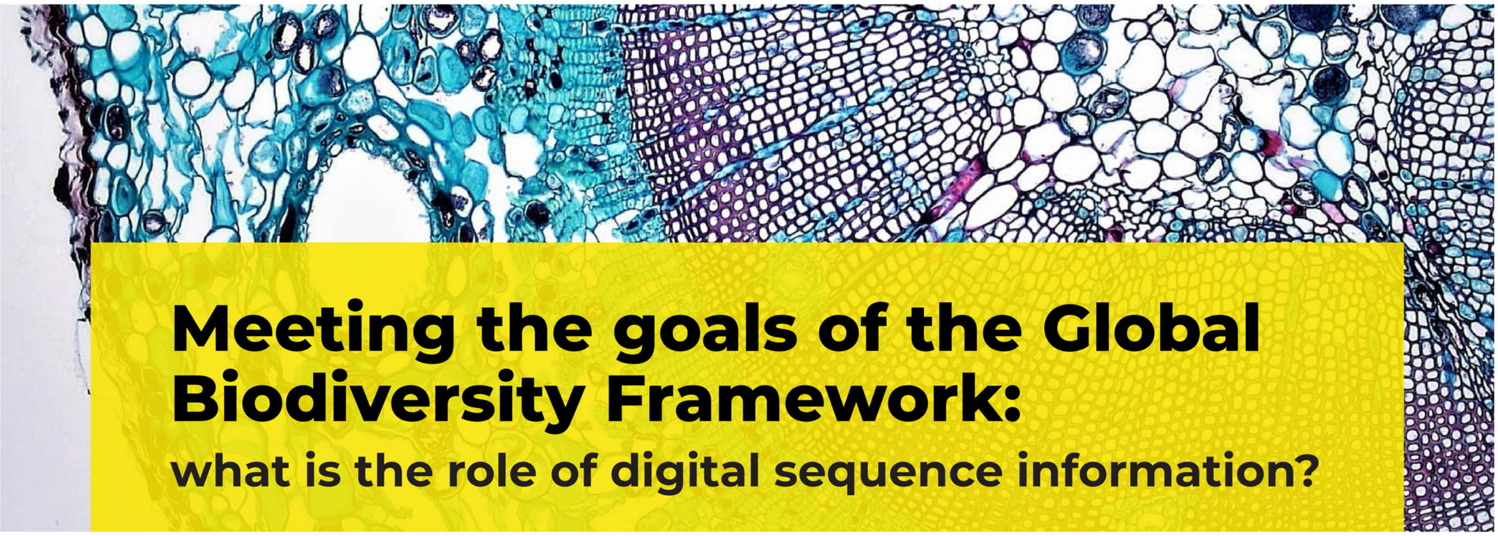
DSI SCIENTIFIC NETWORK
SANBI Biodiversity for Life South African National Biodiversity Institute



