National Biodiversity Monitoring Framework

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Executive summary

South Africa has well-developed biodiversity legislation and is signatory to numerous multi-lateral environmental agreements focusing on biodiversity. Numerous efforts to conserve and sustainably utilise biodiversity are underway across the country, led by government, civil society, and traditional authorities. As a signatory to the Convention on Biological Diversity, the country is required to report at a national level on the targets and indicators of the Kunming-Montreal Global Biodiversity Framework. A number of other global agreements also include biodiversity reporting requirements. Similarly, many national strategies have targets that need to be reported on. To meet the needs of these high-level monitoring processes, a steady flow of relevant biodiversity data are required. Such biodiversity data, when combined with information on the pressures and drivers of change, allow us to track progress towards achieving national and global biodiversity targets.

Existing biodiversity monitoring efforts in South Africa (and globally) have substantial biases (geographic and taxonomic) and are not consolidated or organised in a way that allows for easy use. Over 1000 different monitoring initiatives and projects were recorded across South Africa in 2020. To maximise the impact of the many and varied biodiversity monitoring efforts, a national framework is needed to help bridge the gap between those collecting biodiversity data and the high-level reporting requirements of South Africa's national and international commitments to biodiversity conservation and sustainable use. The goal of the National Biodiversity Monitoring Framework (NBMF) is to lay the foundation for co-ordinated biodiversity monitoring at a national level, built on collaborative efforts, which allows for global and national reporting on the state of biodiversity to inform policies, decision-making and to guide research.

The key objectives of the NBMF are to:

1. Fulfil national and international reporting obligations related to biodiversity.
2. Facilitate implementation and measure progress towards national strategies.
3. Provide guidance for the development of co-ordinated biodiversity monitoring plans for all realms
4. Identify existing data gaps and guide data collection in support of national biodiversity monitoring.
5. Produce long-term datasets that facilitate a greater understanding of the natural variability of ecosystems and the effect of anthropogenic pressures.
6. Facilitate the identification of tools and mechanisms that increase co-ordination and communication for data management and reporting.

Figure 1 shows how the NBMF aims to link biodiversity data collection to data users via a set of biodiversity indicators. The key components of the framework are the global and national reporting channels, a set of recognised biodiversity indicators, realm or thematic biodiversity monitoring plans, and structured data collection and management processes. The ideal scenario is that the needs of the users help to inform the biodiversity monitoring plans, which guide the efficient use of often limited resources to collect biodiversity data, that can be aggregated and assessed to inform key indicators of change that are designed to provide the information required by the user groups.

The NBMF brings together the efforts of the wider community involved in the collection of biodiversity data, the scientists undertaking assessments and calculating biodiversity indicators, and the user groups who are tasked with reporting on global or national biodiversity commitments. The users take many forms, but prominent among them are the focal points for multi-lateral environmental agreements, such as the Global Biodiversity Framework, as well as those involved in tracking progress towards national strategic targets. The biodiversity monitoring information will also feed into national assessments, such as the National Biodiversity Assessment. The data collection community is very large and includes academics, officials, and citizen scientists organised in many ways; such as along taxonomic lines like birds, or on a specific theme like genetic diversity. Making sense of the huge and growing body of biodiversity data are a large and varied group of scientists in academia, non-governmental organisations, and government institutions. These teams produce indicators of

change that allow us to track progress against various targets or answer specific management and planning questions related to biodiversity.

To take the NBMF forward requires the development of realm or thematic biodiversity monitoring plans, in consultation with various stakeholders. In addition, attention must be given towards robust data management systems and interactive dashboards to ensure that biodiversity monitoring information is transparent, interoperable and easily accessible. Finally, support should be given towards networks for collaboration where the data providers, analysts and users can collaborate such that data collection is increasingly integrated, not duplicated, addresses data gaps and is relevant for use in national biodiversity monitoring. To make all of this possible requires financial resources, the development of technical capacity, and long-term commitment from institutions. Doing so will create a system for national biodiversity monitoring that helps to understand changes in South Africa's rich biodiversity at a national level, thereby supporting sustainable development, guiding conservation activities, and contributing to evidence-based decision-making.

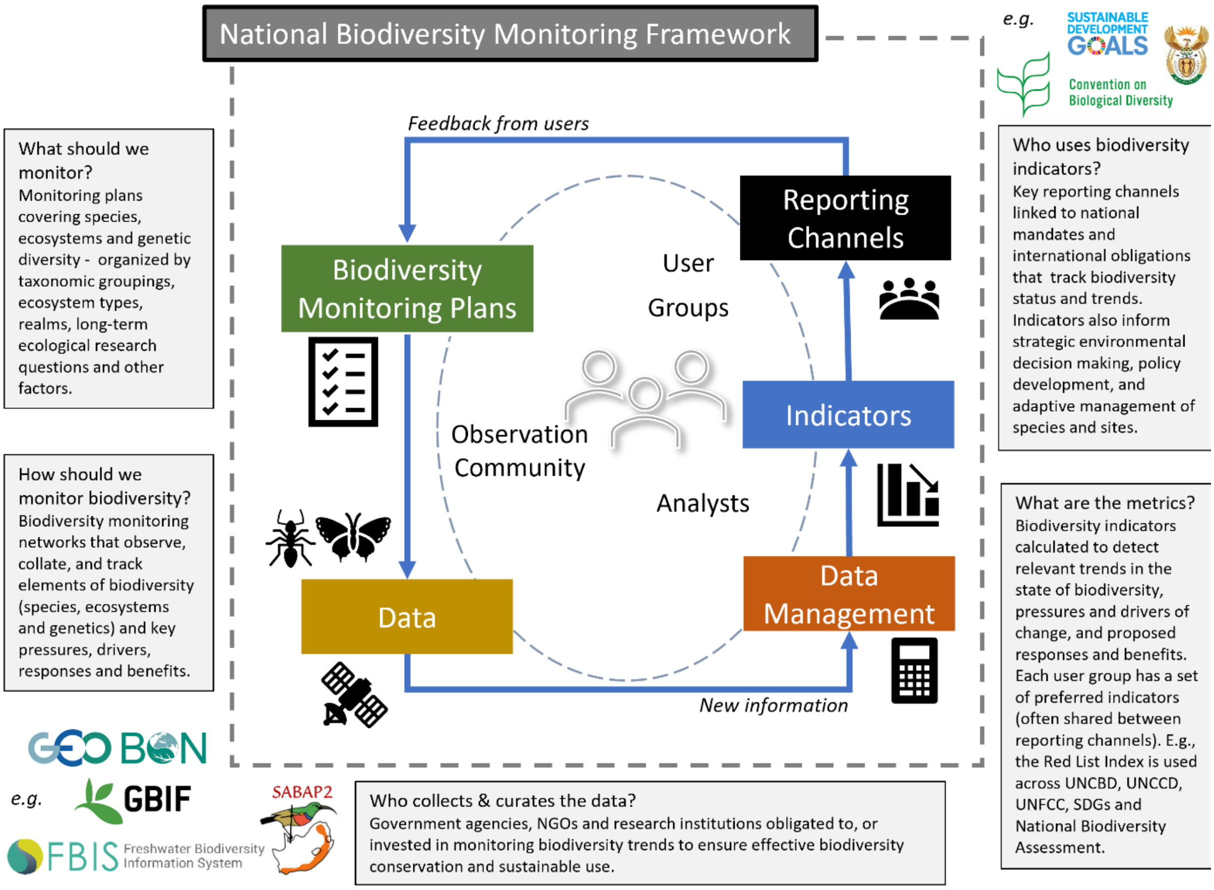

Figure 1: *The key components of the National Biodiversity Monitoring Framework are the global and national reporting channels, the computation of a set of recognised biodiversity indicators, realm or thematic biodiversity monitoring plans, and structured data collection and management processes.*

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Acronyms	Definitions
IAS	Invasive Alien Species
ARC	Agricultural Research Council
AWEA	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
BGIS	Biodiversity Global Information System
BIP	Biodiversity Indicators Partnership
BIOFIN	Biodiversity Finance Initiative
BIMF	Biodiversity Information Management Forum
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CSIR	Council for Scientific and Industrial Research
CWAC	Coordinated Waterbird Counts
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries, and the Environment
DPME	Department of Planning, Monitoring and Evaluation
DPSIR	Drivers, Pressures, State, Impact, Response
DSI	Department of Science and Innovation
EbA	Ecosystem-based Adaptation
EBVs	Essential Biodiversity Variable
EDGE	Evolutionarily Distinct and Globally Endangered
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
GBF	Global Biodiversity Framework
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations – Biodiversity Observation Network
GOOS	Global Ocean Observing System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Areas
MBON	Marine Biodiversity Observation Network
MTSF	Medium-Term Strategic Framework
NBA	National Biodiversity Assessment
NBES	National Biodiversity Economy Strategy
NBF	National Biodiversity Framework
NBIS	National Biodiversity Information System
NBMF	National Biodiversity Monitoring Framework
NBRES	National Biodiversity Research and Evidence Strategy
NBSAP	National Biodiversity Strategies and Action Plans
NCA	Natural Capital Accounting
NDP	National Development Plan
NGOs	Non-governmental organisations
NPAES	National Protected Area Expansion Strategy
NRF	National Research Foundation
OECD	Organisation for Economic Co-operation and Development
OSPAR	Oslo & Paris Convention for the Protection of the Marine Environment of the NE Atlantic
RLI	Red List Index
SABAP2	Southern African Bird Atlas Project 2
SAEON	South African Environmental Observation Network
SAIAB	South African Institute for Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SASPC	South Africa's Strategy for Plant Conservation
SDG	Sustainable Development Goals
SMART	Specific, Measurable, Achievable, Relevant, and Time-Bound
SMCRI	Shallow Marine and Coastal Research Infrastructure
SoER	State of Environmental Report
Stats SA	Statistics South Africa
UN	United Nations
UNCCD	United Nations Convention on Combatting Desertification
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WIO Monitoring Framework	Western Indian Ocean Ecosystem Monitoring Framework
WWF	World Wide Fund for Nature

