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BIODIVERSITY BUILDING BLOCKS FOR POLICY

D6.2. Case study II – *Biological invasions in South Africa*

31/07/2026

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Key takeaway messages

- Effective biodiversity conservation depends on timely, reliable, and accessible information.
- South Africa's national report on the status of biological invasions and their management provides a practical use case for the integration of biodiversity data pipelines that improve reporting processes and support monitoring and policy development.
- Existing indicators used to inform South Africa's national report largely meet national and international reporting requirements, but some require revision to improve alignment, consistency, and their ability to track status and change.
- Documented and repeatable workflows, aligned with biodiversity information standards, have enabled efficient updates and tracking of alien species status and occurrences across South Africa.
- In terms of the latest report for South Africa (due to be finalised in 2026 and released early in 2027), the Biodiversity Building Blocks for policy (B-Cubed) project thus formed the foundation to revise, review and update the indicator factsheets; develop new and improved workflows; and produce key figures and findings. Additional insights from B-Cubed outputs (e.g., on addressing uncertainty) will be incorporated into future reports.

Executive summary

Effective biodiversity conservation depends on timely, reliable, and accessible information. The overarching objective of the B-Cubed project was to develop pipelines to improve the integration of biodiversity data into data cubes that are then used as the basis for models and indicators to monitor biodiversity status and change. South Africa's national report on biological invasions and their management provides a practical use case for integrating biodiversity data pipelines to improve reporting processes and support monitoring and policy development.

The B-Cubed project has strengthened the reporting process for the status report by improving indicator alignment with national and international reporting frameworks, particularly Target 6 of the Kunming-Montreal Global Biodiversity Framework. Documented and repeatable workflows and the adoption of biodiversity information standards have improved the efficiency, transparency, and reproducibility of data processing and analysis. The B-Cubed project has also addressed important gaps in the mobilisation of spatial and impact data, thus providing improved workflows to support indicators on the number and status of alien species, the extent of alien species, alien species richness, and the impacts of biological invasions.

Several B-Cubed products provide opportunities to further strengthen future status reports. Data products such as suitability, dissimilarity, and network invasibility cubes offer new approaches for assessing invasion debt and forecasting future invasions; these will be considered in the next round of revisions of the indicator framework used for the status report. Similarly, several indicators on biodiversity and impact of alien species developed through the project require further refinement and integration before they can be used for the status report. The tools developed to

measure and estimate uncertainty for biodiversity indicators, particularly variation in sampling effort, will improve the robustness and interpretation of future assessments.

Overall, the South African case study shows how the tools and workflows developed through B-Cubed can improve reporting processes and support policy and management. These advances strengthen South Africa's capacity to monitor biological invasions, evaluate the effectiveness of management actions, and report progress towards national and international biodiversity commitments. The South African case study also provides a practical example that other countries can adapt to strengthen biodiversity monitoring, reporting, and decision-making.

Non-technical summary

Protecting biodiversity depends on having reliable and up-to-date information about the environment. Good information helps governments, scientists, and land managers understand where invasive alien species occur, how they are spreading, what impacts they are having, and whether management actions are working.

This document describes how the Biodiversity Building Blocks for policy (B-Cubed) project has helped improve South Africa's national reporting on biological invasions. South Africa produces a national report on the status of biological invasions and their management every three years (the 'status report'), to support biodiversity management and meet national and international reporting commitments. The status report uses information from many different sources, including biodiversity surveys, research projects, and citizen science programmes.

The B-Cubed project improved the way data are collected, combined, and analysed in the status report. B-Cubed also assisted in improving how biological invasions are reported, so that the status report aligns better to international processes; and helped develop repeatable workflows that will make it easier to produce status reports in future. These improvements make the reporting process more efficient, transparent, and consistent.

The B-Cubed project also developed new tools and methods that can improve future status reports. These include approaches to predict where invasive species are likely to spread, estimate their impacts, and measures to report how confident we are that the observed patterns are real. Although these tools are not yet part of South Africa's national reporting system, they provide valuable opportunities to strengthen future assessments and support better planning and management.

Overall, the South African case study shows how better use of biodiversity data can improve decision-making. By developing standardised data workflows and practical analytical tools, the B-Cubed project has strengthened national reporting on biological invasions and provided an approach that can be adapted by other countries to improve biodiversity monitoring, reporting, and policy.

List of abbreviations

B-Cubed	Biodiversity Building Blocks for policy
CBD	Convention on Biological Diversity
CIB	Centre for Invasion Biology
EICAT	Environmental Impact Classification for Alien Taxa
EOO	Extent of Occurrence
FAIR	Findable, Accessible, Interoperable, and Reusable
GBF	Kunming-Montreal Global Biodiversity Framework
GBIF	Global Biodiversity Information Facility
GRIIS	Global Register of Introduced and Invasive Species
IAS	Invasive Alien Species
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
QDGC	Quarter-Degree Grid Cell
SANBI	South African National Biodiversity Institute
SAPIA	Southern African Plant Invaders Atlas
SEICAT	Socio-Economic Impact Classification of Alien Taxa
WP	Work Package

1. Introduction

1.1. B-Cubed project and case studies

The magnitude and dynamics of the global biodiversity crisis are hard to quantify and require rapid, reliable, and repeatable biodiversity monitoring data that decision-makers can use to evaluate policy options. Providing such information – from local to global levels and within timescales relevant to policy – calls for improved integration of data on biodiversity from different sources such as citizen scientists, museums, herbaria, and researchers. The Biodiversity Building Blocks for policy (B-Cubed) project addresses this challenge by transforming biodiversity monitoring into an agile and responsive process (Groom et al. 2025; https://b-cubed.eu/). B-Cubed works closely with existing biodiversity initiatives to identify and address policy needs. It leverages the concept of data cubes to standardise access to biodiversity data using the Essential Biodiversity Variables framework (Jetz et al. 2019). These cubes are the basis for models and indicators of past, current, and future biodiversity. The models are accessible to users in real-time and on-demand in a cloud computing environment, delivering information on biodiversity status and change. To ensure its results can be reused, B-Cubed has created exemplar automated workflows for modelling, using biodiversity data cubes and indicators that monitor biodiversity status and change. The effectiveness of the B-Cubed project's solutions is demonstrated in four case studies, varying in geographic extent, biodiversity richness and data availability (https://b-cubed.eu/case-studies).

The case studies are:

- Case study I – Global and continental biodiversity change
- Case study II – Biological Invasions in South Africa
- Case study III – Regional indicators in Europe
- Case study IV – Stakeholder driven case study

Each case study contributes to assessing:

- the capacity of B-Cubed's indicators to capture key aspects of biodiversity relevant to the specific context;
- the ability of B-Cubed's workflows to deliver tailored outputs aligned with the spatial, temporal, and thematic requirements of stakeholders; and
- effective strategies for communicating outputs in a policy-relevant and user-friendly manner.

1.2. Case study II – Biological invasions in South Africa

The South African National Biodiversity Institute (SANBI) is mandated by national laws to monitor and report on the status of biological invasions and their management in South Africa. These reports (hereafter, status reports) are required every three years since the regulations took effect in 2014. In response to this mandate, a process for reporting on the state of biological invasions in South Africa has been established (https://iasreport.sanbi.org.za/). To date, three status reports have been produced, based on data through to the end of December 2016, 2019, and 2022, respectively. The next status report is in production, includes data through to the end of December 2025, and will likely be released in 2027 (SANBI and CIB 2026a). The status report must include a summary and assessment of the status of invasive species listed in the regulations and of the effectiveness of the regulations and control measures. But more broadly, the status report facilitates the link between foundational research and the monitoring and evaluation of interventions, thereby assisting managers and policymakers (SANBI and CIB 2018).

The 2025 status report served as a case study for the B-Cubed project on biological invasions in South Africa. The data cubes, models, and indicators developed under the B-Cubed project are used in the status report, thereby demonstrating the project's usefulness from an end-user perspective (SANBI). Specifically, the B-Cubed project helps address four of the six key priorities identified in previous status reports, which include: alignment of indicators, mobilisation of spatial data, mobilisation of impact data, and the automation and standardisation of the reporting process. It also improved how reports are communicated (i.e., including workflows and dashboards).

The upcoming status report was produced alongside and influenced by the B-Cubed project. This deliverable report (D6.2) details how the B-Cubed project helped address the key gaps outlined above and how it could support future improvements and extensions to the status report.

2. Alignment of indicators

2.1. Indicator framework for assessing biological invasions in South Africa

The status report is based on a suite of 20 indicators and four high-level indicators (Wilson et al. 2018). These indicators explicitly consider biological invasions in terms of 1) pathways – how alien species are introduced and move around the country; 2) species – the status and impacts of alien species; 3) sites – the degree to which sites are invaded and impacted; and 4) interventions – the effectiveness of the full range of interventions that South Africa has used to address the problem (Figure 1). This indicator framework provides a transparent and objective method for establishing baselines against which to assess trends, set realistic management targets, highlight important gaps in the evidence needed to support decision-making, and support international reporting. As per the guidelines of the Biodiversity Indicators Partnership (2011), a factsheet for each indicator has been developed and published (Wilson et al. 2018).

