> invasions in the Northern Cape were co-developed by multiple local and national stakeholders. This drew heavily on co-developed national strategy suggestions. Similarly, co-development actions for strategic planning have been developed for other taxa, such as invasive cactus species.</p>	Ivey et al. (2024), Jubase et al. (2021a), Kaplan et al. (2017), Novoa et al. (2016), Nxele et al. (unpublished), Shackleton et al. (2017)
D3	Implementation-focused national biodiversity strategies and action plans can help to spur strategic actions and establish the properties of the governance systems required for the successful prevention and control of invasive alien species and the management of biological invasions, and work towards delivering Target 6.	South Africa's National Biodiversity Strategy and Action Plans (NBSAPs) included activities to address biological invasions. The Convention on Biological Diversity's programme of work provides an obligation for South Africa to develop a national strategy (which is under development).	Under development

	Paragraph	Available information for RSA	RSA References
D3	Coordinated efforts to strengthen national regulatory instruments are also priorities, including those for online trading and the creation of appropriate policies for the development and use of environmentally sound technologies, as well as making available data and information accessible.	<p><i>National regulatory instruments:</i> the management of biological invasions is mainly informed by the NEM:BA A&amp;IS Regulations of 2014 and as revised in 2016 and 2020. These regulations provide a list of taxa that require management. Inclusion of taxa in these lists was initially largely informed by expert opinion; however, risk analyses are increasingly being relied upon to inform the list of species targeted for management. Improvements to the regulations have been made, e.g., amendments to The National Environmental Laws Amendment Act, 2022 (NEMLAA) which came into effect on 30 June 2023.</p> <p><i>Online trading:</i> some studies have looked at this, though there is not a specific policy.</p> <p><i>Development and use of environmentally sound technologies:</i> biological control is well regulated.</p> <p><i>Making available data and information accessible:</i> the South African status report provides a crucial function in this regard. Risk analyses are not in public domain yet, but the plan is for them to be published in concert with revisions to regulatory lists. However, much more needs to be done. For example, the current biosecurity landscape is fragmented and characterised by several databases and inventories that are managed by various entities, including government departments and entities, non-profit organisations and research institutions. While there has been some cooperation between these entities, the varying format, content and completeness of these databases make it difficult to fully define the scope of biosecurity. There are significant gaps in the available information on pathways of introduction and dispersal, making it difficult to develop effective biosecurity measures. A centralised and comprehensive system for managing biosecurity, which integrates the existing databases and inventories into a unified system, is in development.</p>	Ivey et al. (2021), Mantintsilili et al. (2022), Nelufule et al. (2020), Shivambu et al. (2020), Wilson and Kumschick (2024)
D3	Market-based instruments such as tax relief and subsidization can be used to incentivize action and spur relevant investment.	Payments for ecosystem services have been proposed, but not yet implemented. Value-added industries that utilise alien biomass have been shown in theory to be beneficial but have not been successful in practice.	Pirard (2023), Turpie et al. (2008)
D3	Sharing efforts and commitment, understanding the specific roles of all actors and encouraging engagement across sectors on prevention, control and environmental liability are integral to the effective management of biological invasions.	The draft National Invasive Alien Species Strategy and Action Plan promises to see a step-change in the coordination of South Africa's response to the issues of biological invasions.	Under development

	Paragraph	Available information for RSA	RSA References
D4	Awareness of the risks of biological invasions will contribute to the effective delivery of several of the Sustainable Development Goals, especially those addressing the conservation of marine biodiversity (Goal 14) and terrestrial biodiversity (Goal 15, including but not restricted to Target 15.8) ...	Acknowledging and managing the threat of biological invasions to South Africa contributes to progress both towards SDG Goals 14 and 15 and to many other goals as well. For example, the large-scale Working for Water Programme, which focuses on clearing invasive plants, contributes to the provision of water (addressing Goals 6, 13) and employment and up-skilling/education of poor rural communities in the country (addressing Goals 1, 2, 4, 8, 10).	Cumming et al. (2017), Van Wilgen and Wannenburgh (2016)
D4	... food security (Goal 2) ...	Management of pests and diseases for major crop species, e.g. fall army worm, is critical to ensure food security. Employment has been created through Working for Water's focus on clearing invasive plants, this has aided household food security of the rural poor.	Cumming et al. (2017), Mendesil et al. (2023), Van Wilgen and Wannenburgh (2016)
D4	... sustainable economic growth (Goal 8) ...	Responsible use of invasive tree biomass can aid sustainable economic growth at local scales.	Ivey et al. (2024)
D4	... and sustainable cities (Goal 11) ...	Some municipalities (e.g., City of Cape Town and eThekweni) have units devoted to working on biological invasions. There is also a large body of work done on municipalities by environmental health practitioners under the framework of the Health Professions Act of 1974.	Gaertner et al. (2016)
D4	... as well as climate change (Goal 13) ...	Managing invasive species will help mitigate climate-related effects and stressors. For example, climate change is expected to impact water security in southern Africa. The Working for Water Programme, which clears invasive trees that use up excess water, thus contributes to climate change mitigation.	Le Maitre et al. (2016), Van Wilgen and Wannenburgh (2016)
D4	... and health and well-being (Goal 3).	Many invasive species in South Africa have direct impacts on the health and well-being of people, e.g., by causing allergies and asthma. In addition, invasive species can hinder well-being by reducing economic options. Managing and reducing these impacts directly aids progress toward Goal 3.  Job creation through large-scale invasive species control (e.g., the Working for Water Programme) provides income and education to poor rural communities, contributing to livelihoods and well-being.	Magadlela and Mdzeke (2004), Shackleton and Shackleton (2018), Van Wilgen and Wannenburgh (2016)