1 Introduction

South Africa has exceptional biodiversity, characterised by high species richness, high levels of endemism and a wide variety of ecosystem types across land and sea (Kier et al., 2009; Skowno et al., 2019). South Africa's biodiversity provides an array of essential benefits to the environment, economy, society, and human well-being (DEA, 2012; SANBI, 2019). Many anthropogenic activities place pressures on biodiversity, these necessitate conservation and sustainable management actions that ultimately help secure the benefits derived from biodiversity and guide sustainable development (DEA, 2012). To do this effectively requires an understanding of the rates, magnitude and geography of changes in ecosystems, species populations and genetic diversity, and the reasons for the observed change (Anderson, 2018). Robust foundational biodiversity data and clear indicators are required to monitor and report on biodiversity trends. Such information is crucial to support defensible (evidence-based) biodiversity policy, planning and decision-making (Feld et al., 2009; DEA, 2012; Geijzendorffer et al., 2016; Gonzalez et al., 2023).

Biodiversity monitoring is essential to national and global reporting. South Africa is signatory to several multi-lateral environmental agreements related to biodiversity that require the country to report towards progress. Principal among these is the Convention on Biological Diversity (CDB), which is implemented through the Kunming-Montreal Global Biodiversity Framework (CBD, 2022). In addition, the National Environmental Management: Biodiversity Act (Act 10 of 2004) (hereafter referred to as the Biodiversity Act) mandates efficient, effective and achievable biodiversity monitoring solutions to track the country's progress towards biodiversity targets (Reyers & McGeoch, 2007). However, biodiversity monitoring supports more than just mandated national and international reporting. Other processes that benefit from monitoring include systematic biodiversity planning, land/sea use decision-making and policy formulation. In addition, managers require trend data to make informed decisions, and a wide range of research relies on trend data to answer fundamental questions on ecology and environmental change (**Figure 2).**

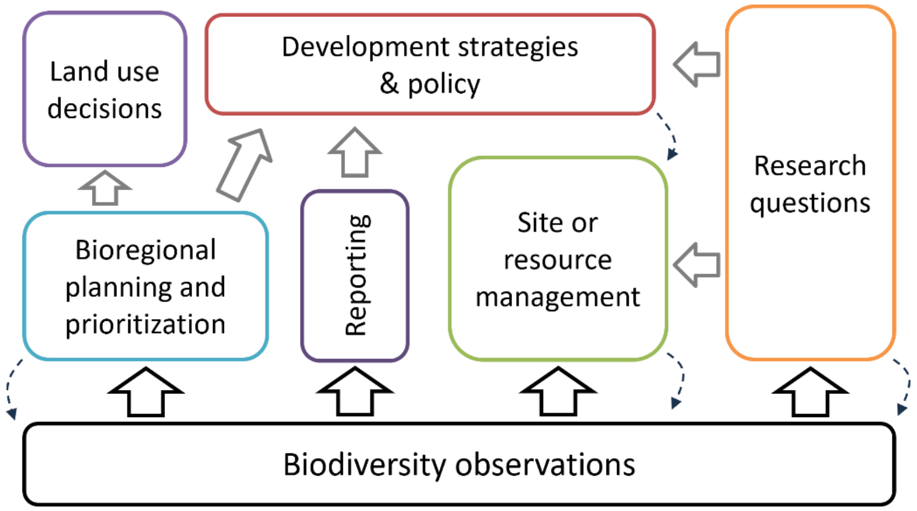


Figure 2: *Biodiversity monitoring supports many different uses beyond national and international reporting.*

This introductory section provides context for biodiversity monitoring in South Africa. It defines biodiversity monitoring and details the potential advantages that a National Biodiversity Monitoring Framework would have for the country. Finally, it considers the main users who would benefit from the NBMF.

1.1 Defining biodiversity monitoring

Monitoring has many definitions, and several reviews attempt to organise ecological and biodiversity monitoring into categories (European Environment Agency, 1999; Lindenmayer & Likens, 2010; McDonald-Madden et al., 2011; Buckland & Johnston, 2017). For this framework, we adopt a hybrid definition from these reviews: *"the process of describing and recording changes (patterns and trends)* *in the state of biodiversity, the drivers and pressures acting on biodiversity and responses to pressures; in order to support evidence-based decision-making, reporting and planning".*

Monitoring generally includes the repeated measures of i) the quality of the environment and each of its components, biotic and abiotic; ii) activities or inputs which may affect the quality of the environment; and iii) the effects of such activities and inputs (OSPAR Commission, 2016). Monitoring can include spatial changes or temporal trends. Further, monitoring should follow an integrated approach, which includes as many different abiotic and biotic components as possible (Smit et al., 2021).

General types of biodiversity monitoring include (Lindenmayer & Likens, 2010; Buckland & Johnston, 2017):

1. **Monitoring to improve management and policy:**
    a. Monitoring to learn the best management actions (adaptive management).
    b. Monitoring to guide government-dependent management and policy.
2. **Monitoring to meet official mandates and international agreements:**
    a. Monitoring to meet legislative obligations and political targets (e.g. Convention on Biological Diversity)
    b. Monitoring for regulatory targets (e.g., harvest limits or quotas for biological resources)
3. **Monitoring linked to long-term research:**
    a. Monitoring where the threats and management interventions are not known a priori and the aim is to understand causal mechanisms through repeated surveys.

Some monitoring efforts are a combination of the broad types and they often share similar data sources and objectives.

1.2 Biodiversity monitoring in South Africa

A wide range of biodiversity-related monitoring occurs in South Africa (Driver et al., 2012; Skowno et al., 2019) conducted by government conservation authorities, government research bodies, academic research, science museums, and non-governmental organisations. There is a multitude of independent research and management-focused monitoring efforts that cover a range of geographies, time frames and focus on a vast array of biodiversity features.

However, there is no official list of biodiversity monitoring programmes in South Africa. A review was undertaken to better understand what biodiversity monitoring was happening in the country. The main aim of this review was to establish the extent and geographic spread of biodiversity-related research monitoring conducted in South Africa, identify trends in monitoring, discover research gaps and determine how the monitoring currently taking place could contribute to national biodiversity monitoring.

An initial list of monitoring programmes was compiled in 2020. A literature review was done using broad phrases related to biodiversity monitoring using Google Scholar and other research and publication repositories. Online search engines were used to find biodiversity monitoring projects from institutional and other websites. Scientists working on biodiversity monitoring research projects were consulted. All the information was consolidated into a biodiversity monitoring database using standardised entries. This resulted in a total of 1322 projects and papers. Since 2021, SANBI undertook to keep the list of monitoring projects up to date on a quarterly basis.

According to the consolidated database, monitoring occurs across all nine provinces and offshore of South Africa. The provinces where the most biodiversity monitoring was conducted were the Western Cape, KwaZulu-Natal, and the Eastern Cape. Most of the monitoring projects were short-term (up to 1 year) but others were medium term (1 – 5 years) or long term (more than 5 years). Themes covered climate change, disease surveillance, ecological conditions, species movement patterns, habitat monitoring, species population monitoring, community composition, ecosystem function, ecosystem structure, genetic composition, species population, species traits and more. Most of the biodiversity monitoring projects were conducted inside protected areas, with fewer conducted outside. The database is available on request from the authors.