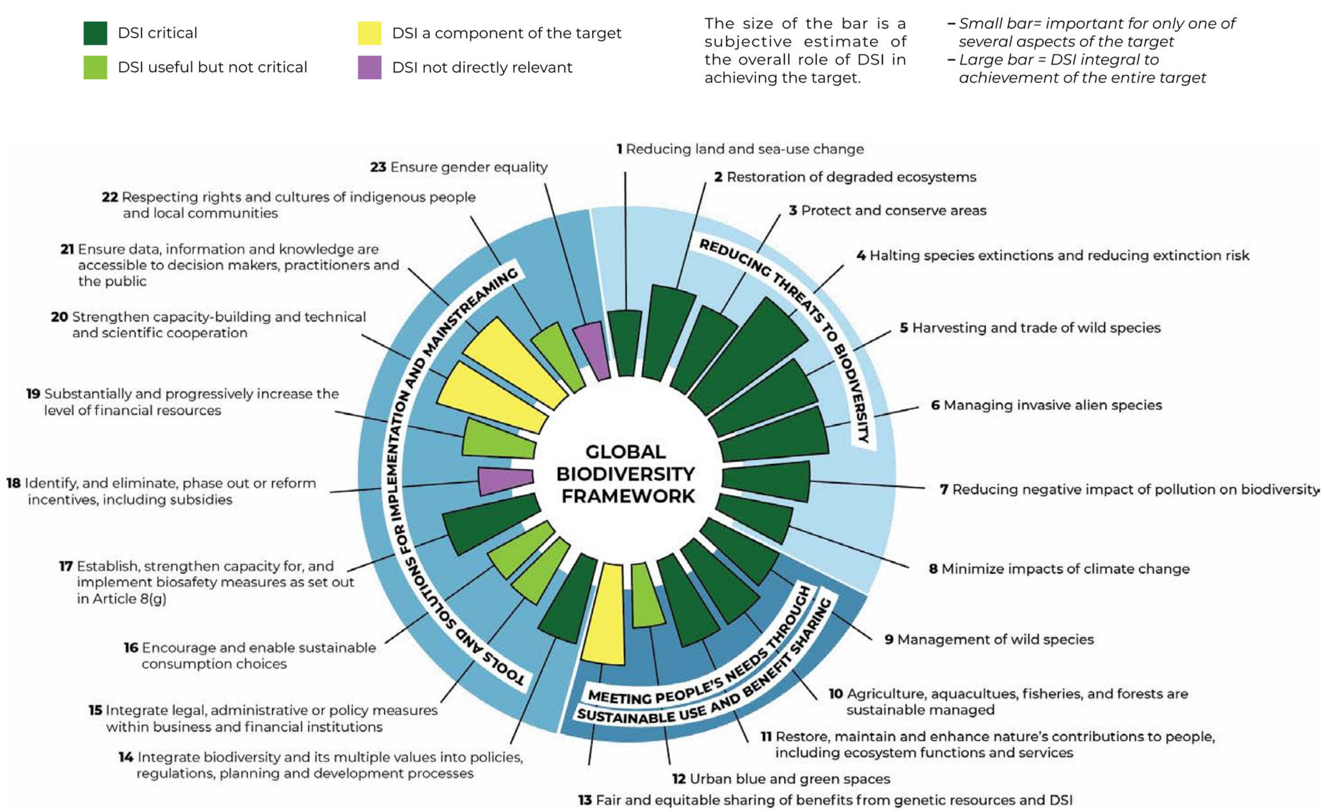
Meeting the goals of the Global Biodiversity Framework:
what is the role of digital sequence information?

Summary

Implementation of the Global Biodiversity Framework and achievement of the targets will not be fully effective and in some cases not possible, without the open use of DNA sequence data and access to large sequence repositories.

Digital sequence information (DSI), specifically DNA sequence data, is relevant to all four of the Kunming-Montreal Global Biodiversity Framework (GBF) goals. While DSI is only explicitly mentioned in one of the 23 GBF targets (Target 13), it has a role in the achievement of 21 targets. For 13 of the targets, DSI is essential for effective implementation, for 5 it is important or could improve implementation, and for 3 it is an integral component rather than having a role in implementation. For most of the targets, DSI has more than one application.

KUNMING-MONTREAL GLOBAL BIODIVERSITY FRAMEWORK
Themes & Targets



The significance of DSI to the GBF is due to its role in:

- Identifying the different components of biodiversity (genes and genetic diversity species and biological community composition of ecosystems)
- Making spatial planning decisions
- Monitoring impacts of threats or of management interventions
- Restoring biodiversity
- Development of products including for improving agricultural practices or other nature-based solutions or for generating monetary benefits
- Verifying and certifying products
- Providing evidence for legal or illegal trade

The implementation of the GBF will be most successful with a more global, integrated DSI dataset. The more data is accessible, the more useful DSI is for research. To leverage the potential of DSI to fulfil the GBF, in most cases, a single DNA sequence has limited value because it has to be compared against other sequences to determine and understand differences or to find a match with a known reference sequence. The larger the DSI dataset that can be used for comparison, the more robust the interpretation in an investigation or application is.

Section 1: What is Digital Sequence Information (DSI), what does it tell us about biodiversity and how can it be applied in science and conservation?