	Paragraph	Available information for RSA	RSA References
D4	Existing collaborative and multisectoral approaches (e.g., One Health) could provide frameworks for cross-disciplinary thinking and could contribute to the management of biological invasions.	There have been academic discussions on the similarities between emerging infectious diseases, forestry health and pathogens and biological invasions. In terms of actual implementation there is little direct output. The University of Pretoria has a One Health network that is a multi-sectoral community of practice, this offers the opportunity for more engagement on work on biological invasions.	Ogden et al. (2019), Paap et al. (2020)
D5	By delivering current data to relevant actors, information systems can facilitate the prioritization of actions and allow for early detection and rapid response.	<p>The South African Emergency Plant Pest Response Plan (SAEPPRP) outlines a response strategy for detecting, identifying and mitigating an emergency plant pest incursion in South Africa.</p> <p>South Africa has an incursion response unit that is part of SANBI and the unit has been active for more than 16 years. Over 80 taxa have been managed by this unit to varying degrees. The NEM:BA A&amp;IS Regulations list taxa that require management and those that are specifically eradication targets. The incursion response unit selects targets from this list, collects data on incursion response targets while managing the taxa. Targets that are not listed in the NEMBA A&amp;IS Regulations are also selected if there is sufficient documented evidence to show the potential for eradication, which warrants in-depth investigation and incursion response.</p> <p>In both cases a clear flow of data from observation to action and suitable data pipelines and workflows are needed.</p>	Wilson et al. (2013)
D5	Information systems can also support improved governance ...	The Water Information Management System (WIMS) was developed to track clearing efforts and improve governance. It has, however, been quite difficult to use. In the absence of quality information, tracking the efficacy of control is difficult.	Kraaij et al. (2017), Marais et al. (2004), Zengeya and Wilson (2023)
D5	... and help develop indicators of biological invasions, which in turn feed into policy support tools.	South Africa has pioneered the development of indicators to track the status of biological invasions. National level indicators have been developed and are implemented in the South African status reports. These initiatives link to international processes including the development of indicators to track progress towards Target 6 of the KM-GBF.	McGeoch et al. (2006), McGeoch et al. (2010), McGeoch et al. (2023), Wilson et al. (2018), Zengeya and Wilson (2023)

	Paragraph	Available information for RSA	RSA References
D5	Collaboration between biological invasion experts and across knowledge systems in all regions, and enhancement of research capacity where needed, can improve data and information availability and the understanding of the context-specific features of biological invasions and their impacts.	<p>The inter-institutional Centres for Invasion Biology and for Biological Control have been highly successful in building research networks across the country and with international partners.</p> <p>Various meetings address biological invasions including the Conservation Symposium in KZN and the National Biological Invasions Symposium. There are also some fora that have ceased to meet, e.g., the Management, Research and Planning (MAREP) meetings. There are also farmers days, integrated working groups, online and in-print pamphlets, popular books and various short courses.</p>	Byrne et al. (2020), Richardson et al. (2020a)
D6	Advances can be achieved through adequately and sustainably resourced public awareness campaigns ...	The Working for Water Programme funded a significant public awareness campaign for many years.	Byrne et al. (2020)
D6	... education ...	Various awareness campaigns are run and popular articles published about biological invasions, with the focus on educating different people (including school children) on what biological invasions are, their impacts and management. Studies in South Africa have shown that improving public awareness promotes acceptance of the management of biological invasions.	Byrne et al. (2020), Novoa et al. (2017)
D6	... citizen science ...	There are numerous citizen science and volunteering initiatives in South Africa such as iNaturalist, SAPIA, SABAAP2, Bird Atlas, society programs (Botanical Society of South Africa) and others (e.g., local hack groups).	
D6	... and targeted investment in research innovation ...	Two large inter-institutional research institutes (the Centres for Invasion Biology and Biological Control) received significant governmental funding for many years, although this funding has dramatically declined in the past few years.	Richardson et al. (2020a)
D6	... and environmentally sound technology.	Biological control of invasive plants has a substantial record with no major direct negative non-target impacts recorded in South Africa. There has been no evaluation of the environmental impact of herbicides to date. Under some conditions, using helicopters to apply herbicides may be cost-effective.	De Lange et al. (2022), Hill et al. (2020)



	Paragraph	Available information for RSA	RSA References
D6	Public engagement with citizen science platforms and community-driven eradication campaigns can raise awareness and contribute to actions that reduce the threat of invasive alien species. This can also be aligned with efforts to share efforts and commitment and understand the specific roles of all actors.	<p>There are numerous avenues to promote awareness and engagement such as the ARC Newsletter, information sheets, and the Invasives South Africa website (<a href="https://invasives.org.za/">https://invasives.org.za/</a>).</p> <p>iNaturalist and other online reporting programmes have grown in usage and South Africa has a relatively large global presence (e.g., in the BioBlitz and City Challenge).</p> <p>Hack groups are spreading awareness and promoting IAS control.</p> <p>From our experience, when people know that taxa are being controlled (e.g., as part of an eradication), people are very willing to help identify new infestations.</p>	Byrne et al. (2020), Jubase et al. (2021a)
D6	Communication strategies based on evidence can help to bring about community action on biological invasions by supporting the co-design of management actions, knowledge exchange and enhanced partnerships among stakeholders.	Various working groups are in place based on particular taxa or regions (e.g., invasive animals and Cactaceae). The link between research and communication projects could, nonetheless, be improved. Developing a comprehensive integrated communication strategy and facilitating co-management should be included in the national strategy.	Byrne et al. (2020), Davies et al. (2020a), Foxcroft et al. (2020), Novoa et al. (2016)
D7	With sufficient resources, political will and long-term commitment, preventing and controlling invasive alien species are attainable goals that will yield significant long-term benefits for people and nature.	The Working for Water Programme has been active since 1995. The funding has not been sufficient to bring plant invasions in South Africa down to maintenance levels, but nonetheless substantial progress has been made, without which the situation would undoubtedly be much worse. Monetary estimates suggest control is feasible, and in a few cases of biological control extremely financially attractive.	McConnachie et al. (2003), McCulloch-Jones et al. (2024), Van Wilgen et al. (2022a)
D7	Increasing the availability and accessibility of information and means of implementation and addressing major knowledge gaps on biological invasions, particularly in developing countries, would result in more robust and effective policy instruments and management actions.	There is often a close working relationship between scientific and governmental institutions in South Africa. Knowledge can be critical to inform effective policy although issues with research-implementation gaps still exist. There is a need to mobilise various information sources making them broadly available, including risk analyses, factsheets on invasive species, supporting the website 'Invasive Species South Africa' and various pamphlets and out-reach material. Various initiatives are underway to develop data pipelines including through the South African status report.	Esler et al. (2010), Zengeya and Wilson (2023)