1.3 Advantages of a biodiversity monitoring framework

A biodiversity monitoring framework can be a valuable tool for promoting sustainable development and preserving the country's rich natural heritage for future generations. The development of a National Biodiversity Monitoring Framework would have several environmental, social and economic advantages:

1. **Data-driven decision making:** A monitoring framework provides decision-makers with scientifically rigorous data and information, enabling evidence-based policy and management decisions. This can lead to more effective resource allocation and targeted interventions to address conservation challenges.
2. **Conservation and management:** A well-designed biodiversity monitoring framework can provide critical information about the health and status of South Africa's diverse ecosystems and species. This information can guide conservation efforts and enable adaptive management strategies to mitigate biodiversity loss and ecosystem degradation.
3. **Ecosystem services:** Biodiversity monitoring can track changes in the various services provided by ecosystems to society, such as clean water, pollination, carbon sequestration, and tourism opportunities. Understanding these services can highlight the value of conservation and sustainable land use practices.
4. **Stakeholder engagement:** Developing a monitoring framework necessitates collaboration among various stakeholders, including government agencies, research institutions, non-governmental organisations, and local communities. Engaging these groups can foster a sense of ownership and shared responsibility for biodiversity conservation.
5. **Capacity building:** The implementation of the framework requires trained personnel who can collect, analyse, and interpret data accurately. This presents opportunities for capacity building and skill development among researchers, field practitioners, and data analysts.
6. **Early warning system:** By regularly monitoring biodiversity, the framework can serve as an early warning system, detecting changes and trends in species populations and ecosystems. This can help identify emerging threats and allow for timely intervention.
7. **International commitments:** Many international agreements, such as the CBD, require signatory countries to report on their progress in conserving biodiversity. A monitoring framework helps South Africa fulfil its obligations under these agreements.
8. **Policy evaluation:** The data collected through the monitoring framework can be used to evaluate the effectiveness of existing policies and initiatives related to biodiversity conservation. It can also guide the development of new policies that align with conservation goals.
9. **Tourism and education:** Well-documented biodiversity can enhance eco-tourism opportunities and environmental education initiatives. Monitoring outcomes can be shared with the public to raise awareness about the importance of biodiversity and ecosystems.
10. **Research and innovation:** Biodiversity monitoring generates a wealth of data that can be used for scientific research. This research can contribute to our understanding of ecological processes, species interactions, and the impacts of environmental changes.

11. **Long-term trends:** A monitoring framework can facilitate the tracking of long-term trends in biodiversity, allowing for a better understanding of how ecosystems are responding to factors like climate change, habitat loss, and invasive species.

1.4 Users and needs

The National Biodiversity Monitoring Framework (NBMF) focuses on high-level monitoring and reporting processes and the indicators required by national and international agreements and strategies. At this level, the Department of Forestry, Fisheries and the Environment (DFFE), South African National Biodiversity Institute (SANBI), and Statistics South Africa (Stats SA) are among the entities that are formally tasked with national reporting. However, biodiversity monitoring draws on information from a large network of collaborating data providers, including academic institutions, non-governmental organisations, and provincial and local government. There are a wide range of other potential users of the information that supports the monitoring framework. Many of these users are interested in trends in specific metrics and indicators that will allow them to answer specific research questions or inform adaptive management (**Figure 2**).

2 Purpose of the framework

The key to a successful monitoring initiative is understanding what the purpose is (Lindenmayer & Likens, 2010). The purpose of the NBMF is to increase observations and assessments so as to better understand the natural and anthropogenic drivers of change in ecosystems, species and genetic diversity, to ensure effective management of biodiversity so that ecosystem services can continue to support sustainable development, now and in the future.

In this section, the fundamental goal, objectives, principles and legal mandate for the NBMF are laid out clearly to define the scope of the NBMF.

2.1 Goal

The **goal** of this framework is to lay the foundation for national biodiversity monitoring and build collaborations to allow for global and national reporting on the state of biodiversity that informs policies, supports decision-making and guides research. To achieve this goal, the framework aims to guide actions to answer these key questions related to biodiversity monitoring, management and planning (SANBI & UNEP-WCMC, 2016):

1. What biodiversity does South Africa have?
2. What is the status or condition of biodiversity across the landscape and seascape?
3. How is biodiversity changing, and what causes the changes being observed?
4. Where and how should South Africa prioritise managing and conserving biodiversity first?

2.2 Objectives

The key objectives of the NBMF are to:

Objective 1: Fulfil national and international reporting obligations related to biodiversity.

Objective 2: Facilitate implementation and measure progress towards national strategies.

Objective 3: Provide guidance for the development of co-ordinated biodiversity monitoring plans for all realms.

Objective 4: Identify existing data gaps and guide data collection in support of national biodiversity monitoring.

Objective 5: Produce long-term datasets that facilitate a greater understanding of the natural variability of ecosystems and the effect of anthropogenic pressures.

Objective 6: Facilitate the identification of tools and mechanisms that increase co-ordination and communication for data management and reporting.

2.3 Legal commitments, mandates and institutions

Responsibility for managing, conserving, and ensuring sustainable use of South Africa's biodiversity is shared amongst a diverse group of government departments, organs of state, intergovernmental structures and public research institutions. These are supported by active non-governmental organisations and civil society. While the NBMF is targeted at all relevant stakeholders, some organisations are specifically mandated to monitor and report on the state of biodiversity.

The DFFE is the primary national government department tasked with managing, protecting and conserving South Africa's environment and natural resources. It gives effect to the constitutional right of South Africans for an environment that is not harmful to their health and well-being, and that is protected for future generations. The national department is responsible for national State of the Environment reporting (DEA, 2012), and for South Africa's national reporting to international agreements. South Africa is a signatory to CBD and hence is obligated to work towards the targets of the Kunming-Montreal Global Biodiversity Framework (CBD, 2022). The National Biodiversity Strategy and Action Plan (NBSAP) (currently for 2015-2025; RSA, 2015) is a requirement of the contracting parties of the CBD which sets out strategies and plans to fulfil the objectives (**Figure 3**). It is a long-term strategy which ensures conservation, management and sustainable use of biodiversity to ensure equitable benefit. The NBSAP is enacted locally through the National Biodiversity Framework (NBF) (currently for 2019-2024; DFFE, 2022), which is a requirement of the Biodiversity Act. The NBF ensures co-ordination and alignment of organisations and individuals involved in the conservation and management of biodiversity in support of sustainable development. In addition to the CBD, South Africa is party to other multi-lateral environmental agreements, and the UN Sustainable Development Goals which contain biodiversity targets.

The South African National Biodiversity Institute (SANBI) is an independent public entity linked to the DFFE. It is legally mandated to monitor and report on the status of biodiversity in South Africa under Section 49 of the Biodiversity Act. SANBI meets part of this mandate through the National Biodiversity Assessment (NBA). The NBA reports on the status and trends of ecosystems, species, and genetic resources on a five-to-seven-year cycle, focusing on high-level indicators such as threat status and protection level for species and ecosystems (Skowno et al., 2019). The NBA is the primary mechanism for reporting on biodiversity status in South Africa, and it feeds into the NBSAP, NBF and other international reporting (**Figure 3**).

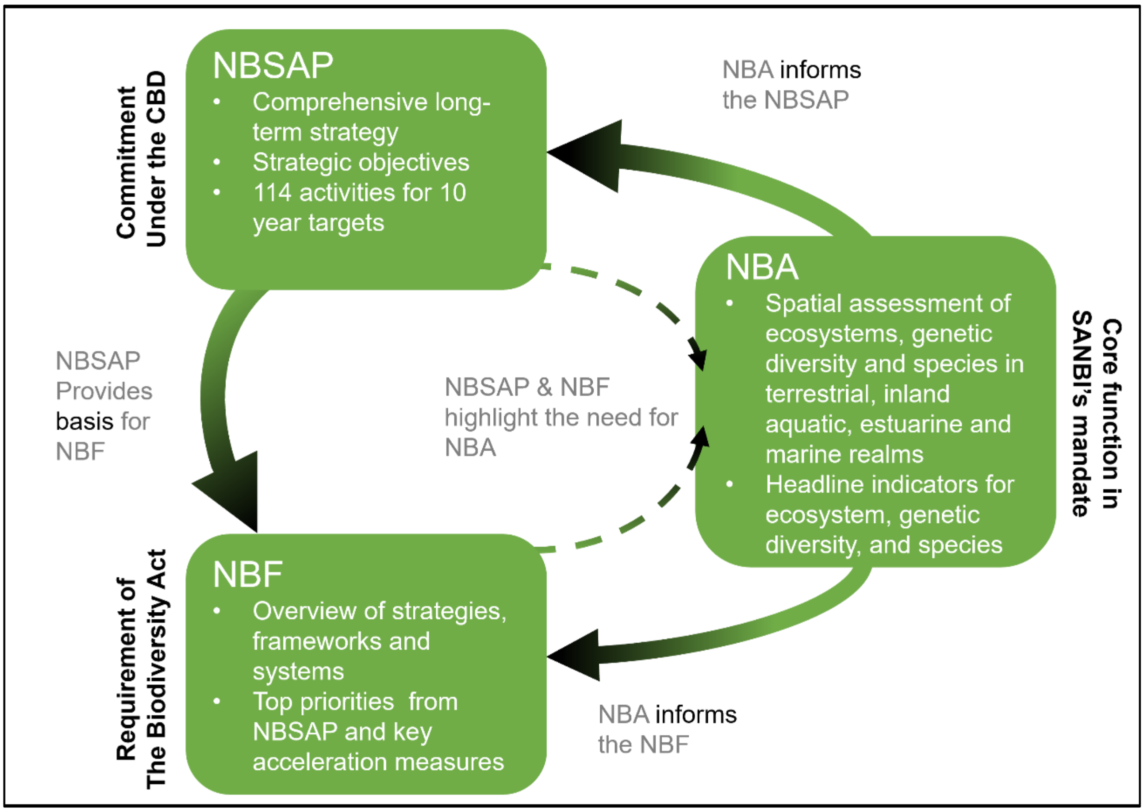


Figure 3. *Biodiversity monitoring is essential for the indicators and metrics used in the National Biodiversity Assessment (NBA), which in turn, informs the National Biodiversity Strategy and Action Plan (NBSAP), and the National Biodiversity Framework (NBF). Figured modified from Skowno et al. (2019).*

The South African Environmental Observation Network (SAEON) is an independent public entity linked to the National Research Foundation (NRF), with a mandate for long-term ecological research and national environmental observation systems (van Jaarsveld et al., 2007). SAEON plays a central role in environmental observation, data collection and information management that could support biodiversity monitoring. SAEON manages and facilitates long-term ecological research at a series of sentinel sites through the Shallow Marine and Coastal Research Infrastructure (SMCRI) and Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) programmes. Other key institutional partners include SAIAB (South African Institute for Aquatic Biodiversity), CSIR (Council for Scientific and Industrial Research), and ARC (Agricultural Research Council).