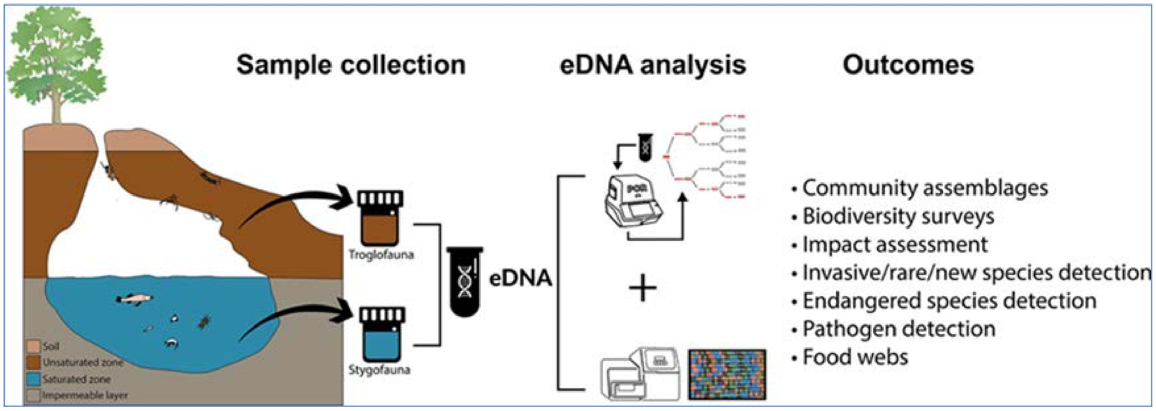
What is DSI and how do you make sense of it?

DNA is the hereditary material that carries genetic instructions for the development, functioning, growth and reproduction of all known organisms and many viruses. DNA stores information in nucleotides. The sequence (or order) of the four types of nucleotides (represented by the letters A,C,T,G) is unique from one organism to the next. This enables sequence information to be used to identify species, understand how much genetic variation exists within a species, or zoom in on unique genes or gene combinations that encode traits. Digital sequence information may include other data types derived from or linked to genetic resources, including, for example, protein and metabolite sequences (but the main focus of this report is DNA sequence information).

Digital Sequence Information (DSI) in the context of biodiversity can come in various forms:

Small DNA Sequences	**Genetic markers** are genes or segments of DNA with a known physical location on a chromosome that can be used to identify specific traits, or to understand the genetic distance between individuals or populations.
	DNA barcodes refer to sequences of a short section of DNA from a specific gene or genes which are compared with reference sequences of identified species.
	Metabarcode data are generated from sequencing multiple barcode genes for all the DNA in a sample which allows for detection and identification of the organisms or traces of organisms present in the sample. This technology is often much faster and cheaper than metagenomic (full-length) sequencing.
Large DNA Sequences	**Whole genome sequences** come from sequencing all the genetic material (the DNA of all the chromosomes) of an organism.
	Metagenomic sequence data are generated from sequencing the genomes of multiple organisms that are mixed together in an environmental sample. These are often used to profile a community of organisms, including bacteria or other microbes, and can shed light on not only the composition (who is there?), but also the functional potential of the organisms (what are they doing?) in the environmental sample.

For all of the above types of sequences, environmental DNA or eDNA can be used. eDNA is simply DNA collected directly from an environmental sample such as soil or water. The DNA may come from whole organisms present in the sample and / or from diverse sources like skin, mucous, saliva, sperm, secretions, eggs, faeces, urine, blood, roots, leaves, fruit, or pollen. By sequencing DNA directly from a habitat, scientists can rapidly identify the plant, animal and microbial species that live there without needing to see or sample them individually. This is especially important in aquatic habitats where it is difficult to survey biodiversity.



Source: Saccò, M, Guzik, MT, van der Heyde, M, Nevill, P, Cooper, SJ, Austin, AD, Coates, PJ, Allentoft, ME & White, NE. 2022. eDNA in subterranean ecosystems: Applications, technical aspects, and future prospects. Science of the Total Environment 820: 153223.

Why do we use DSI?

The use of DSI can provide answers to key questions which are foundational to biodiversity conservation.

DSI provides the answer to the basic question of “what is it? what have we got?” at the level of genes, genetic diversity, species and community composition. DSI can, in some cases, enable the determination of food webs and other interactions between species, which answers the question “what does it do?”. Environmental DNA is increasingly being used to collect geographic locality data for species which allows the question of “where does it occur?” to be answered. The answers to these questions are foundational to conserving and sustainably using biodiversity at the level of genes, species and ecosystems.