	Paragraph	Available information for RSA	RSA References
D7	Additional efforts and cooperation are particularly needed to improve data collection in Africa, Latin America and the Caribbean and Asia.	A core message from this manuscript is the need to work collaboratively with neighbouring countries. There is a need for datasets on biological invasions in the SADC region, and to collaborate to improve management at the regional scale.	

### Supplementary Table S3. Objectives and actions for managing biological invasions with details of the South African situation

The objectives and management actions were taken verbatim from Table SPM.1 of the IPBES IAS Assessment (IPBES 2023). The levels shown (low/easy \*, medium \*\*, high/difficult \*\*\*) are for their: availability (availability of target-specific tools for implementing management); ease of use (ease of implementation or specialist or technological expertise to implement); and effectiveness (likely long-term efficacy and outcomes of implementation). The focus is on mainland South Africa and the immediate offshore environment (including islands). The objective of eradication is defined here at a national level [i.e., eradication from South Africa with a low chance of recolonisation, sensu (Myers et al. 1998)]. The IPBES IAS Assessment distinguished physical methods, chemical methods and adaptive management as actions under the objective eradication. However, in our view, there is not a clear separation in South Africa between the actions used to achieve eradication targets, as such the topic has been combined. The IPBES IAS Assessment also scored ‘terrestrial and closed water systems’ separate from ‘marine and connected water systems’; these were not explicitly separated for South Africa, but differences were noted when appropriate.

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Prevention and preparedness	Horizon scanning	**	**_***	**_***	**_***	?	**_***	Simple systems for use have been developed, noting most are forms of environmental scanning rather than broader horizon scans. Different types of future thinking require different skills. Often such tools require expertise in coding and GIS or in participatory elicitation. A broad range of different disciplinary skills and experience are needed for horizon scanning and scenario development.	Faulkner et al. (2014), Swart and Robinson (2019)
Prevention and preparedness	Import controls and border biosecurity	*_**	**_***	*	*_**	?	*_**	Controls and systems are in place for agricultural diseases, pests and weeds, and animal diseases; for other threats (e.g., environmental) legislation exists, but capacity is low. The Border Management Authority might address this in the coming years.  Data are available on interceptions, but it is often difficult to identify the imported or accidentally introduced organisms. As such competency requires training and experience. Moreover, knowing what to sample where, when and how can be complicated given sampling can conflict with trade.	Nnzeru et al. (2021), Saccaggi et al. (2021), Tshikhudo et al. (2021a,b), Van Wilgen et al. (2023a)

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Prevention and preparedness	Pathway management	*_**	**	*	*	?	*_**	<p>Pathways for agricultural diseases, pests and weeds, and animal diseases are managed [e.g., development of integrated measures in a systems approach (applied during pre-planting, pre-harvest, harvest, post-harvest treatment and handling, and transportation and distribution); treatment pre-border of specific commodities and against certain pests; post border measures (treatment, destroy or send back) as emergency measures to manage pests; and post-entry quarantine to manage pests that are likely to develop at a later stage].</p> <p>There is less work on other pathways and there is no specific requirement for all pathways to have dedicated management plans in place. Competency requires training and experience. Cooperation is needed with the various stakeholders who are responsible for the vectors and pathways (for whom biological invasions is a minor or underappreciated issue).</p> <p>Unaided introductions are difficult to prevent given the nature of South Africa's borders.</p>	Van Wilgen et al. (2023a)
Prevention and preparedness	Risk analysis	***	***	**	*_****	?	***_****	<p>A risk analysis framework has been developed for South Africa and is in place to assess any applications for the import or use of species (in place for environmental introductions since 2014). Competency requires training and experience – there is a regular training course to address this.</p> <p>Pest risk analysis systems developed for DALRRD according to IPPC guidelines (IPSM 2 and 11) and import permits were required well before 2014. To protect South Africa's environment and agriculture from alien pests while promoting trade in plants and plant products, pest risk analysis is used to identify and determine whether a pest is a quarantine pest and to choose risk management strategies. It also contains information on how plant pests impact biological diversity and the environment, including how they could harm wild plants, cultivated or uncultivated plants, habitats, and ecosystems.</p>	Kumschick et al. (2020a,b), Wilson and Kumschick (2024)