The B-Cubed project directly influenced several sections of the forthcoming status report, with specific influence on revising the factsheets for the indicators (SANBI and CIB 2026b). Inspired by the B-Cubed project, and in particular WP 5 and the B-Cubed workshop '*From Data to Trends: Workshop on indicators and metrics for tracking biological invasion'* (17–19 March 2026) held in Brussels, the indicator framework was updated in various ways. First, indicators are now assigned to categories according to both the theory of change approach (e.g., https://www.theoryofchange.org/what-is-theory-of-change/; (inputs, activities, outputs, invasion-specific outcomes, and broad-outcomes) and the DPSIR (driver, pressure, state, impact, and response) framework. Second, the links between the indicators on invasion-specific outcomes (that were developed and are used specifically in the upcoming status report) and indicators of broader environmental and socio-economic outcomes that may be affected by biological invasions are made explicit (Figure 1). Examples of each indicator are also provided (some of which are based on B-Cubed processes). Finally, as per Vicente et al. (2022), there are several desirable properties of indicators used to monitor biological invasions — established, spatially explicit, scalable, temporal, uncertainty appraisal, taxonomic representativeness, invasive alien species (IAS) specific, and reproducible. The indicator factsheets now include an assessment of the degree to which each indicator meets these properties.

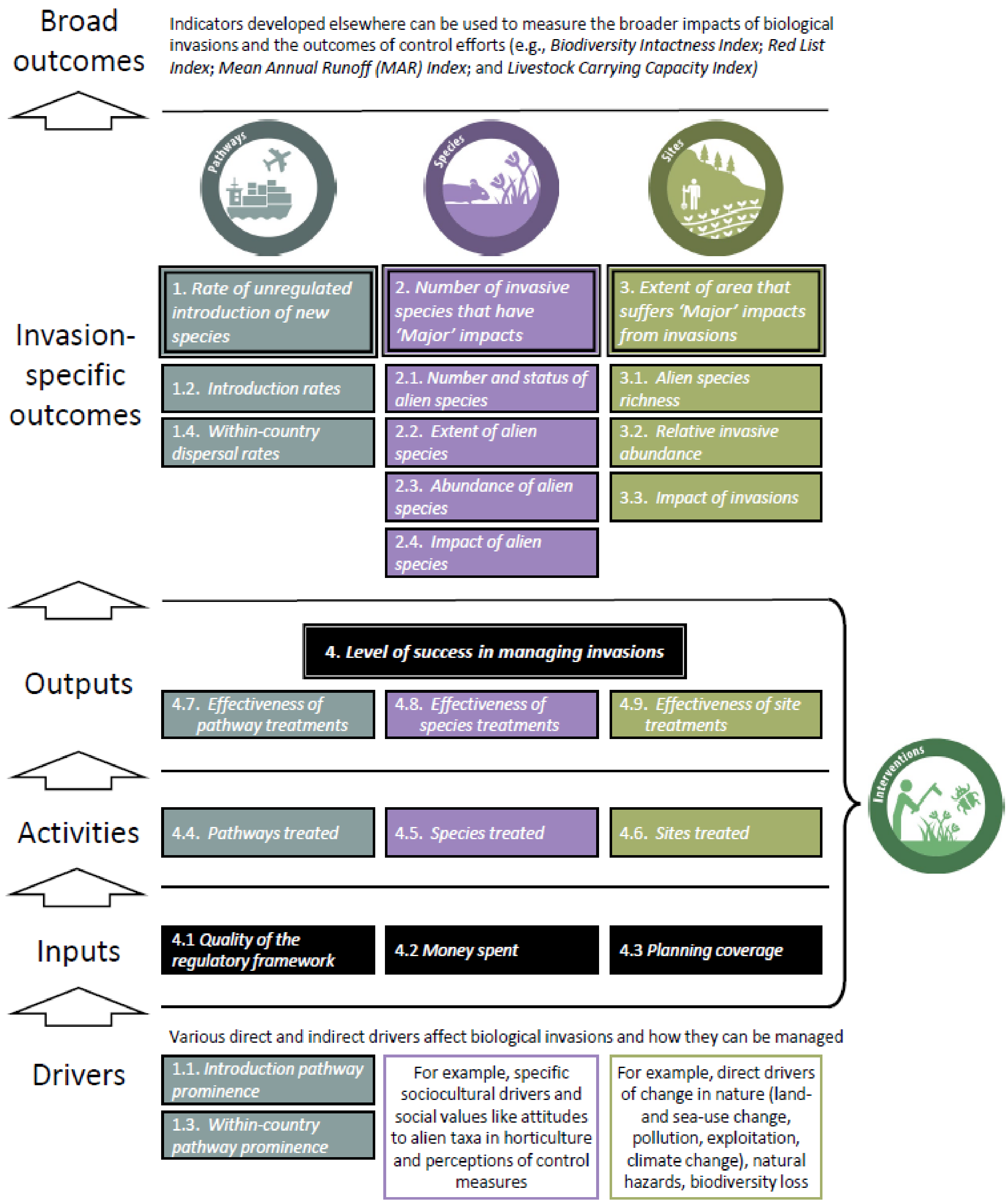

Figure 1: The indicator framework used to report on the status of biological invasions and their management in South Africa. The indicator framework was updated from previous status reports in parallel to and influenced by the B-Cubed project. Reproduced from Figure 0.2 in SANBI and CIB (2026a).

2.2. Links with global indicators

South Africa has an international obligation to report to the Convention of Biological Diversity (CBD) on progress towards Target 6 of the Kunming-Montreal Global Biodiversity Framework (GBF):

Target 6: Reduce the Introduction of Invasive Alien Species by 50% and Minimize Their Impact

Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent, by 2030, eradicating or controlling invasive alien species especially in priority sites, such as islands.

To measure progress towards this target, one headline indicator, three component indicators, and three complementary indicators have been proposed (Table 1).

South Africa cannot, as yet, report on the GBF Target 6 in a manner that will provide reliable trends that can be used to influence policy-making. As part of the 7th national report to the CBD on 28 February 2026, South Africa reported that for the headline indicator there were “No data available”, and that “At this stage, South Africa cannot calculate the indicator for Target 6, however, sufficient national data are available to report on progress towards the target”.

The status report aims to contribute to South Africa’s reporting on Target 6, but has its own indicator framework (Figure 1); and while the indicators proposed by the CBD are related to several of the indicators used in the status report (Table 1), they are not perfectly aligned and work is required to bridge the gap. For example, data on alien species detections need to be regularly updated to measure progress towards the Headline Indicator for Target 6 (Table 1), however, there are often significant delays (SANBI and CIB 2023), and thus ensuring that all monitoring data feed through to local databases and are integrated into the Global Biodiversity Information Facility (GBIF) on a regular basis will be crucial. In addition, sampling effort must be taken into account when calculating the Headline Indicator (Table 1) or misleading patterns will emerge (McGeoch et al. 2023). Survey effort is not routinely captured in South Africa, and thus useful proxies need to be identified and tested.

The B-Cubed project has developed workflows to calculate indicators used to monitor biological invasions in a standardised way, including the Target 6 Headline indicator (Table 1). The *b3alien* package and related workflow (Trekels 2025) were developed for this purpose, and have been piloted on data for South Africa from GBIF (Trekels and Groom 2025). This workflow will be tested and applied in future status reports.

Through the B-Cubed project, several indicators related to the impact of invasive species have been developed, and to assist with their calculation an open-source workflow and R package (*ImpIndicator*) have been developed (Yahaya et al. 2026). These products are related to the component indicator for Target 6: *Rate of invasive species impact and rate of impact* (Table 1). However, work on the status report has identified issues with how impact metrics are being combined in the indicators developed through the B-Cubed project and at this stage further work is required, particularly for spatial analyses of impacts, to ensure reliable policy-relevant estimates.

Workflows and software standards (Huybrechts et al. 2024) developed by the B-Cubed project will be implemented to bridge the gap between the GBF Target 6 indicators and the indicators of the status report. For example, there is a Global Register for Introduced and Invasive Species (GRIIS) page for South Africa published on GBIF (https://cloud.gbif.org/griis/resource?r=south-africa-griis-gbif), but this was last updated in 2020. A workflow will be developed to convert South Africa's national list into the GRIIS format, stream-line the process for information to be fed through to update the GRIIS list, and assist with calculating Target 6 Headline indicator and the related Complementary Indicator (Table 1).

The B-Cubed project has also facilitated the exchange of practical experiences on the processes used to inform indicators and reporting on biological invasions, including indicator alignment, data availability, and gaps. For example, through the B-Cubed workshop '*From Data to Trends: Workshop on indicators and metrics for tracking biological invasion*' (17–19 March 2026) held in Brussels. The knowledge shared by others during the workshop will be used to improve our data, indicators, workflows, and reporting; and improve the alignment of our indicators with those for Target 6 of the GBF. This would not only address the key gaps identified in the most recent status report (alignment of indicators) (SANBI and CIB 2023), but will also assist to address a key gap highlighted in the forthcoming status report (i.e., review indicators nationally and globally to improve national processes; SANBI and CIB 2026a).