Identification of unique genes or combinations of genes linked to traits/ characteristics that can be adaptive, useful or be negative	**Identification of genetic diversity** within a species or population	**Species identification** Separating species that look the same or that are otherwise difficult to identify	**Linking biological materials to the species that they were taken from** (e.g. tree bark, blood, bone, meat)	**Identification of plant and animal community assemblages, as well as that of microbes (bacteria, fungi, viruses)**

DSI that identifies unique genes, genetic diversity, species and biological communities has several applications for conservation and sustainable use of biodiversity. In most cases DSI on its own has limited value and needs to be linked to other types of data for these applications.

For example, spatial planning uses geographic or locality data for species or populations or communities (where is it?) while for monitoring biodiversity, temporal data (when was it there?) as well as comparative historical data are needed to measure change. For the identification of unique genes that are important in breeding programmes, data on the physical or physiological characteristics of individuals are needed. For understanding the ecological roles played by different microbes making up a community, additional metabolic data are used.

Category	Application of DSI in the context of conservation and sustainable use of biodiversity
Assessment of biodiversity What have we got? What is it? What does it do?	• Identification of unique genes / gene combinations, mutations, hybridisation • Identification of threatened species, alien invasive species, pathogens, disease vectors, parasites • Biological community composition • Measurement of biodiversity for credits • Interactions between species in a community (e.g. pollination, food webs) • Ecosystem functional role (e.g. role of microbes in biogeochemical cycles, climate regulation, degradation of pollutants)
Spatial planning Where are the important places?	• Where is unique or high genetic diversity that needs to be protected? • Where are corridors needed for gene flow / connectivity of fragmented populations? • Where are populations, species and biological communities that are at risk or degraded? • What are the pathways of alien invasive species spread?
Monitoring impacts of threats or of interventions to mitigate threats?	• Impacts of threats on genetic diversity • Genetic diversity of threatened or harvested species, geneflow between fragmented populations or habitats • Tracking the spread of alien invasive species or of disease • Community dynamics • Ecosystem functioning
Restoring biodiversity What needs to be put back to make it right?	• Selection of individuals or populations required to restore genetic diversity • Selection of species or combination of species required to restore ecosystems • Selection of microbial and algal communities for breaking down pollutants in soils and water, wastewater treatment, decomposition of organic waste
Product development	• Improvement of crops and livestock • Improved production systems for agriculture (soil fertility, diagnosis and treatment of pathogens) • New products for commercial purposes, human health • Nature-based solutions for environmental threats (biocontrol agents, bioremediation, bioregeneration)
Supporting legal and preventing illegal trade	• Identification of confiscated genetic resources (forensic investigations) • Parentage testing, origin determination (issuing of passports mandatory in wildlife trade) • Determining animal or plant species used in foods and their geographic origin (product labelling)

Section 2: DSI and the Global Biodiversity Framework

The vision of the Kunming-Montreal Global Biodiversity Framework (GBF) is a world living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

Digital Sequence Information is becoming increasingly essential for research that generates knowledge required for conservation, restoration, sustainable use, maintaining ecosystem services and a healthy planet, and for evidence-based decision-making, as well as for implementation of measures to achieve the GBF vision, goals and targets.

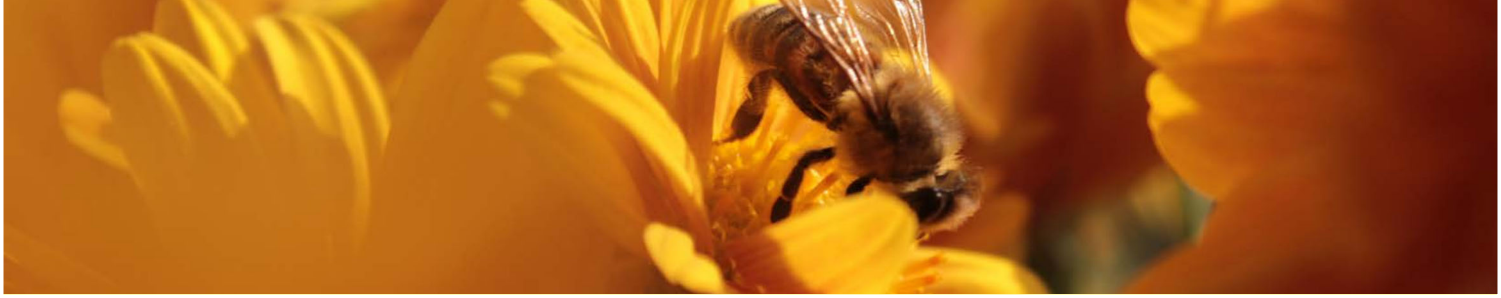
Four Global Biodiversity Framework Goals and the role of Digital Sequence Information