There is a need to formalise the process of biodiversity observation, assessment and monitoring that underpins the NBA, NBSAP and NBF and supports obligations to national and international conventions. This need was described more than 16 years ago (Reyers & McGeoch, 2007), when a National Biodiversity Monitoring Framework was recommended to focus on meeting national monitoring commitments to the CBD and fulfil the monitoring goals of the Biodiversity Act. The need to co-ordinate data collection and strive for interoperability does not imply that all biodiversity monitoring must be centralised. However, to undertake meaningful monitoring and reporting at a national scale requires a collaborative system that fully uses all available observations and information (MacFadyen et al., 2022).

2.4 Guiding principles

Some key guiding principles for the NBMF have been identified:

Risk-based approach: With limited capacity and resources for monitoring, it is recommended to prioritise those species (and their populations), ecosystems and or sites that are most at risk. These are predominantly identified in South Africa using the IUCN Red List of Threatened Species and IUCN Red List of Ecosystems and through systematic biodiversity planning. This reduces the scale of monitoring required while focussing resources where they can have the most impact.

Ecosystem-based approach: The CBD adopts an ecosystem approach, defined as *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way"* (CBD, 2000). An ecosystem approach recognises that ecosystems are complex and interconnected systems that provide benefits to people. The ecosystem approach views ecosystems as the basic unit for assessment and management. Ecosystem-based management includes a more holistic approach to managing species and ecosystems, which considers the three pillars of sustainable development, including the social, economic and ecological aspects of the broader socio-ecological system (Knights et al., 2013; Laurila-Pant et al., 2015; Parravicini et al., 2013; McVittie et al., 2018). Ecosystem types can be mapped systematically across the full extent of the landscape and seascape of a country, incorporating ecological processes, species, habitat structure, and ecosystem services even when they are unknown or poorly recorded. Ecosystem-based Adaptation (EbA) to climate change is also an approach that acknowledges that "biodiversity plays a vital role, as functional ecosystems offer inherent solutions that enhance resilience and support society in adjusting to the adverse effects of climate change (RSA, 2015).

Co-ordination and co-design: There is a need for increased communication amongst and between scientists, experts, policy-makers, managers and communities to increase harmonisation for more effective and efficient monitoring that increases collaboration and reduces duplicated effort. Information should be gathered through joint monitoring initiatives and in a shared manner which creates a national (and regional) pool of data that is easily accessible. Co-ordination would result in coherence, in other words, the same components monitored in similar habitats and points in time using a standardised methodology for easy interoperability and comparability. A co-creation approach which includes community members in a bottom-up system, but also considers managers needs and policy-makers in the early design stage of the monitoring programmes. Stakeholder mapping and engagement are critical to a successful monitoring system.

Adaptive, flexible, and iterative: Changes in external conditions such as additional or new pressures from anthropogenic activities, the implementation of new management measures, or changes to budgets require adaptations of the monitoring system. Often, results of the monitoring activities are used to redefine expectations of the objectives and outputs of the framework, making it flexible and adaptive in an iterative process. These principles allow for a proactive, dynamic and adaptive process which is continuously under review and refined in terms of methods, tools and approaches used (WIO monitoring framework). Monitoring data should enable meaningful assessment of status in time and space. Any adjustment of monitoring methods (for example, in terms of devices, planning in time and space, analysis of the samples, etc.) should be accompanied by a period of simultaneous application of both the old and the new approach to allow for inter-calibration (Kühl et al., 2020).

Built on existing monitoring initiatives: It is essential that the development of monitoring programmes should be based on existing monitoring to minimise costs, improve sampling precision and statistical power, increase the level of biological data coverage or heterogeneity, increase efficient use of capacity and resources and reduce duplication of work (Henry et al., 2008; Kühl et al., 2020). However, existing monitoring programmes might need to be altered to adhere to local or global standards and to increase the comparability and interoperability of data and indicators used (Henry et al., 2008). Adjustments should be balanced against the need for continuity of current monitoring programmes, with a view to long time series required for trend assessments. Aligning with existing monitoring programmes will also help to identify monitoring and data gaps and where to prioritise actions.

Global standards and best practices: There is an extensive published body of work describing best practice for biodiversity monitoring in which the fundamental considerations and techniques are clearly laid out (Lindenmayer & Likens, 2010; Benson et al., 2018; Muller-Karger et al., 2018; Miloslavich et al., 2019; Christensen et al., 2020; Gonzalez et al., 2023). All phases of any monitoring programme, from scoping, to design and implementation, should adhere to published global standards and best practices. For example, the globally relevant DPSIR (Drivers, Pressures, State, Impact, Response) framework is frequently applied to monitoring and evaluation strategies (Rogers & Greenaway, 2005; Patrício et al., 2016; Miloslavich et al., 2018). Some examples of key aspects that are consistently raised include:

- Time series: A time series is a sequence of data points collected over regular intervals. Time series are important for tracking changes in species and ecosystems over time. (see Box 1)
- Temporal resolution: The temporal resolution determines how regularly time series data is collected. It can be important to consider the temporal resolution depending on the rate of changes that are being monitored.
- Baselines: The selection of an appropriate baseline is very important for setting targets and measuring progress. A baseline is a reference point against which changes can be compared over time.
- Spatial scales: The patterns and processes of biodiversity vary across scales. Like temporal resolution, the spatial scale will depend on the scale of the processes that are being monitored, and it is important to use an appropriate spatial scale to detect changes.
- Geographic coverage: Incomplete geographic coverage during biodiversity monitoring can introduce biases or result in a limited understand of the scope of changes. Effort should be made towards even and complete geographic coverage of the effect being monitored.
- Consistency: To build up a thorough understanding of changes in biodiversity status over time and space it is important for monitoring to be consistent and avoid gaps that could mask or confuse trends.
- Transparency of monitoring methods: Whether biodiversity monitoring is used for research, reporting or management, it is important that methods are transparent and repeatable to ensure confidence in the findings.
- Data interoperability: Data interoperability means that it is possible to combine and analyse data from different sources. It is important to be able to make use of the data that is available and improve efficiency in monitoring. (see Box 2). This requires the development and application of data standards, curated by mandated entities.
- Practicality: Biodiversity monitoring cannot be so onerous, expensive or technical that is does not get implemented or the outcomes used.

Box 1: Time series

Time series data are central to all monitoring efforts (Proença et al., 2017). Decision-makers require information on trends relative to a baseline and or target. Information from a single time point is generally of limited value. For trends to be meaningful, data collection and methods for the metrics and indicators need to be consistent over time. The time steps or observation intervals need to match the temporal dynamics and stochasticity of the species' populations or ecosystems being monitored. The length of the time series required also needs to match the characteristics of the target.

Box 2: Essential Biodiversity Variables

Consistency and interoperability between biodiversity monitoring systems has been the focus of recent efforts by the Group on Earth Observations – Biodiversity Observation Network (GEO BON), with the concept of Essential Biodiversity Variable (EBVs) (Pereira et al., 2013). GEO BON developed EBVs as fundamental metrics with the purpose of aggregating, harmonising, and interpreting biodiversity observation data from multiple sources (Navarro et al., 2017; Hoban et al., 2022). While EBVs provide a framework for global consistency at the level of the variables observed at a national scale, the same principles apply to the mandated monitoring and management-focused monitoring. EBVs are state variables standing between primary observations and high-level indicators, representing essential aspects of biodiversity, from genetic composition to ecosystem functioning (Pereira et al., 2013; Hoban et al., 2022, Gonzalez et al., 2023). For more information, visit GEO BON at https://geobon.org/ebvs/what-are-ebvs.