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Early detection	Surveillance	**	*_**	**_***	*	?	***	<p>There is some passive surveillance (e.g., citizen science platforms like iNaturalist) but little dedicated active surveillance for specific targets. State conservation agencies have in-house scientists involved in the detection of invasive species. Various atlassing initiatives provide some degree of active surveillance. In 2008 a unit was set up within the SANBI with the goal of improving detection linked to taxonomic identification (e.g., a project exploring botanic gardens as sentinel sites was developed jointly with the Forestry and Agricultural Biotechnology Institute). Competency can require training and experience; but in some cases (e.g., iNaturalist) simply the ability to see something new and take a good photograph of it.</p> <p>In agriculture, information on particular pests is gathered through general surveillance and provided for use by the National Plant Protection Organisation (NPPO). The NPPO also facilitates dedicated surveys to obtain information on pests of concern at specific sites. IPPC guidelines for pest surveillance are provided in terms of ISPM 6 (survey and monitoring system components for detecting pests; information for use in pest risk assessments, creating pest-free zones and creating pest lists).</p> <p>Despite work to detect taxa, there has been a poor track record of moving from detection to action.</p>	<p>Potgieter et al. (2024), Henderson (2001), Henderson and Wilson (2017), Jubase (2021), Paap et al. (2018), Wilson et al. (2013)</p>

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Early detection	Diagnostics	**_***	*_***	*	*_**	**_***	**_***	<p>A substantial network of experienced taxonomic experts is available for many groups and there are facilities for diagnostics. Staff are usually not embedded within management agencies, but rather at museums or universities, although DALRRD does have such capacity for pests and diseases.</p> <p>South Africa has been utilising DNA Barcoding services to identify intercepted specimens at ports of entry and inland since 2016 through the African Centre for DNA Barcoding at the University of Johannesburg.</p> <p>Competency requires training and experience; more trained taxonomists are needed. Molecular diagnostics can be expensive and still requires substantial interpretation. Often diagnostics are required for groups which local taxonomists do not have expertise on, though there is often significant international collaboration. Diagnostic protocols are not always available (especially for new detections).</p> <p>With some paid or explicit services available diagnostics can be reliable and relatively quick.</p>	Janion-Scheepers et al. (2016), Saccaggi et al. (2016)

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Eradication	Physical eradication & Chemical eradication & Adaptive management	**	*_***	**	*_**	*	*_***	<p>A unit specifically tasked with nationwide eradications was established in 2008, mostly focussed on plants. Other projects are underway to look at animals. More than 70 taxa have been designated as national eradication targets, and dedicated projects have been set up or considered for at least 42 taxa with the majority being terrestrial or freshwater plant taxa often using labour intensive methods.</p> <p>Herbicides need to be registered for legal use, but registered herbicides are not always available, particularly for taxa that are newly detected and only present in a few localities. In many contexts, and particularly after initial control, routine regular follow ups using physical control can be highly effective, although detailed monitoring data are needed.</p> <p>Piscicides (Rotenone) have been used to extirpate invasive fishes from discrete freshwater systems, but it is unlikely any taxon will be eradicated nationwide.</p> <p>One species has been confirmed as eradicated from mainland South Africa to date, but several others are likely to be declared soon, so the effectiveness score is likely to increase soon.</p>	Herbert and Sirgel (2001), Weyl et al. (2016), Wilson et al. (2013)
Containment and control	Physical control	***	*_***	**_***	*	*_***	*	<p>South Africa has a high dependence on manual labour for controlling invasive plants. More than 8 000 full time equivalent jobs per year were created 1998–2020 (though there were many more beneficiaries).</p> <p>At a small scale the skills required can be minimal (and often civic groups go with little or no training). For larger scale operations, coordination becomes much more complicated, and training is needed to ensure control is effective, safe and resources spent appropriately.</p> <p>Effective control has been achieved in some places, but there is low effectiveness overall at a national scale. Arguably there is insufficient use of more complicated mechanised control methods.</p>	Van Wilgen et al. (2016), Van Wilgen et al. (2020), Van Wilgen et al. (2022a)

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Containment and control	Chemical control	**	*_***	**	**	*_***	**	<p>Effective registered herbicides are available for many but not all invasive plants. Piscicides (Rotenone) have been effectively used locally. Insecticides are often used to control agricultural pests and manage household pests such as ants, cockroaches, and houseflies.</p> <p>Competency requires training and experience. The registration of herbicides for a particular target can be very cumbersome and there is often no commercial incentive to acquire registration.</p> <p>The Biodiversity Stewardship Programme (national and provincial) sometimes offer complimentary herbicides to participating landowners as an incentive to engage with the programme and secure properties for conservation.</p> <p>Effective control has been achieved in some places, but the cost of widespread application of chemicals is high and can have significant non-target impacts. A better system for accounting of chemical usage and impacts is needed.</p>	Bellingan et al. (2019), Prinsloo and Uys (2015), Weyl et al. (2013)
Containment and control	Biological control	***	***	*_***	**	***	***	<p>South Africa is a world-leader in biocontrol. Various quarantine, research and mass-rearing facilities are in place. There is a well-regulated system to review proposed biological control releases.</p> <p>Already released agents often self-disperse and form self-sustaining populations (requiring no additional intervention). In other situations, periodic re-introductions might require mass rearing (requiring some technical expertise).</p> <p>Developing and testing new biological control agents, however, requires substantial technical and research expertise and facilities.</p> <p>46 alien plant species are under effective or permanent biological control. Many agricultural pests are also effectively managed using biological control.</p>	Hill et al. (2020), Ivey et al. (2021)



Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Containment and control	Adaptive management	*	*_**	*_**	*	*	*_***	Adaptive management is only really practised in some protected areas as it requires capacity, monitoring, and that organisations can be responsive (e.g., by having flexible budgets).  More adaptative management could lead to significant improvements if more widely used in South Africa.	Foxcroft and McGeoch (2011)
Ecosystem restoration	Adaptive management	*_**	*_***	*_***	*	*_***	*_***	Significant contributions through research have been made to the theory and practice of restoration ecology and local guidelines for ecological restoration have been developed for numerous situations.  Restoration often requires careful planning, goal setting and monitoring to be effective. There are few qualified restoration ecologists and certified practitioners relative to the demand. There has been limited uptake in implementing active restoration projects at larger scales. Restoration efforts, particularly active restoration, remain limited to local scales (often localised to some protected areas), i.e., the scale of restoration is low compared to the scale of the problem.  Effectiveness is reliant on capacity, cost and scale. In some cases, few interventions are needed – the system recovers with passive restoration – in other cases even drastic action would be unlikely to bring about recovery to a pre-invaded state. In cases where active restoration is effective and financially feasible compared to passive restoration, the costs are sometimes deemed prohibitive, and control programmes rely on passive restoration even if it is inappropriate to do so.	Gaertner et al. (2011, 2012a,b,c), Holmes et al. (2020)