Table 1: CBD indicators and the related indicators from South Africa's National Status Report on Biological Invasions (see Figure 1).

CBD Indicator type	CBD Indicator	Related Status Report Indicator(s)
Headline	*Rate of invasive alien species establishment*	• *Rate of unregulated introduction of new species*
Component	*Rate of invasive species impact and rate of impact*	• *Number of invasive species that have 'Major' impacts* • *Impact of alien species* • *Extent of area that suffers 'Major' impacts from invasions* • *Impact of invasions*
Component	*Rate of invasive alien species spread*	• *Within-country pathway prominence* • *Within-country dispersal rates* • *Extent of alien species*
Component	*Number of invasive alien species introduction events*	• *Introduction rates*
Complementary	*Number of invasive alien species on national lists as per the Global Register of Introduced and Invasive Species*	• *Number and status of alien species*
Complementary	*Trends in abundance, temporal occurrence and spatial distribution of non-indigenous species, particularly*	• *Alien species richness*

	invasive, non-indigenous species, notably in risk areas (in relation to the main vectors and pathways of spreading of such species)	
Complementary	*Red List Index (impacts of invasive alien species)*	• *Impact of invasions*

3. Mobilisation of spatial data

The B-Cubed project has addressed a significant gap in the status report on the mobilisation of spatial data by improving the process for downloading and analysing occurrence data for alien taxa in South Africa. Status report indicators for which the process has been improved are: *number and status of alien species* (i.e., whether species are known to be present in South Africa and their stage of invasion); the *extent of alien species* (at national, provincial, biome or other scales); and *alien species richness* (number of alien species at a particular site). See below for how the indicators were updated based on data processed through the B-Cubed project products.

3.1. Number and status of alien species

This indicator provides the basis for constructing lists of alien species for a country. Such information is important for biosecurity to be able to target species which are not yet present and to identify threats based on what is already in the country. If the status (e.g., established but not invasive, or invasive) is known, this can be used to estimate the establishment part of the invasion debt, i.e., how many alien taxa are likely to establish in the future. Occurrence data were used to verify the presence of a species in South Africa and its invasion stage, i.e., whether it was present but not established, established and/or invasive.

3.1.1. Status and trends

A comprehensive list of alien taxa for South Africa was recently published (Zengeya et al. 2026). This list of alien species is the result of a process to consolidate and standardise information on the presence of alien taxa in South Africa from various sources (Zengeya et al. 2025). A separate list has been curated and published for the Prince Edward Islands, South Africa's sub-Antarctic territories (Fernández Winzer et al. 2024, 2025). The list for South Africa includes over 6,000 taxa that have been assessed for presence in continental South Africa, with information and data sources specified for variables related to their invasion status (e.g., established but not invasive), pathways, distributions, impacts, and management. Of the assessed taxa, there is evidence that over 3,500 are present in the country, with over half being plants – this is in line with the view that South Africa is a hotspot for plant invasions. Only about a third of the taxa on the list have been assessed for their introduction and establishment status; 719 of those taxa are invasive, 120 taxa are known to be established but not invasive, and 329 taxa are present but not established (Figure 2). Currently, the list of alien species in South Africa is updated every three years in line with the statutory requirement to produce a triennial report on the status of biological invasions and their management. In future, the process is expected to become increasingly automated, allowing updates to be released as new information becomes available, with detailed assessments to be produced as needed (Zengeya et al. 2025). The B-cubed workflows promise to assist with the move to more regular updates.

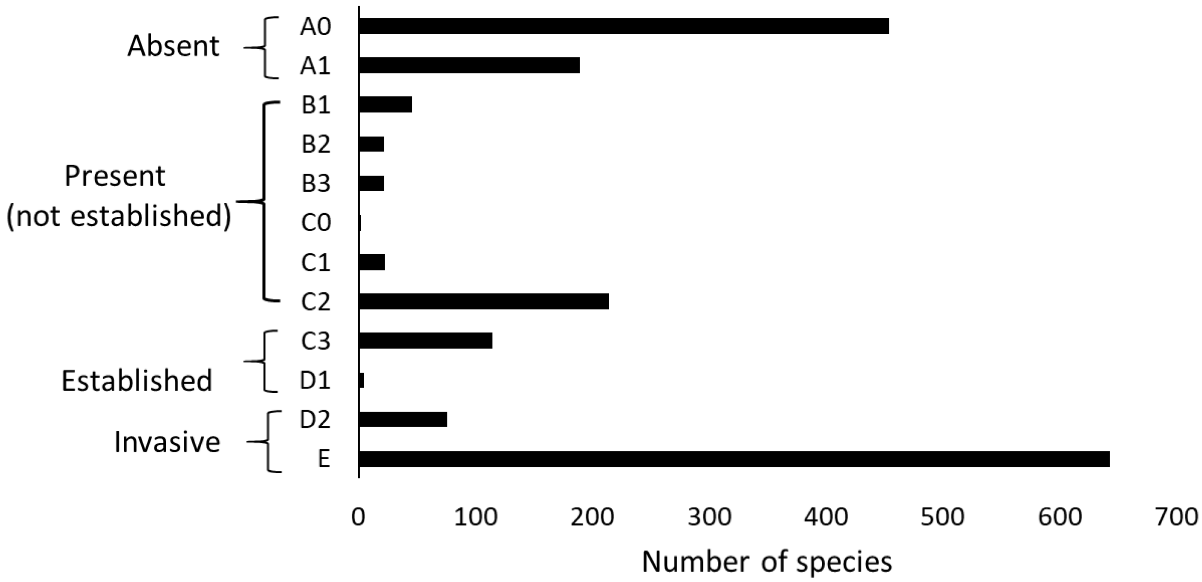

Figure 2: The introduction and establishment status of alien species in South Africa as of December 2025 as per the Unified Framework for Biological Invasions (Blackburn et al. 2011; Groom et al. 2019) and based on Zengeya et al. (2026). Absent (A0–A1)—taxa that have never been introduced beyond the limits of their native range to [a part of] South Africa (A0) or were introduced but no longer present (A1); Present (not established) (B1–C2)—includes a range of taxa from those in quarantine to those that are reproducing outside of captivity or cultivation but where there is no clear evidence of them having formed self-sustaining populations; Established (C3–D1)—taxa where there is establishment, and possibly spread, but there is no clear evidence of forming self-sustaining populations at a significant distance from point of introduction; and Invasive (D2–E)—taxa with populations that are self-sustaining at a significant distance from the point of introduction. Selected species that are not present in South Africa (A0 and A1) are included in the list and status report for various reasons, e.g., they were included on the prohibited lists of versions of the national alien species regulations.

3.1.2. Link to B-Cubed project outputs or indicators

Using the B-Cubed project's outputs has improved our processes of compiling the list of alien taxa in South Africa through:

- Improved documentation – repeatable workflows facilitate transparent updates and tracking of changes in the status of alien species. The B-Cubed software development guide (Huybrechts et al. 2024) was developed to ensure that the software produced for B-Cubed (i.e., computational tools and resources) is of high quality, and meets existing best practices (e.g., is FAIR; findable, accessible, interoperable, reusable). Although developed specifically for B-Cubed software, the guidelines are widely applicable and have been followed during the development of several of the workflows for the status report, such as the automated workflow to standardise taxon names for South African alien species lists (Faulkner 2026) and the workflow to ensure first reports of alien species from molecular analyses are acted upon (Fernández Winzer et al. 2025).

- Standardised data formats and protocols – the species list is aligned to biodiversity information standards such as Darwin Core (Groom et al. 2019) and is presented in a manner that is FAIR (Wilkinson et al. 2016) and tidy (Wickham 2014). This makes it easier to find, reuse and merge with other datasets (interoperable).

3.1.3. Lists of alien taxa in the Global South—three joint journal special issues

Lists of alien taxa are essential for linking evidence to action (Wilson et al. 2026). However, the recent IPBES IAS Assessment identified significant gaps in the completeness and availability of lists of alien taxa in the Global South (IPBES 2023). To address this, and as part of the need to develop processes for the list of alien taxa in South Africa, three joint special issues were developed and published early in 2026. The special issues were based on data collected from over 40 countries (Figure 3) and consist of 11 papers in African Biodiversity & Conservation (www.abcjournal.org) that address African issues, six papers in Bioinvasiones (http://bioinvasiones.org/) that address issues in Latin America and the Caribbean, and 12 papers in NeoBiota (https://neobiota.pensoft.net/topical_collection/270/) that address issues of broader interest or from other regions (see full list of papers published in the Annex). The papers compare lists of invasive taxa from different countries; present lists for particular countries, types of taxa, and environments (including social wasps, horticulture, marine ecosystems, and protected areas); and develop workflows and protocols to assist with the creation of lists (e.g., guidance as to how to incorporate information from citizen science and molecular databases, and to address uncertainties). Twelve papers specifically address biological invasions in South Africa. Four of these are based on B-Cubed workflows and biodiversity information standards that have improved the compilation of South Africa's alien species list, making the process repeatable and aligned with international best practice (Faulkner 2026; Fernández Winzer et al. 2025; Zengeya et al. 2025, 2026).