GOAL A The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050; Human induced extinction of known threatened species is halted, and, by 2050, the extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels; The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential.	**Ecosystems** DSI is used for assessing, monitoring and restoring: – Integrity: composition of communities making up ecosystems – Connectivity: determining whether plants and animals can move across fragmented habitats to avoid loss of genetic diversity – Resilience: genetic diversity allows adaptation to future change **Species** DSI is used for: – Threatened species identification and detection: DNA barcoding and genome sequencing is increasingly being used to identify species and detect presence in environments where they are difficult to see – Healthy levels: identification of pathogens, parasites and disease vectors that threaten species – Resilient levels: measuring, monitoring genetic diversity is critical to ensure resilience to disease, climate change **Genetic diversity** DSI is fundamental to: – Understanding, assessing and maintaining genetic diversity within and between populations

GOAL B Biodiversity is sustainably used and managed and nature's contributions to people, including ecosystem functions and services, are valued, maintained and enhanced, with those currently in decline being restored, supporting the achievement of sustainable development for the benefit of present and future generations by 2050.	DSI plays a significant role in: – Sustainable use and management: identification of species, populations and genes with beneficial properties; establishing harvesting plans and quotas that maintain genetic diversity – Restoration of ecosystem functions and services: assessment of ecosystem functionality; selecting populations, species and communities required for restoration (adaptation to local conditions, resilience, functional role in the case of microbial communities)

GOAL C	
The monetary and non-monetary benefits from the utilization of genetic resources and digital sequence information on genetic resources, and of traditional knowledge associated with genetic resources, as applicable, are shared fairly and equitably, including, as appropriate with indigenous peoples and local communities, and substantially increased by 2050, while ensuring traditional knowledge associated with genetic resources is appropriately protected, thereby contributing to the conservation and sustainable use of biodiversity, in accordance with internationally agreed access and benefit-sharing instruments.	DSI plays a role in or is a component of: – Fair and equitable sharing of benefits: identification of harvested species / populations in support of legal trade – Substantially increasing benefits from the utilization of genetic resources and digital sequence information by 2050 biotechnology to develop new products, improve existing products

GOAL D	
Adequate means of implementation, including financial resources, capacity-building, technical and scientific cooperation, and access to and transfer of technology to fully implement the Kunming- Montreal Global Biodiversity Framework are secured and equitably accessible to all Parties, especially developing country Parties, in particular the least developed countries and small island developing States, as well as countries with economies in transition, progressively closing the biodiversity finance gap of $700 billion per year, and aligning financial flows with the Kunming-Montreal Global Biodiversity Framework and the 2050 Vision for biodiversity.	Considering the significant role of DSI in achieving Goals A, B and C: – Capacity building for generating and using DSI is essential for equitable means of implementation – Technical and scientific co-operation and technology transfer are essential for incremental knowledge development (building on existing sequence data and knowledge), avoiding duplication and waste of resources in DSI generation, and for use of extensive, global repositories of DSI – Financial resources: Commercialisation of products developed through use of DSI has increasing potential as a source of funding for implementation of the GBF



DSI and implementation of the 23 GBF targets

While DSI is only explicitly mentioned in one of the 23 GBF targets (Target 13), it has a role in the achievement of 21 targets, and for 13 of these it is essential for effective implementation, for five it is important or could improve implementation, and for three it is an integral component rather than having a role in implementation. For most of the targets, DSI has more than one application.

For more information on the role of DSI in each Target, see Annex 1 and 2.