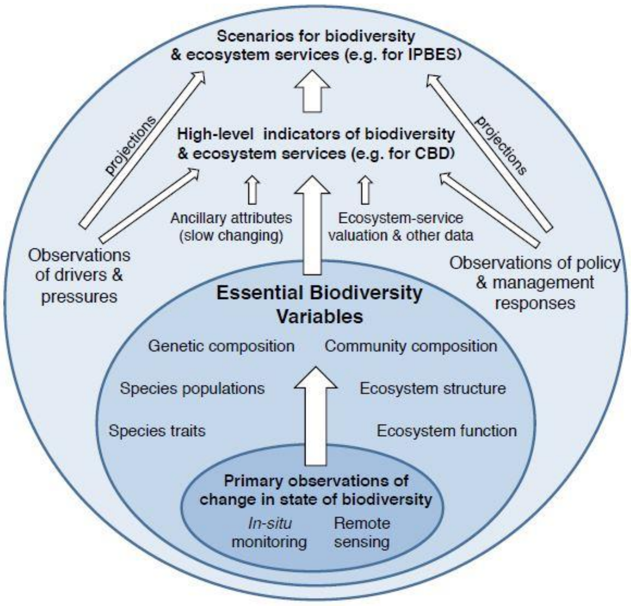


Figure 4: Examples of candidate EBVs indicating relevance to high level targets and indicators (from Pereira et al. 2013).

2.5 Scope

Despite a strong policy and legislative framework for the conservation, management and sustainable use of biodiversity, it can be overwhelming to ensure that all obligations are met and to successfully implement all of them. The amount of foundational data, combined with the broad scope of the various biodiversity-related mandates and different levels of government, makes for many potential indicators. If the monitoring concept is broadened to include biodiversity research and adaptive management, the list of biodiversity indicators explodes. For this reason, it is necessary to narrowly define the scope of the NBMF:

1. **Biodiversity:** The scope is limited to monitoring of biodiversity. Biodiversity is defined here, according to the CBD, as *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species (genes), between species and of ecosystems."* This includes monitoring of relevant drivers of change, pressures and responses (as capture din the DPSIR framework, European Environment Agency, 1999), but excludes wider environmental monitoring, or monitoring of socio-economic factors, except where there is a clear link to biodiversity.
2. **National:** The scope is limited to national-level reporting, including that which feeds into global agreements to which South Africa is party as a country. A wide range of monitoring is

also done at sub-national and project levels, some of which would have direct relevance to national reporting, but these are only considered here in terms of their relationship to national reporting.

3. **Targets:** Only those agreements, strategies or frameworks that have clear reporting obligations, with targets and or with pre-defined indicators are included in this monitoring framework. It is recognised that there is significant overlap across these reporting requirements, many of which can be addressed using the same biodiversity information.

3 The framework

The National Biodiversity Monitoring Framework (NBMF) focuses on national-level monitoring of the state of biodiversity. It aims to link biodiversity data collection and data users via a set of biodiversity indicators. The NBMF consists of (A) national and international reporting channels that South Africa is obligated to report on; (B) a set of relevant indicators and metrics which provide information necessary to such reporting, including the analyses required to compute these indicators; (C) biodiversity monitoring plans organised in various ways across realms, taxonomic groups and themes; (D) the plans inform biodiversity data collection from numerous sources and collaborators to gather the biodiversity data needed; and (E) biodiversity information systems to organise the data and make it available (Figure 5). The framework includes feedback loops, wherein the monitoring plans rely on information from the users, and the plans in turn ensure that monitoring is relevant and efficient and that it aids in filling key data gaps.

In this section, each of the components of the NBMF is discussed.

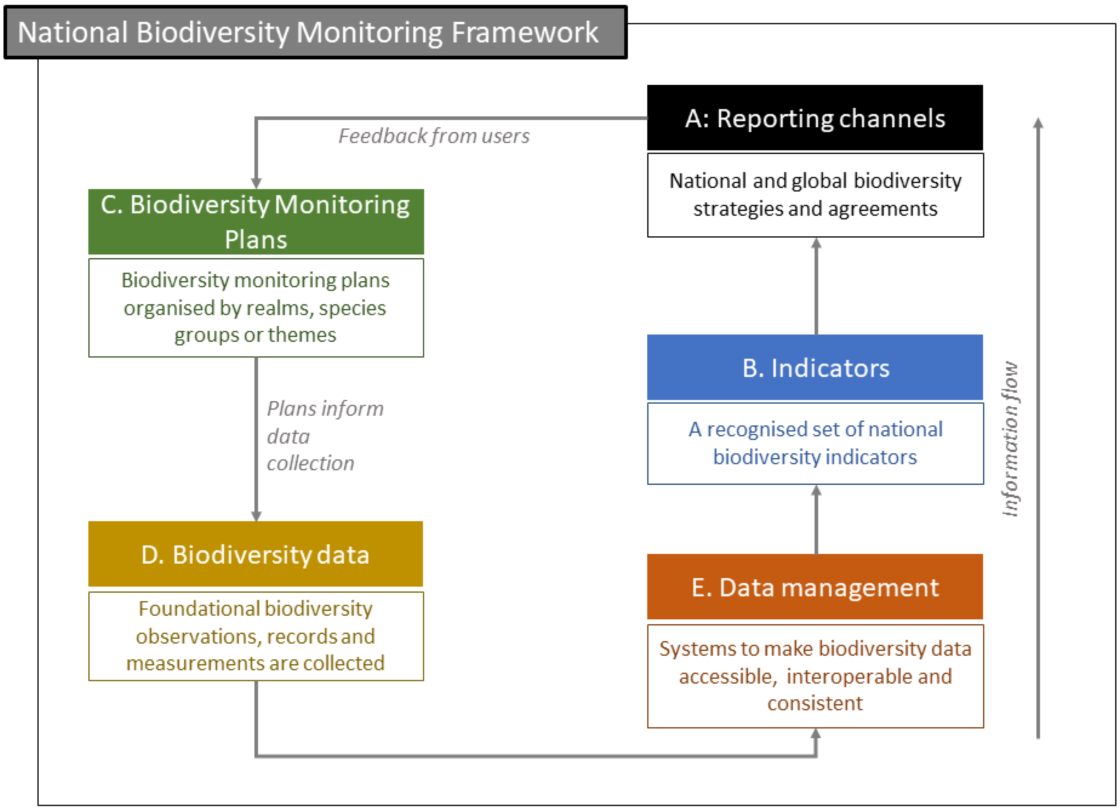


Figure 5. *The National Biodiversity Monitoring Framework (NBMF) focuses on delivering metrics and indicators to key global and national users through high-level reporting channels.*

3.1 Reporting channels

The NBMF is structured around the ultimate use of the monitoring information – the high-level "reporting channels" (Table 1) that can be divided as follows: i) the strategies, agreements and policies that receive the monitoring information as part of mandated reporting against predefined targets; and ii) the national and global biodiversity assessment processes that gather, analyse and present key biodiversity trends.

In keeping with the defined scope of the NBMF, the strategic reporting channels are primarily the biodiversity components of three overarching agreements or plans: i) the Sustainable Development Goals (SDGs), ii) the Convention on Biological Diversity (CBD) and its Global Biodiversity Framework (GBF), and iii) the National Development Plan (NDP) and its Medium-Term Strategic Framework (MTSF). Other mandated reporting channels have more focused goals, including the Ramsar Convention on Wetlands (Ramsar), Africa-European Waterbird Agreement (AEWA), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on Migratory Species (CMS), amongst others (Table 1). Fortunately, efforts are underway to improve the alignment between indicators between these agreements. A case in point is the efforts to align the CBD indicators with existing SDG and Ramsar indicators. The reporting channels also include national-level strategies and frameworks that have set targets and indicators, such as the National Biodiversity Economy Strategy (NBES) and the National Protected Areas Expansion Strategy (NPAES) (Table 1).

Primary among the assessment reporting channels is the National Biodiversity Assessment, which is a summary of the state of South Africa's biodiversity prepared as part of SANBI's mandate under the Biodiversity Act (Skowno et al. 2019). At a global scale are the global, regional and thematic assessments of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Further assessment reporting channels relate to biological invasives, state of the environment reporting or state of the coasts reporting. Natural Capital Accounting uses an internationally agreed accounting system to measure a country's natural assets and resources (SANBI, 2021).