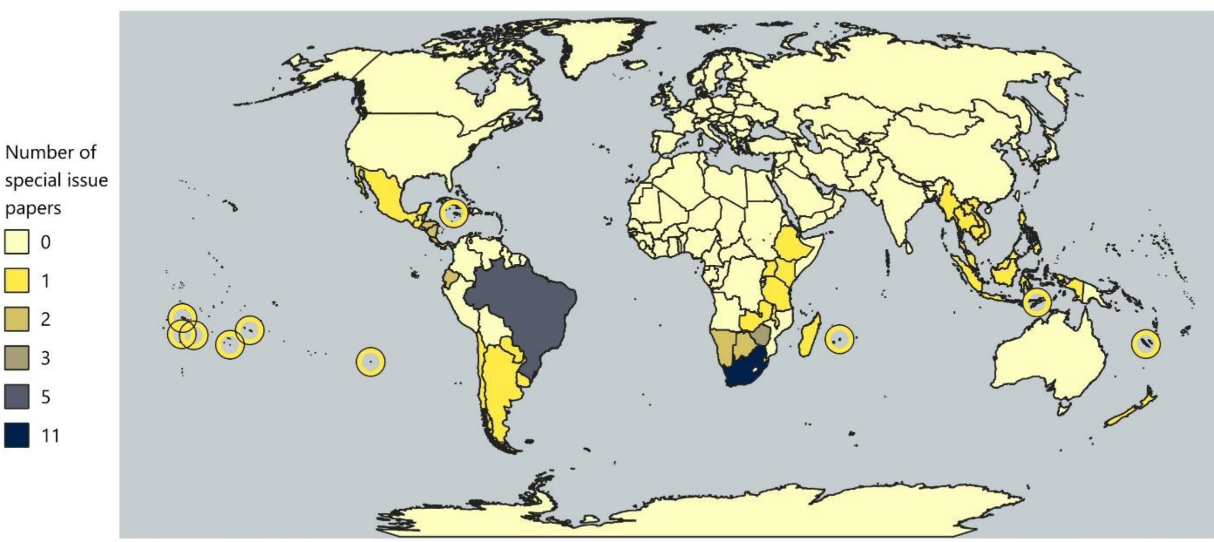

Figure 3: The countries addressed by the papers in the special issues. Six of the 28 papers included data from multiple countries. To improve visibility, the numbers for small islands and island groups are shown using circles. The full list of papers in the special issues is available in the Annex (Table A1) to this document. Adapted from Wilson et al. 2026.

3.1.4. Challenges/issues – need to establish a baseline

Several key data sources still need to be verified and incorporated into the list of alien taxa for South Africa (particularly species in cultivation or captivity), and many alien species are yet to be detected and documented. As data are captured and collated, the list will increase in length and content. Consequently, the list is not yet a complete baseline of the knowledge of alien taxa presence in the country. The aim is for the list to become comprehensive and dynamic, allowing the number and status of alien taxa to be tracked over time – vital if the information is to support timely management planning and regulatory decisions.

3.2.Extent of alien species

The indicator *Extent of alien species* provides an indication of how widespread alien species are and information that is the basis for other indicators, e.g., how sites are invaded and impacted. This indicator can be applied at multiple spatial scales, including broad administrative regions (e.g., provinces), finer-scale grids (e.g., quarter-degree grid cells; QDGCs), or as estimates of species range size (e.g., km^2 or ha). The units are all estimates of the extent of occurrence (EOO) at a particular spatial scale with a specified resolution.

3.2.1. Status and trends

Occurrence data for taxa included on the list of alien taxa for South Africa showed that alien taxa are distributed across the country, but the majority of the taxa are localised (e.g., found only in one province), and a few are widespread. However, the potential for spread is large, and many species are spreading [e.g., fungi occupy at most 100 QDGCs while many plants occupy more than 500 QDGCs out of almost 2000 QDGCs covering South Africa; Figure 4].

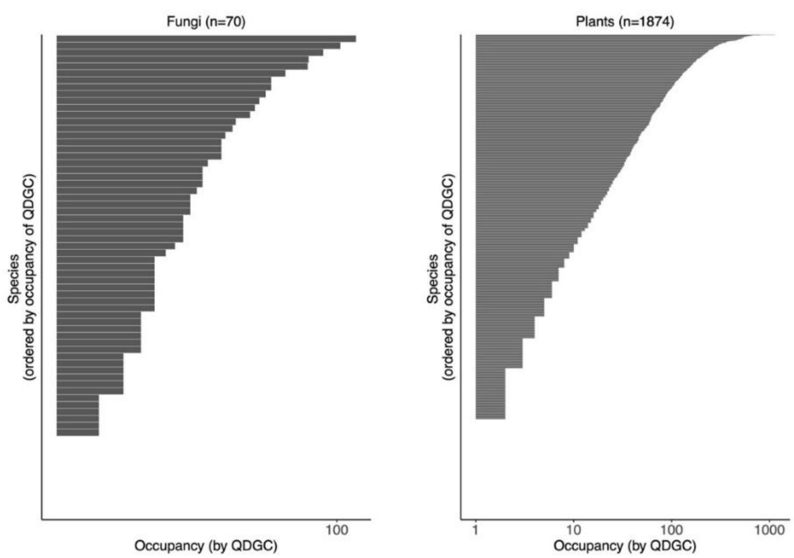

Figure 4: The extent of alien fungi and plants in South Africa in terms of occupancy of quarter-degree grid cells (number of QDGCs occupied).

3.2.2. Link to B-Cubed project outputs or indicators

The list of alien species for South Africa (Zengeya et al. 2025) was used to retrieve occurrence records from GBIF (https://www.gbif.org/). The GBIF platform allows users to create and download species occurrence cubes, which organise species occurrence data across taxonomic, spatial, and temporal dimensions (species × site × time) (Groom et al. 2025). The use of occurrence cubes and associated workflows has improved how occurrence data for alien taxa in South Africa are downloaded and analysed in several ways:

- **Reduced processing time:** The use of occurrence cubes has reduced the processing time for downloading occurrence data required for spatial analyses from weeks to a few hours. Instead of returning millions of individual occurrence records, occurrence cubes provide aggregated summaries that substantially reduce download sizes and computational requirements, enabling efficient analysis of large biodiversity datasets (for South Africa this is over 700,000 records consisting of over 6,000 taxa). Furthermore, occurrence cubes can also be generated directly from the GBIF platform using simple SQL queries, reducing the need for advanced programming skills.
- **Standardisation of data:** Occurrence cubes combine biodiversity records from multiple sources, including museum collections and citizen science platforms, into a common format. Users can apply data-quality filters (e.g., taxonomic status, coordinate uncertainty, and temporal uncertainty) when generating occurrence cubes, improving the consistency and reliability of analyses. This has improved the quality of the records for our list by returning only data that meet customised quality filters.
- **Flexibility:** Users can define the exact structure of the occurrence cube based on their needs. The basic occurrence cube includes three dimensions—taxonomic, spatial, and temporal, which were sufficient for our data needs (e.g., how many taxa have occurrence data for the reporting period)—but additional dimensions (e.g., environmental variables, estimating taxon sampling effort, or observation type) can be added to support more detailed analyses.
- **Scaling**: Standardised workflows make it easy to aggregate or disaggregate occurrence data to different spatial or temporal scales. This allows users to use the same methods consistently across various scales. For the status report, we downloaded occurrence data at a finer scale (QDGCs) for the list of alien taxa for South Africa and where required these were aggregated up to broad-scale administrative units (provinces, urban areas), and biogeographical regions (biomes, water catchments).
- **Repeatability:** Occurrence cubes support automated and repeatable analyses. Each download includes metadata describing the SQL query, contributing datasets, and a persistent download link (with every occurrence cube also assigned a Digital Object Identifier (DOI)). Together these make our analyses transparent, citable, and easy to reproduce.
- **Integration:** Occurrence cubes can be easily combined with other spatial and temporal datasets, such as environmental, climatic, land-use, and impact data, supporting more comprehensive analyses and biodiversity indicators. This has been flagged for future status reports.

3.2.3. Challenges/issues

Data on the distribution and abundance of alien species need to be collected, collated, and integrated into national and global databases to support management planning and regulatory decision-making. Occurrence data used for the indicator *Extent of alien species* are derived primarily from GBIF, with additional records from national datasets such as the Southern African Plant Invaders Atlas (SAPIA). Citizen science platforms and the digitisation of historical records have increased knowledge of the distribution of some alien taxa, but there is a decline in active surveillance for plants (e.g., a hiatus of SAPIA in 2020). Prior to 2020, SAPIA provided standardised data on the distribution of alien plants by collating observations from roadside surveys across the country, contributing more than 90,000 records. These data enabled reliable assessments of changes in the extent of plant invasions over time (e.g., Henderson & Wilson, 2017).