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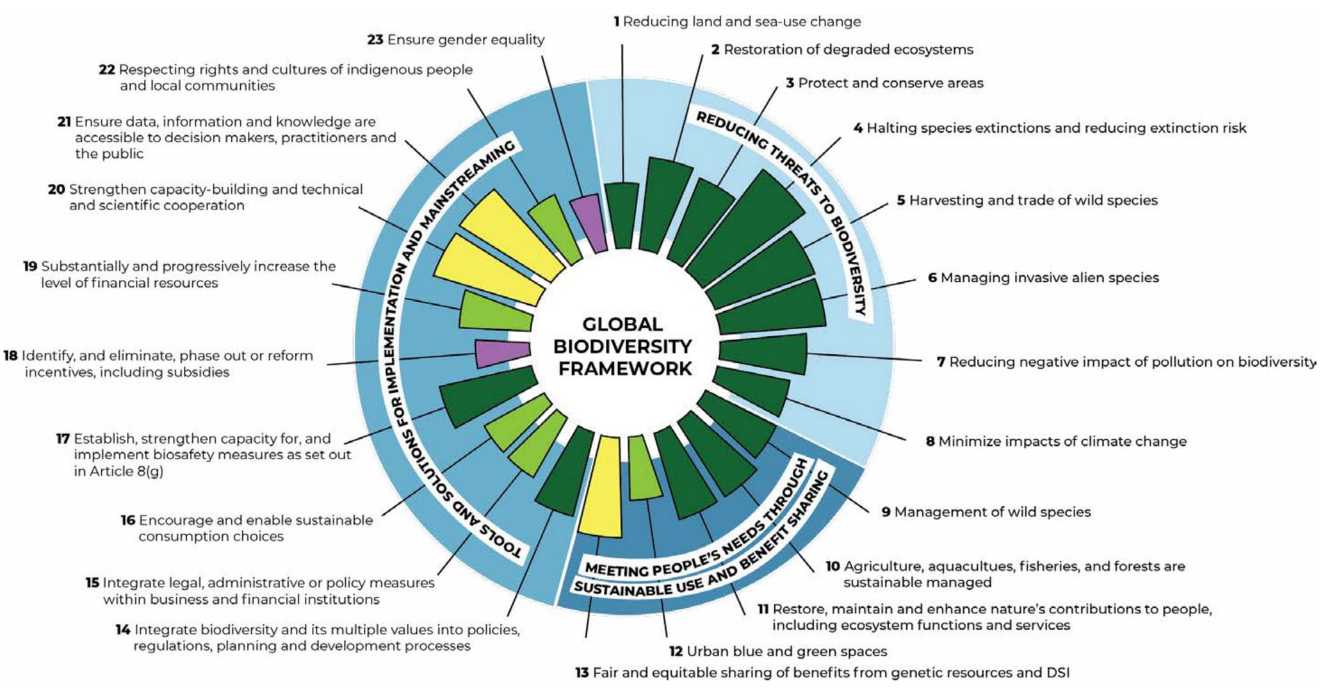

DSI critical
DSI useful but not critical
DSI a component of the target
DSI not directly relevant

The size of the bar is a subjective estimate of the overall role of DSI in achieving the target.
– *Small bar= important for only one of several aspects of the target*
– *Large bar = DSI integral to achievement of the entire target*

Section 3: Examples of the role of DSI in achieving the GBF targets

For more examples of the role of DSI in achieving the GBF targets, view Annex 3.

Genetic diversity and restoration of threatened species

For some targets the role of DSI is obvious. **Target 4 requires DSI to identify genetically diverse populations, to understand which genes influence adaptation to stressors such as drought or disease, to understand threatened species with low genetic diversity**, and to select individuals or populations for restoration efforts.

The White Rhinoceros

Species that may appear abundant, may actually be genetically unhealthy. For example, the white rhino is deemed a conservation success story with over 13 000 individuals currently recorded, which is a substantial increase from the estimated 200 animals that remained at the turn of the 20th century. However, the effective population size is ~20, indicating that the majority of individuals are genetically identical and highly inbred (Sánchez-Barreiro et al., 2021). This information can guide conservation breeding programs to help increase genetic diversity within the overall population.

DSI is also important for understanding the **genetic diversity represented in *ex situ* collections such as gene banks, zoos or botanical gardens** and whether this is representative for native, wild and domesticated species.

Using DNA to identify cryptic species and conservation implications

Less obvious applications of DSI in Target 4 are for separating species that are impossible to identify based only on appearance, which often has threat status implications.

The Forest Elephant

African elephants were long considered to comprise a single species. DNA analyses was critical in supporting their classification into **two highly divergent species:** savanna elephant and forest elephant. Recognition of the **forest elephant** as a distinct species has conservation implications because it has been **categorised as Critically Endangered**, which is a higher threat status than the savanna elephant which is Endangered.