Table 1. *Key high-level biodiversity reporting channels linked to national mandates and conventions. The primary focus of the National Biodiversity Monitoring Framework (NMBF) is the Kunming-Montreal Global Biodiversity Framework of the UN Convention on Biological Diversity, and South Africa's National Biodiversity Assessment.*

Category	Reporting channel	Level	Responsible	Reference
Strategy/ agreement/ policy	Convention on Biological Diversity (UNCBD) and the Kunming – Montreal Global Biodiversity Framework	Global	DFFE (technical support from SANBI)	https://www.cbd.int/gbf/
	Sustainable Development Goals	Global	Stats SA & DFFE (technical support from SANBI)	https://sdgs.un.org/goals
	African Union – First ten-year implementation plan	Regional	Stats SA & DFFE	https://au.int/en/agenda2063/ftyip
	National Biodiversity Strategy and Action Plan (NBSAP) linked to the UNCBD	National	DFFE (technical support from SANBI)	https://www.dffe.gov.za/sites/default/files/docs/publications/SAsnationalbiodiversity_strategyandactionplan2015_2025.pdf
	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	Global	SANBI / DFFE Scientific Authority	https://cites.org/eng/parties/country-profiles/za/national-authorities
	National Integrated Strategy to Combat Wildlife Trafficking (NISCWT)	National	DFFE (technical support from SANParks, department of justice, NGOs, and other parties)	https://www.saps.gov.za/DPCI/downloads/niscwt.pdf
	Convention on Wetlands of International Importance (Ramsar)	Global	DFFE (technical support from SANBI)	https://www.ramsar.org/
	United Nations Framework Convention on Climate Change (UNFCCC)	Global	DFFE	https://unfccc.int/
	United Nations Convention to Combat Desertification (UNCCD)	Global	DFFE (technical support from SANBI & Agricultural research council)	https://www.unccd.int/
	Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA)	Global	DFFE (technical support from SANBI)	https://www.unep-aewa.org/
	Convention on the Conservation of Migratory Species of Wild Animals (CMS)	Global	DFFE	https://www.cms.int/
	Benguela Current Commission	Regional	DFFE	https://www.benguelacc.org/
	Marine Strategy Framework Directive	Regional	DFFE	http://data.europa.eu/eli/dir/2008/56/oj
	National Development Plan – Medium Term Strategic Framework	National	DPME & DFFE (technical support from SANBI)	https://www.dpme.gov.za/keyfocusareas/outcomesSite/MTSF_2019_2024/2019-2024%20MTSF%20Comprehensive%20Document.pdf

	National Biodiversity Framework (NBF)	National	DFFE	https://www.gov.za/sites/default/files/gcis_document/202208/46798gon2423.pdf
	National Protected Areas Expansion Strategy (NPAES)	National	DFFE (technical support from SANParks, provinces and other collaborators)	https://www.gov.za/documents/national-protected-areas-expansion-strategy-south-africa-2016-25-oct-2018-0000
	National Biodiversity Economy Strategy (NBES)	National	DFFE (technical support from multiple government and private partners)	https://www.dffe.gov.za/sites/default/files/reports/nationalbiodiversityeconomystrategy.pdf
	National Biodiversity Research and Evidence Strategy (NBRES)	National	DFFE (technical support from SANBI, CSIR, research institutions, NGOs, and experts)	https://www.dffe.gov.za/sites/default/files/docs/biodiversity_research_strategy.pdf
	National Natural Capital Accounting Strategy	National	Stats SA (technical support from SANBI, DFFE, DMPE, DSI, etc.)	https://www.statssa.gov.za/publications/04-01-00/04-01-002021.pdf
	Strategic Framework and Overarching Implementation Plan for Ecosystem-based Adaptation (EbA) in South Africa	National	DFFE & SANBI (technical support from government organisations, NGOs, and experts)	https://www.sanbi.org/wp-content/uploads/2018/09/Strategic-Framework-and-Overarching-Implementation-Plan-for-EbA-in-SA.pdf
	South Africa's Strategy for Plant Conservation	National	SANBI	https://www.cbd.int/doc/world/za/za-nbsap-oth-en.pdf
	The Biodiversity Finance Plan (BIOFIN)	National	DFFE & SANBI (technical support from national treasury, government conservation entities and private)	https://www.biofin.org/sites/default/files/content/knowledge_products/BIOFIN%20SA_BFP_Min%20Approved.pdf
Assessment/ report	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)	Global	DFFE & CSIR (technical support from SANBI)	https://www.ipbes.net/
	National Biodiversity Assessment (NBA)	National	SANBI (technical support from multiple collaborators)	https://nba.sanbi.org.za/
	South Africa Environment (state of environment reports)	National	DFFE (technical support from SANBI)	https://soer.environment.gov.za/soer/
	Natural Capital Accounts	National	Stats SA & SANBI	https://www.statssa.gov.za/?page_id=5992
	National Status Report on Biological Invasions	National	SANBI	https://iasreport.sanbi.org.za
	South African State of Coast reports	National	DFFE & Provinces	
	Western Indian Ocean State of the Coast report	Regional	DFFE	

3.2 Indicators

At the core of the NBMF are the indicators that are required for global and national monitoring and reporting). A key output of the NBMF is a regularly updated and accessible suite of biodiversity indicators that are sensitive to change, clearly interpretable, and aligned with South Africa's national and international monitoring and reporting commitments.

There is a huge range of possible indicators, metrics and indices to detect trends in the state of biodiversity, pressures on biodiversity, drivers of change, and societal responses that have been proposed and adopted by various processes such as the Biodiversity Indicators Partnership (BIP).[1] At a national level, the DFFE maintains an Environmental Indicators Database with themes across atmosphere and climate; biodiversity and ecosystem health; environmental governance; and environmental sustainability[2].

Many of the indicators across the reporting channels are related and draw on similar data. For this reason, it is useful to link the indicators to the underlying Essential Biodiversity Variables (see Box 2). The indicators can be loosely organised into themes relating to their focus on species distribution and abundance, ecosystem extent; risk assessments for species and ecosystems; protection and planning; genetic diversity; biodiversity benefits; climate change; threats; and regulatory indicators (**Table 1**). Grouping the indicators helps to see how they are related and how similar information can be used for reporting across different reporting channels.

[1] https://www.bipindicators.net
[2] https://enviroindicator.environment.gov.za/

Table 2. Indicators linked to the reporting channels, grouped by common themes.

Indicator Group*	Examples of headline indicators (reporting channel in parentheses)	Variables
Ecosystem extent and integrity	Ecosystem Area Index (CBD, NBA); Forest extent (SDG 15.1.1); Ecosystem Integrity Index (CBD; NBA); Land degradation (SDG 15.3.1); Freshwater Ecosystem Extent (SDG 6.6.1, CBD, NBA), Species Habitat Index (CBD); Mountain Green Cover Index (SDG 15.4.2)	Ecosystem Structure and Function
Ecosystem status / risk	Red List of Ecosystems (CBD, NBA); Red List Index for Ecosystems (CBD, NBA)	Ecosystem Structure and Function; Distribution and intensity of threats and drivers
Species distribution and abundance	Living Planet Index (CBD), Live coral cover (CBD)	Species Populations
Species status / risk	Red List of Species (NBA, CBD); Red List Index for Species (SDG 15.5.1; CBD, NBA)	Species Populations; Distribution and intensity of threats and drivers
Protection and planning for ecosystems and species	Ecosystem Protection Level (NBA); Ecosystem Protection Index (NBA, CBD); Terrestrial Biodiversity Protection Index (NDP); Marine Biodiversity Protection Index (NDP); Protection of Terrestrial, Freshwater and Mountain Ecosystems (via KBAs) (SDG 15.2.1, SDG 14.5.1, SDG 15.4.1, CBD); Species Protection Level (NBA); Species Protection Index (NDP, NBA, SDG 14.1.1 and 15.1.2); Spatial Biodiversity Plan coverage (CBD); Protected Area Effectiveness (CBD); Species Recovery Plans (CBD)	Protected Areas and OECM coverage; Management Effectiveness; Ecosystem and Species Distribution.
Genetic diversity	Effective population size > 500 (NBA, CBD); Number of populations within species maintained (NBA, CBD); Number of species or populations being monitored used DNA methods (NBA, CBD); Phylogenetic diversity [PD], Phylogenetic endemism [PE], Evolutionarily distinct [ED], Evolutionarily distinct and globally endangered [EDGE] (NBA)	Genetic Composition
Combined biodiversity indices	Biodiversity Intactness Index (CBD, SDG 15.1.2); Multi-Dimensional Biodiversity Index (under development); Ocean Health Index (CBD)	Ecosystem Structure and Function, Species Populations, Community Composition, Distribution and intensity of threats and drivers
Benefits from nature	Proportion of human population benefiting from Ecosystem Services (CBD, SDG 15.6.1); Value of Ecosystem Services (CBD); Inland and coastal water quality (CBD); Trends in illegal trade of indigenous species (CBD); Proportion of wild fish stocks sustainably utilised (CBD); Integrity of Ecological Infrastructure for coastal protection and flood protection; Benefit sharing agreements in place (CBD); Extent of Green and Blue spaces for people, primarily urban (CBD). Coastal protection (IPBES/CBD); Carbon sequestration (IPBES)/Trends in carbon stocks (CBD)	Uncertain variables and data sources
Other threats and drivers	Rate of spread of invasives (CBD, SDG 15.8.1); Impacts from invasives (SDG 15.8.1); Water Quality (SDG 6.3.2); Plastics density (SDG 14.1.1); Pesticide usage; Solid waste (SDG 11.6.1); Air Quality and emissions (SDG 11.6.2)	Species Populations, Ecosystem Structure and Function. Distribution and intensity of invasives, pollution.
Climate	CO_2 emissions per capita (SDG 9.4.1); Number of deaths and missing persons affected by climate disaster per 100,000 people (SDG 13.1.2)	Emissions and human populations
Regulatory and economic	Biotrade regulations (CBD); Natural Capital Accounting Adoption (CBD); Sustainable consumption regulations (CBD); Change in Water Use Efficiency (by people) over time (CBD); Biosafety Measures in place (CBD); Track harmful incentives (CBD); Expenditure for biodiversity (CBD); Biodiversity Observation System development (CBD); Indigenous peoples rights and tenure (CBD).	Uncertain variables and data sources

3.2.1 Enabling factor: Dashboards and accessibility

An increasingly important aspect of biodiversity monitoring is the development of interactive platforms to make biodiversity information and indicators available online (Han et al., 2014). A biodiversity dashboard is an interactive online tool that visualises trends in biodiversity indicators to track conservation progress. The key biodiversity indicators often used to build dashboards are linked to international reporting channels. Dashboards can simplify monitoring to support national monitoring and reporting, and improve accessibility to biodiversity indicators (Han et al., 2014; Lacroix et al., 2019). Biodiversity dashboards can have several uses, including i) informing policy, ii) measuring conservation progress, iii) guiding conservation decision-making, and v) helping to visualise key biodiversity indicators.