We highlight that not all documented occurrence records for alien species in South Africa are currently available through the GBIF platform. This is partly due to a lag between observations being made and records being published, while several occurrence records reported in the scientific literature have yet to be incorporated into GBIF. Consequently, occurrence data from GBIF were available for only approximately 35% of the taxa included in the list of alien taxa for South Africa (2,202 of approximately 6,000 taxa), highlighting substantial taxonomic and geographic data gaps. Most available records are for plants and birds, whereas occurrence data for other groups, such as invertebrates, soil organisms, microorganisms, and marine taxa, remain limited.

Citizen science continues to improve knowledge of the distribution of some alien species, particularly in and around urban areas. Remote sensing also shows considerable promise for improving species distribution monitoring, but it has not yet produced datasets that are suitable for informing the indicators presented in the status report.

There are currently no national long-term monitoring programmes to track biological invasions across South Africa. Establishing and sustaining structured surveillance programmes, and integrating these data with historical records, GBIF, and citizen science observations, will improve the coverage and quality of occurrence data. This will enable more reliable assessments of the extent of alien species and provide a stronger evidence base for management planning and regulatory decision-making.

3.3.Alien species richness

The indicator *Alien species richness* estimates the number of alien species at a particular site; a higher number of invasive species indicates a higher number of issues experienced, while the number of alien species indicates a higher risk of invasions. This indicator can be used at a range of scales, for example, a country, a province, or a municipality; or at primary, secondary or tertiary catchment scales; and can be aggregated upwards from data collected at finer scales.

3.3.1. Status and trends

Alien species are distributed across South Africa, with differences in richness recorded among most broad-scale administrative units, biogeographical regions, and protected areas. Significant increases have occurred across these regions; however, in the absence of active surveillance, these trends may reflect increased reporting and data uploads to the GBIF platform by citizen science initiatives (such as iNaturalist), the digitisation of historical records, and multiple atlassing projects. Invasive bird and plant species richness remain high around the main urban centres (see Figure 5 for overall plant distribution across the country), likely due to greater survey efforts in those areas, because some species are commensal with humans, and as most species were first introduced in urban centres.

Figure 5: Alien species richness of plants in South Africa per quarter-degree grid cell (QDGC).

3.3.2. Link to B-Cubed project outputs or indicators

Occurrence cubes were used to map alien species richness across provinces, biomes, water catchments, and QDGCs (see Figure 5 for an example). Similar to the indicator *Extent of alien species*, occurrence cubes and associated workflows have improved the download and analysis of occurrence data by reducing processing time, standardising data, supporting analyses at multiple spatial scales, improving repeatability, and making it easier to combine occurrence data with other datasets (for details see Section 3.2.1)

3.3.3. Challenges/issues

The indicator *Alien species richness* relies on the same occurrence data as indicator *Extent of alien species* and it therefore faces the same challenges and limitations (for details see Section 3.2.3). Data remain incomplete for many taxa and sites. Reliable estimates of alien species richness are currently available only for a limited number of locations, including selected protected areas, urban areas, mountain catchments, and from a few atlassing and remote sensing projects focusing on invasive plant species in water catchments and terrestrial biomes. The absence of a coordinated national monitoring programme further limits the ability to track changes in alien species richness over time. The indicator is influenced by survey efforts and there is a need to integrate tools developed through the B-Cubed project to measure and estimate uncertainty for biodiversity indicators to mitigate the bias from sampling effort (see Section 5.2).

Mobilisation of impact data

The B-Cubed project has addressed a significant gap in the status report on the mobilisation of impact data by informing the process to develop indicators to assess impacts of alien taxa in South Africa. Relevant indicators include: *the impact of alien species* (the degree to which alien species have impacts) and *the impact of invasions* (the combined impact of invasive species at a site) (Figure 1).

3.4. Impact of alien species

The indicator *Impact of alien species* helps to identify which alien species are causing the largest negative impacts and the mechanisms of impact that are most common. Environmental impacts of species are assessed using the Environmental Impact Classification for Alien Taxa (EICAT; Blackburn et al. 2014; Hawkins et al. 2015), and non-environmental impacts are assessed using the Socio-Economic Impact Classification of Alien Taxa (SEICAT; Bacher et al. 2018). The EICAT and SEICAT are based on published evidence and aim to make impact assessments comparable by providing a clearly defined protocol to identify impact mechanisms and their magnitudes, and minimise assessor bias (Figure 6).

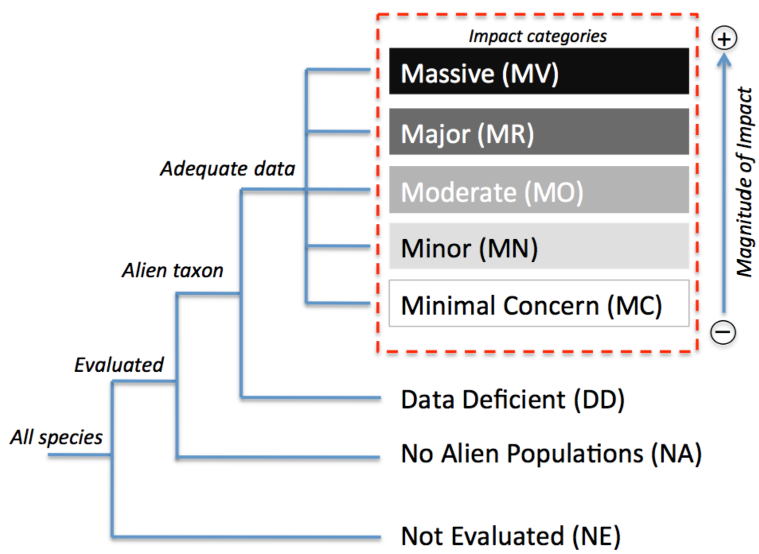

Figure 6: The Environmental Impact Classification for Alien Taxa (EICAT) assesses the environmental impacts of alien species across 12 mechanisms: competition, predation, hybridisation, disease transmission, parasitism, poisoning/toxicity, biofouling, grazing/herbivory/browsing, chemical impacts on ecosystems, physical impacts on ecosystems, structural impacts on ecosystems, and indirect impacts through interactions with other species. The Socio-Economic Impact Classification for Alien Taxa (SEICAT) similarly assesses the impacts of alien species on human well-being across four categories: safety; material and immaterial assets; health; and social, spiritual, or cultural

aspects. For both EICAT and SEICAT, impact magnitude is classified into five levels: Minimal Concern (MC), Minor (MN), Moderate (MO), Major (MR), and Massive (MV).

4.1.1. Status and trends

The negative impacts of invasive species on biodiversity and people's livelihoods in South Africa are known to be substantial, in particular those of trees and freshwater fishes. National-level EICAT assessments have been done for 36 species, but in many cases (62%), there were no reliable data. A total of 18 species have been classified as causing Major or Massive environmental impacts. Among plants, these include the grasses giant reed (*Arundo donax*) and reed meadow grass (*Glyceria maxima*), which competitively displace native species (Visser et al. 2017); red gum (*Eucalyptus camaldulensis*), which forms dense stands along waterways that dominate or exclude native vegetation (Tererai et al. 2013; Hirsch et al. 2020); two *Neltuma* species (formerly *Prosopis*; mesquite), which displace native vegetation and alter bird and invertebrate communities through competition (Steenkamp and Chown 1996; Dean et al. 2002; Schachtschneider and February 2013); six Australian *Acacia* species (wattles), which have Major impacts on native species through competition and changes to ecosystem functioning (Jansen and Kumschick 2022); and lantana (*Lantana camara*) and triffid weed (*Chromolaena odorata*), which modify ecosystem structure, resulting in changes to invertebrate community composition and the loss of some native taxa (Samways et al. 1996; Mgobozi et al. 2008).

SEICAT has only been applied to a limited range of taxa so far, including gastropods and some mammals alien to South Africa (Hagen and Kumschick 2018; Kesner and Kumschick 2018), and Australian *Acacia* species (wattles) (Jansen and Kumschick 2022).

4.1.2. Link to B-Cubed project outputs or indicators

Occurrence cubes can be used to map and quantify the impacts of alien species across space and time. The B-Cubed project developed the *impIndicator* R package to provide a standardised, reproducible workflow for estimating the impacts of alien species on biodiversity (Yahaya et al. 2025). The package combines species occurrence data from GBIF with EICAT assessments to produce evidence-based indicators of alien species impacts (Figure 7). By integrating species distributions with standardised impact scores, the workflow enables consistent assessment of how the ecological impacts of biological invasions vary across space and time, supporting biodiversity monitoring and policy implementation.

The workflow produces three complementary indicators: a *species impact indicator*, which estimates the impact of individual alien species over time; a *site impact indicator*, which identifies locations where alien species are likely to have the greatest cumulative impacts; and an *overall impact indicator*, which tracks changes in the combined impacts of alien species across a region. The package allows users to apply different methods for aggregating impact scores and generates maps and time series that support biodiversity assessments, management prioritisation, and reporting against policy frameworks such as the Kunming–Montreal Global Biodiversity Framework Target 6 and the Sustainable Development Goals.