Objective	Management action	Availability		Ease of use		Effectiveness		Notes	References
		RSA	Global	RSA	Global	RSA	Global		
Public understanding	Public engagement	**	***	*_**	*_**	?	***	<p>There are numerous educational campaigns (e.g., 'Alien busters'), 'hacking days' through volunteers that require minimal funding, and education through Working for Water that is increasingly drawing on co-developed management initiatives including various stakeholders.</p> <p>Various on-line resources are available (see above). Resources and capacity are needed, as well as translation into other languages.</p> <p>Outcomes have rarely if ever been monitored so it is unclear what works.</p>	Byrne et al. (2020), Ivey et al. (2024), Murray (2005)

# **Supplement Table S4.** Knowledge and data gaps identified in the IPBES IAS Assessment in the context of South Africa

This is based on Table SPM.A1 of the IPBES IAS Assessment (IPBES 2023). Five categories were considered: very low, low, medium/intermediate, high, and very high. Seven types of gaps were identified (the following wording is taken verbatim from the IPBES IAS Assessment): 1. Gaps in biomes, units of analysis and species groups; 2. Regional gaps in data and knowledge; 3. Interoperable data for monitoring invasive alien species and effects of drivers of biodiversity change; 4. Gaps in how invasive alien species affect nature's contributions to people; 5. Management and policy approaches; 6. Gaps to fill to support the implementation of policy and management; and 7. Gaps in knowledge on invasive alien species of particular relevance to Indigenous Peoples and local communities. The focus is on mainland South Africa and the immediate offshore environment (including islands). Some gaps were combined where the responses were the same. At least during the plenary sessions, it was often found to be difficult to score the potential management gain and potential understanding gain, so we have little confidence that these are reliable estimates.

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
1	Incomplete or lack of inventories of invasive alien species in marine, tropical and Arctic ecosystems	<p>Marine surveys have taken place, but these are primarily in harbours, with less known about natural habitats.</p> <p>Tropical areas (a relatively small area of the country) are not specifically under-sampled in South Africa, in fact the alien taxa in the Kruger National Park are regularly inventoried.</p> <p>Arctic ecosystems are not found in mainland South Africa, though see Box 3 on the Prince Edward Islands.</p>	<ul style="list-style-type: none"> <li>Integrate data from citizen science into inventories for marine protected areas and other relevant databases.</li> <li>Coordinate long-term monitoring and data curation concurrently with detection activities.</li> </ul>	High (marine) Low (tropical) NA (Arctic)	Very High (marine) Low (tropical) NA (Arctic)