There are an increasing number of global dashboards, such as the Biodiversity Indicators Partnership[3], UN Biodiversity Lab[4], OECD[5] and many others. At a national level, the DFFE is moving

[3] www.bip.net
[4] https://www.unbiodiversitylab.org
[5] https://data.oecd.org

the State of Environment Report to a web-based platform where indicators, workflows and selected underlying data can be accessed and shared. The DFFE is also investigating the development of a Clearing House for all biodiversity-related data that could aid in national and international reporting. The National Biodiversity Assessment for South Africa is progressing towards an online platform (Poole et al., 2023). This process is coupled with SANBI's efforts to build an integrated and connected Biodiversity Advisor platform, uniting the multitude of independently developed legacy information systems that currently exist.

While sophisticated systems are being planned and implemented, an important consideration is whether to lead with messages - emanating from careful consideration of trends for selected indicators - or with the indicators, trends and maps themselves. Further, developing a web-based platform or dashboard requires a collaborative effort between data providers and technical, scientific and design teams to ensure its functionality and continuity.

3.3 Biodiversity monitoring plans

Biodiversity monitoring plans are a crucial component (**Figure 5**C) that help to structure the NBMF so that observers are guided to collect biodiversity data that is directly relevant to the reporting channels. They are the main feedback mechanism through which the end users of biodiversity indicators can be linked with the data sources. The monitoring plans will help to align future research, management activities and long-term monitoring with national policies and reporting obligations to help streamline data collection, processing, management and communication.

Biodiversity monitoring plans can focus on realms, taxonomic groups or themes, though they are likely to cover a combination of these. A realm or thematic focus will help to define the geographic scope and main areas of work for the monitoring plan. For example, two plans under development by SANBI and partners have a focus on terrestrial plants and freshwater invertebrates (realm and taxon). In contrast, the thematic plan for monitoring biological invasions in South Africa (Wilson et al., 2018) attempts to encompass all relevant taxon groups and realms but has a specific thematic focus.

The NBMF provides the overarching framework for all the realm, taxonomic or thematic biodiversity monitoring plans to be developed. In line with the scope of the NMBF, the monitoring plans should focus on the national and global reporting channels and biodiversity indicators identified by the NBMF. This will ensure that all the monitoring plans developed are aligned and share similar goals, objectives, principles and scope (see Section 2: Purpose of the framework).

The development of biodiversity monitoring plans should follow global best practice (see Section 2.4 Guiding principles). They can cover any future period, but should be at least for five years.

Biodiversity monitoring plans should:

- **Make clear links to mandated reporting channels**: Identify the key reporting obligations and current reporting processes within the respective realms or themes. This includes identifying all the relevant national and international policies, frameworks and agreements that require data to inform the necessary indicators.
- **Identify existing monitoring initiatives and data sources:** Conduct a detailed review on the current monitoring initiatives and data providers relevant to the realm or theme. This process will help to identify the types of biodiversity data already available, to avoid replicating efforts. It will also identify data gaps in spatial and temporal coverage that can inform data collection and research priorities.
- **Engage stakeholders:** Identify mandated institutions responsible for long-term monitoring or other key role-players that conduct biodiversity monitoring linked to short- or long-term data collection. A thorough stakeholder mapping exercise should be conducted. Then, efforts should be made to increase co-ordination among and within institutions.

- **Establish data collection protocols:** For each indicator, standard operating procedures and data collection protocols should be developed. This will improve standardisation and data interoperability across institutions and organisations. Some key elements that should be considered include equipment, people (workforce), training (skills), sampling design, statistical power, data cleaning and management, quality control, cost-effectiveness and repeatability (also see MacFadyen et al., 2022).

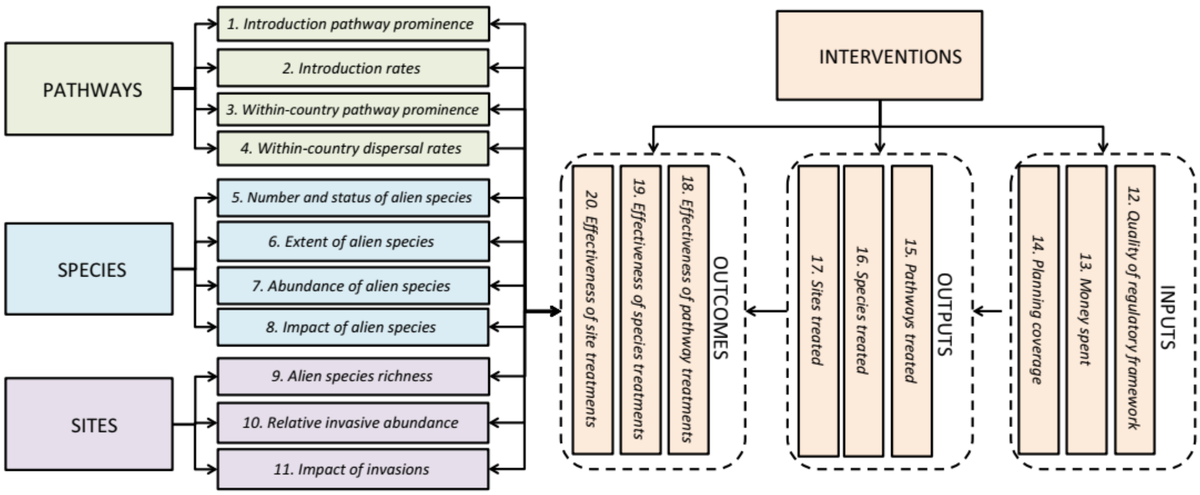
Once the monitoring plans have been developed, they need to be implemented by the identified stakeholders. Implementation should follow a flexible and adaptive approach, with iterative improvement of the monitoring plan. Ideally, monitoring plans should be revised every five to seven years, with the recommendation that they align with the NBA which will identify research priorities for the next iteration, and other policy developments. Progress should be measured against specific SMART (Specific, Measurable, Achievable, Relevant, and Time-Bound) targets and goals.

Box 3: Case study of a biodiversity monitoring plan

Invasive Alien species (IAS) have negative impacts on biodiversity and human livelihoods (McNeely, 2001; Shackleton et al., 2019; Pyšek et al., 2020). There are many challenges to capturing data on the movement and sources of IAS, but it is essential to develop standardised monitoring indicators to robustly assess the status of IAS and report on this to global agreements (McGeoch et al., 2010; Wilson et al., 2018).

A study by Wilson et al. (2018) examined the feasibility of developing indicators for monitoring biological invasions in South Africa and beyond. Given the availability of data in the country, 20 indicators were proposed for use in reporting the status of biological invasions at the national level. The indicators were related to introduction pathways, relevant species, the richness and abundance of IAS at specific sites, and indicators of the management interventions undertaken to deal with IAS. Recognising that 20 indicators is too many for general reporting at national level, four high-level indicators were also developed.

All the indicators were estimated using information collected as part of the National Status Report on Biological Invasions (SANBI and CIB, 2020), scientific evidence and direct inputs from expert. The results indicated that data is available in South Africa, although it is poorly collated. Incorporating the high-level indicators into the national status report will help evaluate trends and identify gaps in the evidence required for policy implementation and inform decision-making. The indicators are well aligned with Kunming-Montreal Global Biodiversity Framework, ensuring that national and global reporting requirements can be met with the same monitoring data.



3.4 Foundational biodiversity data

There is no lack of biodiversity data. New technologies are rapidly used to generate ecological and environmental data (Díaz et al., 2019; MacFadyen et al., 2022). There is an increase in the volume of datasets generated through citizen science platforms, camera traps, aerial remote sensing, acoustic technology and satellites (Heberling et al., 2021). Although myriads of datasets are available, they are scattered across different sources. What is needed is a structured framework to ensure that appropriate data feeds into national monitoring and reporting (MacFadyen et al., 2022).

The biodiversity monitoring plans will help to organise existing and additional biodiversity data collection, taking into account:

- Observation targets or variables, for example species, ecosystems, genes, or pressures.
- Variables measured, for example distributions, abundance, structure, function, composition, diversity.
- Source of data, for example university, government institution, NGO, global sources.
- Data types, for example incidental records, inventories, species surveys, contextual, pressures and threats.
- Methods of collection or observation, for example scientific sampling, citizen science (see Box 4), earth observation (remote sensing), or technology.
- Geographic scope, for example from site to region to globe.
- Temporal regime, for example ad hoc, daily, multi-year.