The workflow was demonstrated using *Acacia* species in South Africa, illustrating how impact indicators can identify high-impact species, invasion hotspots, and temporal changes in impacts. The indicator values remain influenced by the quality and completeness of occurrence data, particularly sampling effort, and to circumvent this, uncertainty estimates will be integrated using the *dubicube* package in future versions. The *impIndicator* package provides a transparent and scalable approach for monitoring alien species impacts and supporting evidence-based conservation and management decisions. tThese indicators, however, have not yet been integrated into the status report indicator framework. Further refinement, particularly for spatial analyses, is required to ensure that the resulting estimates are robust, ecologically meaningful, and suitable for policy reporting.

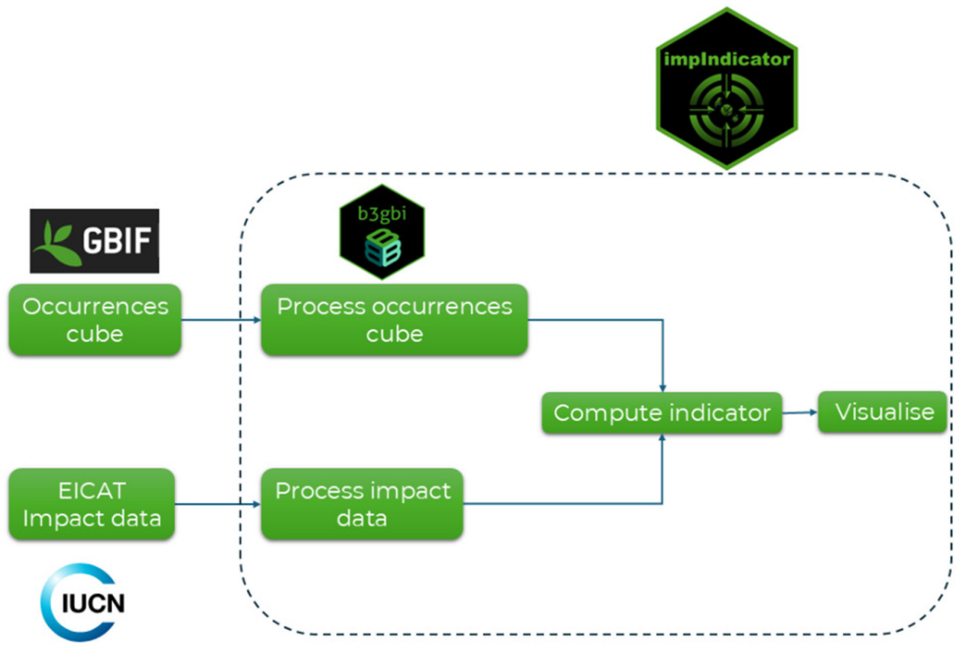

Figure 7: Workflow implemented in the *impIndicator* R package for computing and visualising alien species impact indicators. The workflow integrates GBIF occurrence cubes with Environmental Impact Classification for Alien Taxa (EICAT) assessment data to generate species-, site-, and overall impact indicators and associated visualisations.

4.1.3. Challenges/issues

More studies are needed to assess the impacts of invasive species in South Africa. Advances in impact assessment methodologies have improved the identification of high-impact species, while new frameworks, models, and global standards continue to strengthen assessments of invasion risks and impacts. However, these approaches have so far been applied to only a small proportion of the alien taxa present in South Africa. In addition, our assessment identified limitations in how impact metrics are combined within the B-Cubed indicators.

The indicators implemented in the *impIndicator* R package have not yet been incorporated into the status report indicator framework and will require further conceptual alignment before they can be adopted. For example, the species impact indicator may show increasing impact values over time, but these trends primarily reflect the expansion of species distributions and increases in occupied grid cells, which are also influenced by sampling effort. Consequently, the indicator represents the spatial extent of potential impact rather than changes in the magnitude or severity of ecological impacts. Further refinement and integration with the status report framework are therefore needed to ensure that the indicators are interpreted consistently and appropriately for policy reporting.

3.5. Impact of invasions

The indicator *Impact of invasions* assesses the combined impact of all invasive species at a particular site on the delivery of selected ecosystem services or on biodiversity. It should have a focus on those ecosystem services that are important in the context of the site concerned (for example on water resources in dry regions, livestock production in rangelands, or biodiversity in protected areas) and can be used to prioritise sites for management interventions (Figure 8).

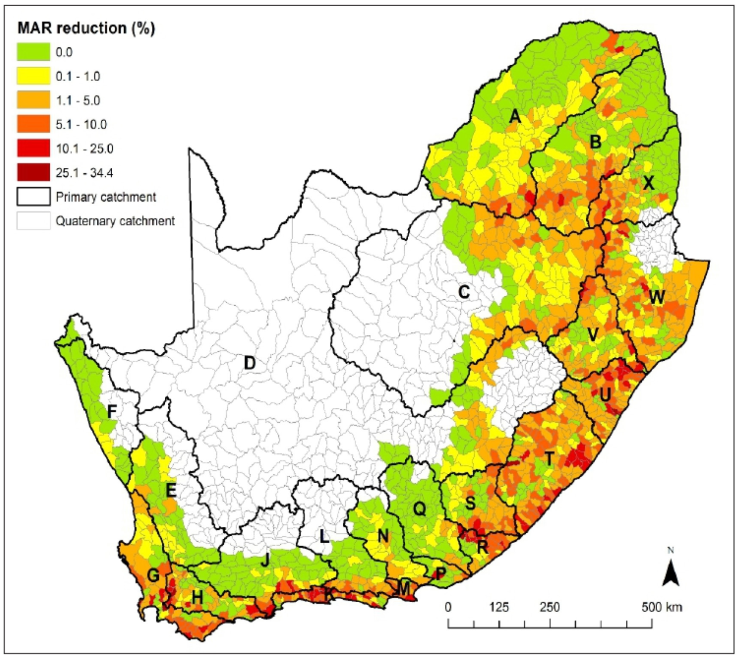

Figure 8: Estimates of the reductions in mean annual run-off (MAR) due to invasive alien plants in the quaternary catchments of South Africa. Capital letters refer to primary catchments. The quaternary catchments that were completely excluded are shown in grey; many others were only partially mapped; the Kruger National Park was also excluded. Data from Le Maitre et al. (2016), figure taken from SANBI and CIB (2018).

4.2.1. Status and trends

A handful of influential historical studies in South Africa have indicated the severe impacts of invasions on water resources, rangeland productivity and biodiversity (van Wilgen et al. 2008; Le Maitre et al. 2000, 2016). These studies showed that: i) invasive trees use 3–5% of South Africa's surface water runoff each year; ii) invasive plants reduce the value of livestock production from natural rangelands by ZAR 340 million per year; and iii) biological invasions are responsible for 25% of all biodiversity loss, placing them as the largest impact to South Africa's biodiversity after cultivation and land degradation.

4.2.2. Link to B-Cubed project outputs or indicators

Previous studies have been used to report on specific impacts [in particular van Wilgen et al. (2008)], but these studies were not found to be repeatable and so do not provide a suitable basis for an indicator (SANBI and CIB 2026a). Through the B-Cubed project, there have been attempts to combine impacts of particular alien taxa at a site level for South Africa (e.g., Boulesnane-Guengant et al. 2025; Yahaya et al. 2025), but these methods focus on combining the impacts of individual taxa as estimated using EICAT or SEICAT, so they collapse into a species-based approach. Moreover, in both cases, there were recognised concerns about the need to correct for sampling biases.

The calculation procedure for these indicators has thus not, yet, been finalised. In broad terms the steps would seem to be: 1) define an asset (e.g., biodiversity or water runoff) that is valued and threatened by invasions at a given site; 2) develop a metric specific for estimating how invasions impact that asset; 3) identify a spatial layer for that asset; 4) gather spatial data on the occurrence and/or abundance of invasions that impact that asset; and 5) overlay the layer of impactful invasions onto the layer of the asset of interest to estimate the spatial extent and overall magnitude of the impacts (and potentially how interventions have been or could be reducing the impact). Until these indicators are further developed the relevant sections in the status report are purely descriptive and the indicators will be subject to revision.

While the B-Cubed project has not resolved the issue, it has played a fundamental role in clarifying the issue and how different approaches might productively address it.

4.2.3. Challenges/issues

Biological invasions cause impacts on biodiversity, ecosystem services, and human livelihoods by reducing South Africa’s water resources, degrading pasturelands, and exacerbating fires. These impacts are likely to increase as invasive species continue to spread and as control efforts are scaled back in response to fiscal constraints. These estimates, however, have not been recently revised, and the indicator has been evaluated and found not fit for purpose. There is therefore a need to develop systematic processes for evaluating the combined impacts of invasions at a given site.

4. Link to other B-Cubed products

4.1. Modelling current and future scenarios

Work Package (WP) 4 integrates species occurrence cubes with climate change and land use change scenarios through existing models to project past, present, and future biodiversity. It creates exemplar workflows for modelling with biodiversity data cubes, demonstrating how biodiversity data can be used to create policy-relevant forecasts and current estimates. In South Africa, a national report on the status of biological invasions, by definition, should focus on what the current state is, but this is often largely a function of historical events and processes (Figure 9). Given that the report will form the baseline for predictions of how problems will evolve under different scenarios, that is, invasion debt, indicators need to be responsive to changes. We propose forecasted indicators (*introduction debt*; *establishment debt*; *spread debt*; and *impact debt*) – as over time, invasion debt can result in new introductions, new invasions, more area invaded, and greater impacts (Rouget et al. 2018; Wilson et al. 2018). The challenge is to develop models and techniques that can help improve decision-making and allow for adaptive management at various scales. The products from WP4 (e.g., suitability cube, dissimilarity cube, network invasibility cube) can be used to inform on the invasion debt in South Africa. However, these products have not yet been integrated into the indicator framework that informs the status report (Figure 1). They have been identified for potential inclusion during future revisions and updates of the indicator framework.