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
1	Incomplete or lack of inventories of invasive alien microorganisms and invertebrates	<p>No systematic inventory of micro-organisms in part due to issues with biogeographic knowledge, but also as existing information has not been collated within the framework on biological invasions.</p> <p>There are various invertebrate lists, but there is significant under-sampling.</p> <p>The completeness of particular lists depends on the availability of relevant taxonomists and sampling.</p> <p>Biocontrol introductions are well documented and inventoried.</p> <p>Better knowledge would provide opportunities for eradication or control.</p>	<ul style="list-style-type: none"> <li>• Integrate current data sources and database into current species list (e.g., the Foundational Biodiversity Information Programme).</li> <li>• Ensure molecular data and eDNA surveys are linked to ground truthing surveys and conventional sampling (in particular for studies on microorganisms).</li> <li>• Link foundational biodiversity data to lists of aliens.</li> <li>• Support foundational work by taxonomists.</li> <li>• Support general surveys targeting invertebrates and microorganisms.</li> </ul>	High	Very High
1	Lack of understanding of the drivers of change that facilitate biological invasion for some animal groups (notably invertebrates), fungi and microbes	<p>Drivers of ecosystem change in terrestrial, freshwater and marine ecosystems are fairly well studied for some taxa (plants and vertebrates) but less so for fungi, microbes and invertebrates.</p> <p>There are gaps in our understanding of pathways for invertebrates, fungi and microbes; particularly accidental introductions. Deliberate introductions are much better understood.</p> <p>Better knowledge would enable risks to be estimated and mapped, and interventions to be targeted and become pro-active.</p>	<ul style="list-style-type: none"> <li>• Map the drivers facilitating invasions and look at scenarios for how they might change in future, particularly around accidental introductions.</li> <li>• Explore how organisms move around the country (deliberately and accidentally).</li> </ul>	Very High	Very High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
1 & 2	Lack of understanding and synthesis of the impacts of invasive alien microbes (1) & Incomplete data on the impacts of invasive alien species across Africa and Central Asia (2)	<p>There are few limited studies on the impacts of alien microbes. For example, recent studies have highlighted the impact of the polyphagous shot hole borer and its fungal symbiont, <i>Fusarium euwallaceae</i>. In general calls for greater interaction between microbiologists and invasion scientists have not been met.</p> <p>Improved impact assessment methodologies have aided in identifying highly impactful species in South Africa. There is ongoing development of frameworks and models assessing potential impacts and risks posed.</p> <p>Better knowledge would assist management but only if effective interventions are feasible.</p>	<ul style="list-style-type: none"> <li>Promote and fund studies that formally assess the impacts of alien species, especially underrepresented taxa such as microbes.</li> <li>Test existing risk analysis and impact frameworks for their applicability to microbes (and develop new tools as needed).</li> <li>Create working groups or points of interaction between pathologists, fungal biologists and those working on biological invasions.</li> <li>Collate existing information in terms of biological invasions.</li> <li>Develop pathway management strategies relating to high-risk microbes or implementation of contingency plans.</li> <li>Institutionalise alerts through surveillance mechanisms.</li> </ul>	Very High	Very High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
1 & 2	Poor understanding of drivers of change that facilitate biological invasions in aquatic and marine systems (1) & Comparative lack of understanding of the drivers of change that facilitate biological invasions in developing economies (2) & Lack of data and knowledge of the drivers of biological invasions in sub-Saharan Africa, tropical Asia and South America (2)	<p>Drivers of ecosystem change in terrestrial, freshwater, and marine ecosystems are fairly well studied but there are some gaps. Eutrophication and variation in water flow are well known to have impacts on aquatic weeds. The impact of plastic pollution on the marine environment (South Africa is a collector of plastics) is not known. Elevated dissolved CO<sub>2</sub> levels is likely to affect aquatic plant growth.</p> <p>FBIS (<a href="https://freshwaterbiodiversity.org/">https://freshwaterbiodiversity.org/</a>) provides a baseline of species distribution, richness and abundance to enable an understanding of drivers in freshwater ecosystems.</p> <p>Better knowledge would enable risks to be estimated and mapped, and interventions to be targeted and become pro-active.</p>	<ul style="list-style-type: none"> <li>Fund research into how the impacts of biological invasions interact with other drivers of global change.</li> </ul>	Very High	Very High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
1	Lack of data on successful restoration attempts in terrestrial and marine systems	<p>South Africa has been a leading country in the science of restoration of invaded habitats in riparian and terrestrial ecosystems. Such studies need long-term monitoring of restoration success post invader removal. Some specific active restoration projects have been well documented.</p> <p>The Working for Water Programme has substantial clearing activities, but it is not designed specifically for restoration (largely relying on passive restoration).</p> <p>Nothing has been done in marine systems as uncertainties are too high. As eradication is not feasible, removal and ensuing restoration would need to be ongoing, making it costly.</p> <p>Better knowledge would allow for adaptive management.</p>	<ul style="list-style-type: none"> <li>• Develop tools [e.g., the 'Management Unit Clear Plan' (MUCP)] to track clearing activities and expand these to explicitly include restoration.</li> <li>• Ensure data on the costs, the spatial coverage of work, and volunteer and paid work hours are captured and made available, so methods are transferable.</li> <li>• Upscale the restoration component of management projects.</li> <li>• Develop indicators to track ecosystem recovery and incorporate those into evaluations of the outcome of interventions.</li> </ul>	High	High
2	Comparatively incomplete inventories of invasive alien species in Africa and Central Asia	<p>South Africa has reliable estimates of invasive mammals, plants, birds, and freshwater fishes but not of other taxa.</p> <p>Knowledge in neighbouring countries tends to be a lot less than in South Africa.</p> <p>Better knowledge is foundational for regulations and the prioritisation of interventions.</p>	<ul style="list-style-type: none"> <li>• Curate and regularly update inventories.</li> <li>• Formalise processes and workflows for adding or removing species from national inventories.</li> <li>• Collaborate with neighbouring countries to improve data flow.</li> </ul>	Very High	Very High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
3	Lack of standardization of terminology for invasive alien species monitoring	<p>South Africa has terminology set out in regulations and national syntheses (see Box 1 of the paper).</p> <p>The understanding of mandates can be affected by views on terminology belonging to a particular discipline (e.g., pests are agriculture, invasives are biodiversity, emerging infectious diseases are health), potentially leading to a disconnect.</p>	<ul style="list-style-type: none"> <li>Align regulatory terms with terms used in the glossary in the South African status report and to those used in practice.</li> <li>Where possible and desirable align terms to international standards.</li> <li>Curate terms used in a single place.</li> <li>Ensure terms are defined wherever used</li> </ul>	Medium	Medium
3	Lack of information on the role of indirect drivers, especially governance and sociocultural drivers, in affecting biological invasions	<p>Various conflicts have arisen when all stakeholders are not considered, including through perverse incentives (e.g., a narrow focus on increasing tree cover can lead to the planting and spread of invasive trees).</p> <p>Better knowledge would allow for more integrated governance and likely facilitate management.</p>	<ul style="list-style-type: none"> <li>Incentivise interdisciplinary research (e.g., looking at causal loops and feedbacks).</li> <li>Conduct a stakeholder mapping exercise.</li> <li>Evaluate information on social media culture and 'fashions' as an indirect driver to assist with evaluating the degree to which alien species have been incorporated into tradition and culture.</li> </ul>	High	High
3	Lack of understanding of the net effects of multiple interacting drivers in shaping and promoting biological invasions & Lack of knowledge on interactions and feedback across drivers in promoting invasions	<p>There is a realisation that interactions between drivers can be important, but few studies explicitly look at them (given how difficult such studies often are).</p> <p>Different governmental departments with different mandates and performance measures are not conducive to looking at interacting drivers.</p>	<ul style="list-style-type: none"> <li>Set up mechanisms to allow for cross-departmental and cross-provincial alignment of strategies and monitoring efforts (integrated governance).</li> <li>Utilise symposia to exchange ideas and promote cross-sectoral collaboration.</li> </ul>	Unknown (potentially very high if effective)	Unknown



Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
4	Incomplete data on impacts on nature's contributions to people and good quality of life	<p>While arguably South Africa is a leader in research on the topic, much more is needed. All impacts have been understudied. A handful of preliminary studies have evaluated impacts using the SEICAT framework. There are historical studies on the impact of invasions on ecosystems services, economics, and livelihoods.</p> <p>There are few collaborations between invasion scientists, social scientists, and economists in South Africa. Where this has happened, the papers have been highly cited and the research very impactful.</p> <p>Better knowledge would help demonstrate the impacts on nature's contributions to people and good quality of life and likely be highly effective for prompting action.</p>	<ul style="list-style-type: none"> <li>Synthesise studies on the impact of biological invasions on South Africa and update the estimates where possible.</li> <li>Set up methods to collect data &amp; systematically monitor impacts on nature's contribution to people and good quality of life.</li> </ul>	Very High	Unknown
5	Lack of control options for marine invasive alien species and invasive alien microbial fungal pathogens of plants and animals	<p>There are very few control options in marine systems in South Africa (as globally), almost all are mechanical, very difficult, and often very dangerous.</p> <p>Some control techniques have been developed for fungal pathogens of plants, but only in a few cases.</p> <p>It seems unlikely that game-changing technologies will come along soon.</p>	<ul style="list-style-type: none"> <li>Piggyback on the development of novel technologies as they become available.</li> <li>Interact with plant pathologists to explore control options.</li> </ul>	Very High	Low

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
5	Lack of agreed-upon methods of supporting management decision-making for invasive alien species with both positive and negative impacts	<p>The current regulatory system is well established and it includes mechanisms for consultation. The risk analysis framework used in South Africa considers positive and negative impacts.</p> <p>There has been some historical disagreements around the introduction of biocontrol agents (e.g., to control invasive trees used in forestry) that have been resolved, some are ongoing (e.g., on pines). Economic studies have been used to justify the introduction of biocontrol agents on species with both positive and negative impacts. Some species prioritisation exercises have been undertaken, for example for plants suitable for biocontrol.</p>	<ul style="list-style-type: none"> <li>Continue consultation on regulatory listings.</li> <li>Ensure listing decisions are transparent and can be contested, e.g. by publishing risk analyses.</li> <li>Align regulatory instruments across sectors.</li> </ul>	Medium	Very low
5	Lack of methods of managing pathways for invasive alien species arriving as contaminants, or through shipping containers, e-commerce (legal/illegal), biofouling or ports, and across land borders and along trade supply chains	<p>Current methods for contaminants and along trade supply chains focus on agricultural and health pests, a greater focus on environmental threats is needed. The DFFE has established a trial at Durban Harbour on shipping containers. Mail arriving at OR Tambo is inspected, but e-commerce is largely unmanaged.</p> <p>In terms of shipping, there have been studies on hull encapsulation for yachts, but most activities are focussed on keeping hulls clean for other reasons, and in-water hull cleaning could lead to more invasions.</p> <p>Post-border monitoring is in place for specific species (e.g., agricultural pests) that are likely to spread from neighbouring countries into South Africa.</p> <p>Preventing accidental introductions will likely be harder than deliberate introduction though the only way to currently address marine invasions.</p>	<ul style="list-style-type: none"> <li>Increase understanding of relative risks posed by the pathways and routes.</li> <li>Co-ordinate actions at ports of entry.</li> <li>Piggyback on methods developed for other sectors.</li> <li>Align pathway-management actions and goals between different agencies.</li> <li>Establish pathway management programmes for specific pathways or vectors.</li> </ul>	Very High	Medium

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
5	Lack of methods for adaptive management of invasive alien invertebrates and plants using alternative approaches given the declining number of chemical control options	<p>There is a lack of flexibility in governance systems (e.g., to redirect funds as needed) so management is not adaptive.</p> <p>Biological control is highly cost effective against some targets, but in other cases there are no current replacements for herbicides.</p>	<ul style="list-style-type: none"> <li>Establish mechanisms to allow decisions to be made at the appropriate level (so can respond to monitoring and flexibility to change).</li> <li>Invest in biological control.</li> </ul>	<p>Very High (for taxa if no chemical alternatives available)</p> <p>Low (if effective biocontrol in place)</p>	Low
5	Lack of eradication guidelines and strategies for generalist invasive alien invertebrates, diseases and hard-to-detect freshwater and marine invasive alien species	<p>There have been few eradication attempts in South Africa. Eradication of fruit flies has not been achieved. However, some areas are kept free of <i>Bactrocera dorsalis</i> and in other areas <i>Ceratitis capitata</i> is kept at low prevalence.</p> <p>Guidelines are available for fish (extirpating from discrete stretches of river or waterbodies).</p>	<ul style="list-style-type: none"> <li>Extirpate invasive fishes where feasible and desirable.</li> <li>Formalise and make accessible the process for identifying and evaluating eradication targets and declaring eradication.</li> </ul>	<p>Low</p> <p>High (for freshwater fishes)</p>	Low
5	Lack of scenarios and models of invasive alien species that consider interactions with other drivers of global change	<p>Not addressed at a management/policy level in South Africa.</p> <p>Scenarios and models are important to justify and guide interventions, though need to be critical of the value of model outputs if models are not appropriately informed by experiments and field observations, and particularly in cases where extrapolations have been made.</p>	<ul style="list-style-type: none"> <li>Set up mechanisms to allow for cross-departmental and cross-provincial alignment of strategies and monitoring efforts (integrated governance).</li> <li>Utilise symposia to exchange ideas and promote cross-sectoral collaboration.</li> <li>Fund specific research on scenario and model development focussing on the potential futures of biological invasions in South (and southern) Africa.</li> </ul>	High	Medium