Box 4: Citizen science initiatives

Citizen science is a collective voluntary participation and collaborative network between members of the public and scientists who collect data for different projects to reach certain objectives. Citizen science is a cost-effective alternative to traditional monitoring of biodiversity (Vianna et al., 2014). Over the past years, volunteer observers have contributed extensively to data covering a range of taxa such as plants, butterflies, birds, coral reefs, mammals, alien invasive species, and many other taxa (Vianna et al., 2014; Marcenò et al., 2021; Lee et al., 2022). Observers tend to participate without fixed protocol or structure and with little requirement of observer's knowledge or long-term observers' (Pocock et al., 2017; Johnston et al., 2022). As such, citizen science can suffer from challenges of spatial bias, observer differences, reporting preferences, false positive error, validation, detectability, multi-species models; and poor data integration (Johnston et al., 2022). In South Africa, there are several structured citizen science platforms through which biodiversity is monitored (Potts et al., 2021; Lee et al., 2022), for example, iNaturalist, atlases such as the South African Bird Atlas Project 2 (SABAP2), and structured monitoring such as the Co-ordinated Waterbird Counts (CWAC) (Fernandez-Gimenez et al., 2008; Johnston et al., 2022). Understanding the structure of citizen science data in South Africa may help to lay the foundation for a national biodiversity observation and monitoring system, to support high-level reporting at global and national level.

3.4.1 Enabling factor: Networks for collaboration

To facilitate the successful implementation of the NBMF, the biodiversity monitoring plans must be connected to a collaborative and co-ordinated network of data collectors and relevant data management systems. The data collection community is very large and includes expert groups comprised of academics, conservation agency officials, and citizen scientists – organised in many ways, such as along taxonomic lines (African Bird Atlas Project), or on a specific component of biodiversity such as, genetic diversity. To make sense of the wide range of existing biodiversity monitoring projects (including citizen science platforms and other data collection efforts) requires that stakeholders work collaboratively to coordinate data collection and avoid duplication. Collaboration is necessary to ensure that the multitude of data meet the wide range of users in a coherent manner. For this reason, the NBMF also endorses the continuation or establishment of relevant discussion platforms or communities of practice centred around biodiversity data and information management.

SANBI has previously convened the Biodiversity Information Management Forum (BIMF), a national platform dedicated to discussing biodiversity information management issues. It brought together key role-players in biodiversity information management to ensure initiatives are aligned, co-ordinated and relevant in a rapidly changing world. At a global scale, GEO BON is also working to create collaborative structures to centrally bring biodiversity observation systems together in the service of improving monitoring, reporting and decision-making. Globally, GEO BON is gathering momentum as a coordinated effort to further biodiversity monitoring. South Africa is already an active GEO member state, with SAEON acting as one of the observation networks established as part of GEO BON. It is possible to establish a similar South Africa Biodiversity Observation Network (SA BON), or thematic or realm-based platforms that could align with the biodiversity monitoring plans. In the marine realm, there are numerous existing co-ordinated networks for observing the ocean and marine environments such as the Global Ocean Observing System (GOOS BioEco and OceanOPS), Ocean Biogeographic Information System (OBIS), Marine Biodiversity Observation Network of GEO BON (MBON) and Freshwater BON.

3.5 Biodiversity data and information management

A vitally important component of the NBMF is effective data management to ensure that the wide array of data underpinning indicators is collated, curated and freely available and accessible. The need for robust data management stems from the challenge of having multiple sources, formats and themes of data at differing scales and across a diverse environmental (spanning all realms) landscape (Wieczorek et al., 2012). Effective data management will improve access to existing biodiversity data and increase integration of these data between disciplines while maintaining the data holders' ownership, control of the data and ensuring that standardisation is maintained for consistency, interoperability and comparability (see Wieczorek et al., 2012; Robertson et al., 2014; MacFadyen et al., 2022). It is recommended that data management should be standardised, as best as possible, across realms and themes or at least share common principles at a national level (Wieczorek et al., 2012). However, it is a considerable undertaking to identify, collate, integrate, manage and disseminate vast and diverse amounts of biodiversity information, especially for national reporting objectives.

Generally, most organisations, data platforms or projects will have their own internal data management policies and frameworks. However, there are general principles for data and information management that should be considered:

- Collect data once and use them for many purposes.
- Data should be interoperable, accessible and free of restrictions on use.
- Data should use commonly agreed formats and up-to-date tools for data exchange.
- Data should be validated for quality control.
- Information management should respect data ownership and intellectual property rights.
- Data should be accompanied by relevant metadata.

A study by MacFadyen et al. (2022) proposed the development of a South African bioinformatics hub that would establish a co-operative network for biodiversity observations and monitoring datasets from the ground-up that align with global and national reporting channels.

The Biodiversity Information and Planning Directorate within SANBI was established to effectively organise South Africa's biodiversity information, including its datasets, and make it universally available and useful. It developed Biodiversity Advisor[6] as a system to provide integrated biodiversity

[6] https://biodiversityadvisor.sanbi.org/

information to various users, including the general public, environmental practitioners, academics, policy-makers, and non-governmental organisations (Daly and Ranwashe, 2023). Users can access up-to-date geospatial data, plant and animal species distribution datasets, ecosystem-level data, literature, images and metadata. The platform was developed to i) deliver a centralised location with open access to information to enable research, assessment and monitoring; ii) support policy development; and iii) foster collaboration and advance governance. The datasets used in this platform are aggregated from multiple, diverse data partners across South Africa, such as CapeNature, Botanical Society of South Africa, South African Universities, Government departments, South African museums, and the National Herbarium of South Africa (Daly and Ranwashe, 2023).

4 Feasibility

4.1 Feasibility

The feasibility of implementing a NBMF in South Africa depends on several factors, including technical, financial, institutional and logistical considerations. Some of these have been discussed in the document (points 1 to 5) while others require further attention (points 6 to13):

1. **Data collection and management:** Consider how data will be gathered, managed, and stored. Developing uniform data-gathering techniques and ensuring data quality is essential for producing trustworthy and comparable outcomes.
2. **Scale and scope:** Define the geographic scale and scope of the monitoring framework. Will it encompass the entire country or focus on specific biomes or protected areas? Clarifying the scope aids in the efficient allocation of resources.
3. **Integration with policies:** Align the monitoring framework with existing conservation and environmental policies to ensure the collected data directly informs decision-making processes.
4. **Data accessibility and sharing:** Plan how the collected data will be accessible to researchers, policymakers, and the public. Open data policies can enhance transparency and encourage collaboration.
5. **Stakeholder engagement:** Engage stakeholders, such as local communities, indigenous groups, conservation organisations, and industry sectors, to ensure their participation and support for monitoring initiatives. This can aid in resolving possible disagreements and increasing the framework's validity.
6. **Technical capacity:** Assess whether the necessary technical expertise, equipment, and methodologies are available for biodiversity monitoring. This includes accurately identifying species, analysing ecological data, and employing remote sensing technologies.
7. **Institutional support:** Determine whether relevant governmental agencies, research institutions, and non-governmental organisations are willing and able to collaborate in establishing and implementing the monitoring framework.
8. **Technology and innovation:** Explore how technological advancements, such as satellite imagery, remote sensing, and data analytics, can enhance the efficiency and accuracy of data collection and analysis.
9. **Adaptive management:** Build flexibility into the framework to allow for adjustments based on lessons learned and changing priorities.
10. **Long-term commitment:** Biodiversity monitoring requires a long-term commitment to observe changes and trends over time. Ensure that there is ongoing support and dedication to sustaining the monitoring efforts.
11. **Capacity building:** Assess the need for capacity building and training programs to equip personnel with the necessary data collection, analysis, and interpretation skills.
12. **Public awareness:** Consider strategies to raise public awareness about the importance of biodiversity monitoring and how it contributes to the country's sustainable development goals
13. **Financial resources:** Analyse the financial options available to support a monitoring framework's development and ongoing operation. Biodiversity monitoring can be resource-

intensive, requiring funds for field surveys, data analysis, personnel salaries, equipment, and infrastructure.

While there are obstacles to overcome when implementing the NBMF, there are also many advantages for conservation, decision-making, and sustainable development.

5 Conclusions

Preserving South Africa's distinctive and diversified ecosystems depends on establishing a strong framework for biodiversity monitoring. The framework will help to understand the processes of biodiversity loss and ecosystem degradation by working with stakeholders, using standardised indicators, integrating technology, adopting a long-term perspective, ensuring data accessibility, building capacity, and embracing adaptive management principles.

The rich biodiversity in South Africa is a global asset as much as a national treasure. Ultimately, a well-designed biodiversity monitoring framework will ensure that these priceless ecosystems and species are preserved for future generations by supporting sustainable development, guiding conservation activities, and contributing to evidence-based decision-making.

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