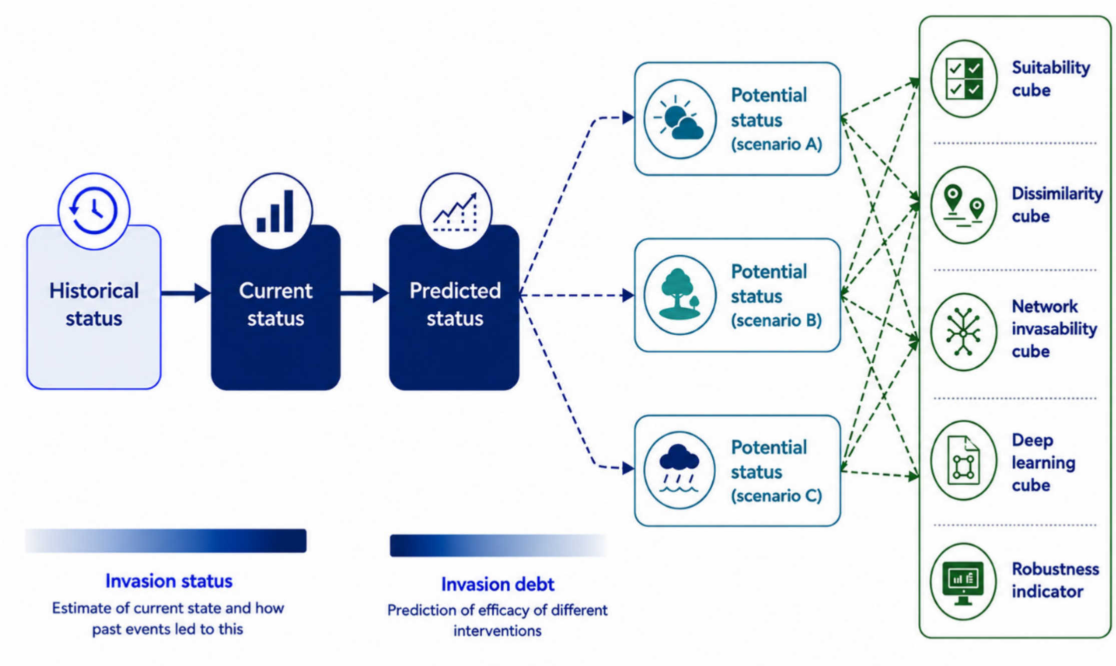

Figure 9: Conceptual framework illustrating the use of biodiversity data cubes to estimate invasion status and support future predictions. Historical and current species occurrence data are integrated to quantify present invasion status, while predictive models estimate future invasions (invasion debt) under different scenarios. These scenarios could use several modelling tools created in the B-Cubed project, such as the suitability cube, dissimilarity cube, network invasibility, deep learning, and robustness indicator cubes.

5.2. Improving and assessing the reliability of indicators

GBIF provides large volumes of biodiversity data, creating new opportunities to estimate the status and trends of biological invasions. These data, however, are 'unstructured' as they come from a variety of sources, and are collected in a variety of ways (e.g., eDNA, mobile applications) and for various purposes, often without a sampling design or records of sampling effort. This results in several issues, such as temporal, spatial, and taxonomic biases; and errors, which mean that biodiversity indicators derived from GBIF data may not reflect real world patterns and trends.

The B-Cubed project addressed this challenge through Task 4.5 (Langeraert et al. 2026), which aimed to determine the conditions under which indicators derived from aggregated occurrence cubes from GBIF can be considered sufficiently robust for reporting and policy use. The task was based on a comparative approach, which contrasted results based on unstructured GBIF cube data with structured monitoring data from bird surveys in Flanders (Belgium) and the Western Cape (South Africa).

Several recurring technical challenges that affect the reliability of indicators derived from unstructured occurrence cubes were noted in the deliverable report, D4.3 (Langeraert et al. 2026):

- **Spatial uncertainty**, where large uncertainty in the coordinates of the records distorts spatial patterns.
- **Taxonomic inconsistencies**, including unresolved names that inflate species counts and introduce spurious variation.
- **Publication delays**, which can create declines or breaks in temporal trends.
- **Dataset dominance**, where contributing datasets disproportionately influence results.

The deliverable (D4.3) provides practical guidance to address these technical challenges; through the implementation of baseline data-quality filters during cube preparation, exploratory assessment of data coverage and structure, and the development, implementation and documentation of operational quality criteria.

The deliverable report (D4.3) also highlighted the importance of quantifying and, where possible, incorporating into analyses, survey effort, survey completeness, and species detectability. To address these challenges, diagnostic frameworks to quantify survey effort and completeness were implemented; a survey-effort score was presented that captures record volume, temporal replication, and taxonomic coverage; and to examine species detectability a survey-based detection probability metric was implemented to distinguish between genuine ecological signals and reporting biases. Some of these assessments have been operationalised through software developed through the B-Cubed project, specifically the *gcube* R package for simulating occurrence cubes (Langeraert 2026); the *dubicube* R package for quality checks and quantifying indicator uncertainty (Langeraert and Van Daele 2026a); and the *b3gbi* R package for estimating completeness (sample coverage) and hill numbers (e.g., estimated species richness based on coverage-based rarefaction) (Dove 2026).

The status report is based on indicators calculated from raw biodiversity records, and they, therefore, reflect the biases and other issues discussed above. For example, in the status report published in 2020, the indicator *Alien species richness* appeared to show a notable increase in invasive plant species richness in parts of the country (the southern Cape in particular, Figure 4.1D in SANBI and CIB 2020), however, these increases were a direct result of a dedicated road-side survey in the area conducted in March 2018 as part of the SAPIA project (Henderson 2018). This suggests that this indicator is highly sensitive to sampling effort, and that interpreting patterns in the data can require an understanding of very specific details of the monitoring. Going forward, models and corrections will be necessary to ensure the indicators better reflect the patterns and trends in biological invasions (Jetz et al. 2019). The guidance, diagnostic frameworks, and metrics implemented and tested in Task 4.5 will be trialled in future status reports.

5.3. Creating indicators of biodiversity change and quality measures

Through WP5, the B-Cubed project has created reproducible and sustainable workflows to calculate indicators and their uncertainty, as well as to evaluate the quantity and quality of biodiversity observations in order to identify data gaps. Software has also been developed to allow others to apply the workflows and indicators and to develop their own workflows. Various products from WP5 were produced including indicators on biodiversity, phylogenetic diversity, and impacts of alien taxa, and measures to assess and mitigate uncertainty in data and indicators.

5.3.1. Biodiversity indicators

Biodiversity indicators are essential for monitoring ecological change, informing conservation, and supporting evidence-based policy, but their calculation is often constrained by fragmented and heterogeneous biodiversity data. The *b3gbi* R package, developed within the B-Cubed project, provides standardised, reproducible workflows for calculating a broad range of biodiversity indicators from biodiversity data cubes (Dove 2026; Table 2). The package uses biodiversity data cubes obtained from GBIF, prepares the data for analysis, and generates biodiversity indicators, maps, and time series, enabling transparent and scalable biodiversity assessments across taxa and regions.

Some of the general biodiversity indicators made available through *b3gbi* are directly aligned with those used in the status report, including *observed species richness, total occurrences*, and *species range*. However, several indicators—such as *occurrence density (occurrences km⁻²)*, *mean year of occurrence (newness)*, *evenness*, *rarity*, *species richness (estimated by coverage-based rarefaction)* and *Hill–Shannon diversity*—are not yet incorporated into the current indicator framework and will need to be integrated into the framework before inclusion in future status reports. In addition, the *b3gbi* package estimates uncertainty for many biodiversity indicators by calculating bootstrapped confidence intervals, following the approach implemented in the *dubicube* package (Langeraert and Van Daele 2026a). These uncertainty estimates, particularly those that account for variation in sampling effort, will improve the robustness and interpretation of biodiversity indicators used in the status report.

Table 2: An overview of biodiversity indicators in the *b3gbi* R package, and how these link to indicators used in the status report.