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
5	Missing information on the implementation of adaptive-collaborative governance for biological invasions and factors important to the success of that governance strategy	Implementation is often not coordinated between government departments responsible for managing invasions, so information on such implementation is missing, affecting integrated control.	<ul style="list-style-type: none"> <li>Set up mechanisms to allow for cross-departmental and cross-provincial alignment of strategies and monitoring efforts (integrated governance).</li> <li>Promote interdisciplinary work and invasion science from a social perspective (particularly political ecology).</li> </ul>	High	High
5	Incomplete data on the effectiveness of policies, management strategies and actions related to biological invasions	The effectiveness of most interventions has not been assessed nor is current monitoring sufficient to do this. This is well established as a significant problem.	<ul style="list-style-type: none"> <li>Consolidate information on an accessible platform.</li> <li>Establish systems to track the effectiveness of all interventions.</li> </ul>	Very High	Very High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
6	Lack of tools and frameworks to predict biological invasions	Many tools and frameworks are available, but they are often not integrated into policy and management. A risk analysis framework has been developed and provides some predictions. Species distribution models have been created for many taxa to allow for environmental scanning, and in a few instances explicit risk maps have been produced. There have been some efforts at horizon scanning and scenario planning, but it is often unclear whether they have been accepted and adopted. Maps of invasions are often outdated and relatively coarse, although some detailed maps exist for local areas.	<ul style="list-style-type: none"> <li>• Explore the uptake of existing tools and frameworks and how they are used by decision-makers.</li> <li>• Ensure mapping of species spread is up to date.</li> <li>• Collate clearing information in an accessible format.</li> <li>• Develop tools to address taxa that have no invasion history elsewhere.</li> <li>• Adapt tools for the South African situation where needed.</li> <li>• Initiate a broad future thinking exercise to facilitate pro-active management and set up a process to ensure the exercise is regularly updated.</li> </ul>	High	Medium
6	Lack of tools to reduce the barriers to information-sharing within and across countries	<p><i>Within South Africa:</i> there are various forums in place and data shared; barriers to information sharing are relatively low (includes list server and information campaigns).</p> <p><i>Internationally:</i> several platforms are available (GBIF, GRISS and iNaturalist) but often not populated.</p>	<ul style="list-style-type: none"> <li>• Consolidate information from South African in an accessible platform that allows for integration with mobile phone applications.</li> <li>• Support international working groups.</li> </ul>	High	Low
6	Lack of research and data on how best to implement integrated governance systems to manage biological invasions	The social network of people managing and studying biological invasions in South Africa has been explored and some sectors, such as social sciences, are largely missing.	<ul style="list-style-type: none"> <li>• Promote interdisciplinary work and invasion science from a social perspective (particularly political ecology).</li> <li>• Facilitate implementation of environmental, social and governance of conveyancers (air, land and sea).</li> </ul>	High	High

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
6	Design principles for an integrated governance system to manage biological invasions	This is largely lacking in South Africa. Governance is mainly top-down (e.g., through the Working for Water Programme).	<ul style="list-style-type: none"> <li>Promote co-development of management plans and collaborative implementation among stakeholders.</li> <li>Assist companies (especially those linked to transport supply chains/logistics) to comply with regulations.</li> </ul>	High	High
6	Lack of mechanisms that allow effective collaboration among different elements of the socioecological systems	Several alien clearing prioritisation activities have taken place to account for different aspects of the social-ecological system. Often social, ecological and economic information is used to define priorities. However, it is unclear if these priorities have affected action.	<ul style="list-style-type: none"> <li>Promote interdisciplinary work and invasion science drawing on social-ecological systems thinking.</li> <li>Reduce the reliance of national data that does not consider issues relevant to management at local scales.</li> </ul>	High	High
7	Lack of information on invasive alien species status and trends on land and water managed by Indigenous Peoples and local communities	<p>There is fairly good broad-scale information on the presence of alien species in terrestrial systems (e.g., through the Southern African Plant Invaders Atlas); though information on trends and perceptions is lacking.</p> <p>No marine areas are specifically managed by Indigenous Peoples and local communities though there are examples of co-management of some marine resources (e.g., within Isimangaliso Marine Protected Area).</p> <p>An important issue is the concept/meaning of 'land and water managed by indigenous peoples and local communities' in South Africa. Does the land and water refer to that covered by Natives Land Act, 1913? Land ownership is often contested, and terminology should be adjusted to make it appropriate to the South African context (see Box 4 in the main manuscript).</p>	<ul style="list-style-type: none"> <li>Encourage collaboration with communities to understand perceptions, usages and distribution of invasive species and how they are incorporated into traditional knowledge systems.</li> </ul>	Medium	Medium

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
7	Lack of information on Indigenous and local knowledge, values and culture regarding the drivers and impacts of invasive alien species on land and water managed by Indigenous Peoples and local communities	South Africa has had a strong research focus in this area. There are many studies on the environment, livelihood, ecosystem service and human well-being implications of invasive species in communal land settings.	<ul style="list-style-type: none"> <li>Conduct research into how local communities interact with invasive species in the context of freshwater and marine invasions.</li> </ul>	Medium	Medium
7	Lack of understanding of and mechanisms for sharing knowledge on invasive alien species and their drivers, impacts, management and governance among Indigenous Peoples and local communities and researchers and other outsiders	There are several programmes and projects in South Africa that are aimed at local communities (e.g., the Tsitsa in the Eastern Cape). These have adopted a holistic approach to land management, conservation and water conservation.	<ul style="list-style-type: none"> <li>Support local communities to reduce alien biomass and fire risk.</li> </ul>	Medium	Medium

Type	Gap(s)	Situation in South Africa and notes on value of improved knowledge	Proposed actions for strategy	Management gain	Understanding gain
7	Lack of consideration of the knowledge and perceptions of Indigenous Peoples and local communities in scenarios and models	The ASSET project aimed to be inclusive in their approach to clearing and beneficiation exercises to support restoration activities ( <a href="https://assetresearch.org.za/interactive-restoration-models/">https://assetresearch.org.za/interactive-restoration-models/</a> ).	<ul style="list-style-type: none"> <li>Combine participatory mapping exercises to improve the inclusion of local communities in scenario planning and modelling exercises.</li> </ul>	High	High



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