Indicator	Description	Link to the status report indicators
Total occurrences	Provides the overall number of species occurrence records within a spatial unit or temporal period. Provides important context for interpreting biodiversity indicators, helping distinguish ecological patterns from sampling effects. For example, high observed richness with few occurrence records may indicate sampling bias rather than true biodiversity	Indirect – *alien species extent*
Density of occurrences (ooc/km^2)	Measures the number of occurrence records per site, helping identify well-sampled and under-sampled locations	Direct – *alien species extent*
Mean year of occurrence (newness)	Measures the average year of occurrence for all records within a given spatial (grid cell) or temporal unit (e.g., year). Indicates the relative recency of observations and temporal patterns in data collection. Provides an estimation of the relative recency of observations. It is valuable for understanding the	Direct – *alien species extent*

	temporal context of available data (e.g., shifts in data collection activities)	
Observed species richness	Measures the total number of unique species over time. Shows how new species records accumulate over time, helping to evaluate sampling effort and overall recorded biodiversity for a given site	Direct – *alien species extent, alien species richness*
Evenness (Simpson's Evenness and Williams' Evenness)	Measures how uniformly individuals (or observations in GBIF data) are distributed among species within a given area or over time. It complements species richness by providing insight into community structure	Indirect – *alien species richness*
Rarity (abundance-based rarity and area-based rarity)	Quantifies the scarcity or infrequency of species, and when summed over multiple species, serves as a crucial biodiversity indicator for conservation	Indirect – *alien species richness*
Species richness *Hill-Shannon diversity* *Hill-Simpson diversity* (all estimated by coverage-based rarefaction)	Provides a unified framework for various diversity measures, allowing for different emphases on rare versus common species using model parameters	Indirect – *alien species richness*
Species occurrences	It is an Essential Biodiversity Variable (EBV) that documents observed species distributions through space and time. Provides a proxy for relative abundance for species with similar detectability	Indirect – *abundance of alien species*
Species range	Refers to the observed geographical extent of individual species. However, observed range may be a subset of the true ecological range due to incomplete sampling	Direct – *alien species extent*
Taxonomic distinctness	Measures the average taxonomic distance between any two randomly chosen species in a sample, incorporating their phylogenetic or taxonomic relatedness. It is an Essential Biodiversity Variable (EBV) that complements richness and evenness by reflecting the evolutionary breadth of a community	Indirect – *alien species richness*
Occupancy turnover	Measures the rate at which species composition changes over time within a community. High turnover can indicate environmental change but is sensitive to incomplete sampling and differences in survey effort	Indirect – *alien species richness*

5.3.2. Phylogenetic diversity

The B-Cubed project developed the *pdindicatoR* R package to calculate phylogenetic diversity metrics and indicators from species occurrence cubes and phylogenetic trees (Breugelmans et al. 2024). The package matches occurrence records to phylogenetic trees, computes phylogenetic diversity metrics, and generates spatial maps and indicators (Figure 10). These outputs support biodiversity assessment, conservation planning, and policy by identifying areas of high evolutionary diversity. Documentation and exemplar workflows are included to facilitate reproducible analyses. This is a potentially better metric for biodiversity in relation to policy than simple species counts, and it can be easily scaled to large areas and many species using cloud computing and the occurrence data cubes. Whether indicators for phylogenetic diversity will provide meaningful actionable insights for those tasked with managing biological invasions (e.g., in terms of risk analyses) is debatable, nonetheless there is the potential to inform revisions to the indicator framework in future.

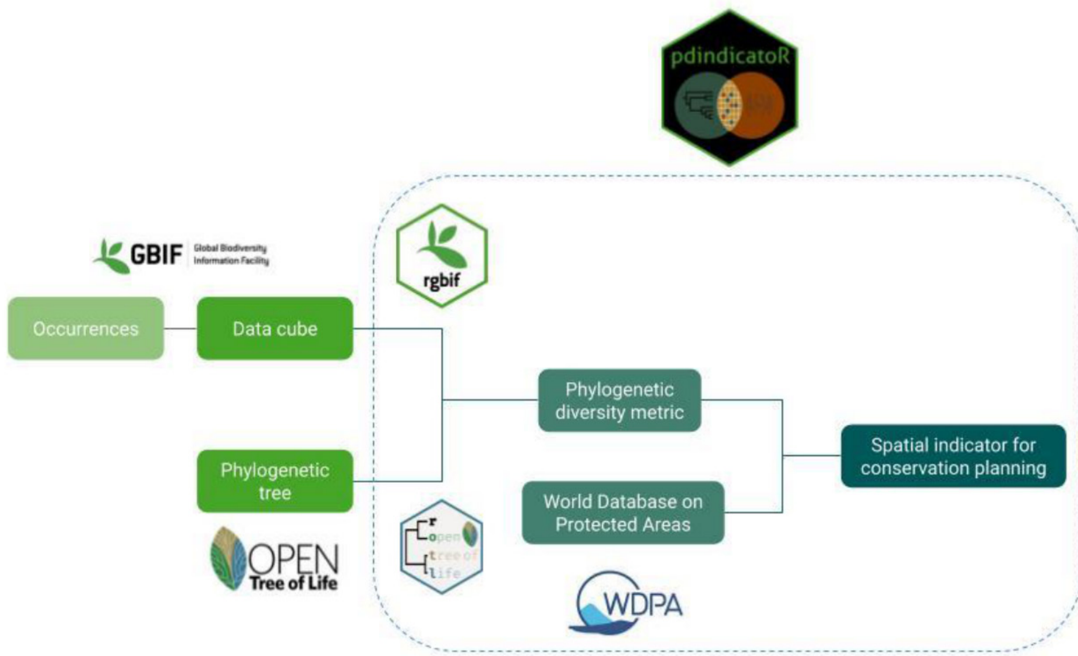

Figure 10: Workflow implemented in the *pdindicatoR* R package. GBIF occurrence cubes are combined with phylogenetic trees from the Open Tree of Life to calculate phylogenetic diversity metrics, generate spatial maps, and estimate the proportion of high phylogenetic diversity protected within conservation areas.

5.3.3. Robustness assessment

The *dubicube* R package was developed as part of the B-Cubed project to improve the reliability of biodiversity indicators calculated from biodiversity occurrence cubes (Langeraert and Van Daele 2026a, b). Biodiversity data are often incomplete, unevenly sampled, and collected from multiple sources. The *dubicube* package helps users evaluate whether the available data are suitable for producing reliable indicators before they are used for reporting or decision-making.

The package provides tools to assess data quality, identify potential sampling biases, and evaluate how sensitive biodiversity indicators are to differences in the underlying data. It also estimates confidence intervals using bootstrap resampling, allowing users to quantify the uncertainty associated with indicator values. These tools help distinguish genuine biodiversity trends from patterns that may simply reflect limitations in the available data.

In addition, the *dubicube* package provides methods to classify and visualise biodiversity trends while explicitly showing their uncertainty. The package integrates with other packages developed in the B-Cubed project, including *b3gbi, pdindicatoR*, and *impIndicator*, enabling biodiversity indicators to be reported together with measures of confidence. This improves the transparency, reliability, and interpretation of biodiversity assessments and supports more informed conservation and policy decisions.

By incorporating data quality assessment, sensitivity analyses, and confidence intervals, the *dubicube* package can substantially improve the robustness and interpretation of biodiversity indicators. These tools still need to be integrated into the status report indicator framework to inform future reports.

5. Conclusions and future directions

The overarching objective of the B-Cubed project was to develop pipelines to improve the integration of biodiversity data into data cubes that are then used as the basis for models and indicators to monitor biodiversity status and change. South Africa's national report on biological invasions and their management provides a practical use case for biodiversity data integration pipelines that improve reporting processes and support monitoring and policy development. The project addressed four priority areas identified to improve the status reports: aligning indicators with biodiversity frameworks, mobilising spatial occurrence and impact data, the automation and standardisation of the process, and developing repeatable, transparent assessment workflows to improve how the reports are communicated.

The B-Cubed project has strengthened the reporting process for the status report by improving indicator alignment with national and international reporting frameworks, particularly Target 6 of the Kunming-Montreal Global Biodiversity Framework. Documented and repeatable workflows and the adoption of biodiversity information standards have improved the efficiency, transparency, and reproducibility of data processing and analysis. The B-Cubed project has also addressed important gaps in the mobilisation of spatial and impact data, providing improved workflows to support indicators on the number and status of alien species, the extent of alien species, alien species richness, and the impacts of biological invasions.

Several B-Cubed products provide opportunities to further strengthen future status reports. Data products such as suitability, dissimilarity, and network invasibility cubes offer new approaches for assessing invasion debt and forecasting future invasions but are not yet incorporated into the indicator framework used for the status report. Similarly, several indicators on biodiversity and impact of alien species developed through the project require further refinement and integration before they can be used for the status report. The tools developed to measure and estimate uncertainty for biodiversity indicators, particularly variation in sampling effort, will improve the robustness and interpretation of future assessments.

Overall, the South African case study shows how the tools and workflows developed through B-Cubed can help turn biodiversity observations into information that supports policy and management. By improving the way biodiversity data are integrated, analysed, and reported, the project has made national reporting on biological invasions more efficient, transparent, and reproducible. These advances strengthen South Africa's capacity to monitor biological invasions, evaluate the effectiveness of management actions, and report progress towards national and international biodiversity commitments. The approaches developed through the B-Cubed project are also applicable beyond South Africa and provide a practical framework that other countries can adapt to strengthen biodiversity monitoring and reporting.

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9. Annex

Table A1: Papers produced as part of the joint special issues 'Lists of alien taxa in the Global South'

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