Environmental DNA (eDNA) metabarcoding has revolutionized biodiversity monitoring and invasive pest biosurveillance programs.

eDNA metabarcoding of sea water samples was shown to detect 44% more shark species than underwater visual censuses and baited remote underwater video station survey methods in the New Caledonian archipelago (south-western Pacific), even with a much lower sampling effort (Boussarie et al. 2018). eDNA analysis has been widely tested for assessing diversity of sharks in various parts of the world.

eDNA was extracted from sand samples from turtle nesting sites and showed that the sequence data could be used to investigate population genetics and for monitoring pathogens. Genetic information was obtained from sand many hours after nesting events, which reduces sampling stress on the turtles, and means that eggs do not need to be sacrificed for genetic studies (Farrell et al., 2022).

Metabarcoding of bulk samples of plankton or insects for assessment and monitoring

Metabarcoding of organisms collected in bulk samples such as plankton or insects can provide the identities of species in the sample without time consuming sorting and expertise to identify each individual in the sample. This has significant application for monitoring ecosystems and communities.

Monitoring insect diversity, alien invasive species and pests

Globally researchers have documented **drastic declines in insects** over the last 30-years. Given the crucial roles of insects in the food chain, pollination, and nutrient cycling, this unprecedented loss will negatively impact ecosystems, the economy, and human health. Monitoring insect diversity is challenging because of the incredible diversity of species and the lack of expertise to identify insect species. Recent advances in **metabarcoding of trap samples** that include hundreds or even thousands of different species means that **insects can be effectively and efficiently monitored,** but access to DNA barcode **reference databases is required for more meaningful data.** This technique can not only be used for monitoring the number of species and their relative abundance (relevant for Targets 1, 2, 3, 4, 7, 8, 11), but also for the **detection of insect alien invasive species** (Target 6), **agricultural pests, and disease vectors** (Target 10).

Using DNA sequence data for product verification and forensic investigations

For Target 5, **safe use of wild species requires DSI to identify pathogens and parasites** (fungi, viruses, bacteria and protozoa) associated with harvested and traded resources and to track their source to reduce the risk of pathogen spillover. DSI is also used to **support legal trade** in wild species through providing "passports" for captive bred individuals, and to verify the identity and geographic origin of materials that are traded, which is also important in **forensic investigations into illegal trade**.

Illegal trade in pangolins

Trade in pangolins is illegal, and yet tons of their scales and products are seized at various ports. Identifying the species and geographic origin is critical for prosecution and for informing anti-poaching action but is impossible without DNA sequence data. Two large shipments of pangolin scales were seized in Singapore in 2019. **Rapid DNA extraction and sequencing were used to link the scales to three pangolin species, and to identify the likely location of source populations that had not previously been exploited, or that had showed a resurgence of poaching** (Yao et al., 2024).

In a separate study, sequencing of viruses associated with 161 pangolins that had been smuggled into China revealed 28 vertebrate-associated viruses, including four that infect humans ((Shui et al., 2022).

Use of DSI to assess, monitor and restore microbial diversity

Microbes such as fungi and bacteria support all life on Earth, and contribute to nutrient cycling and climate regulation, and have a crucial role in primary production, food production, and the overall health of the planet. **Understanding of microbial ecology, including community composition and functional roles has grown exponentially since the development of advanced sequencing technologies.** These tools have allowed ecologists to document microbial diversity in many habitats, to predict the effects of climate change on microbial communities, and to address challenges in ecosystem restoration. Metagenomic sequence data for microbes is essential for monitoring the management of ecosystems (Targets 1, 3, 11), for restoring ecosystem functions (Targets 2, 11), for understanding the impact of climate change (Target 8), and for remediation of pollutants in soils and the ocean (Target 7).

Annex 1: How does DSI support implementation of the GBF?

Note that there may be additional examples but the most obvious ones associated with the main text for the target have been included.

Targets	Role of DSI in implementing or achieving target
Target 1 Ensure that all areas are under participatory, integrated and biodiversity inclusive spatial planning and/or effective management processes addressing land- and sea-use change, to bring the loss of areas of high biodiversity importance, including ecosystems of high ecological integrity, close to zero by 2030, while respecting the rights of indigenous peoples and local communities.	**Identification of areas of high biodiversity value for spatial planning** • Analysis and mapping of DSI for species is required to identify areas with unique genotypes (genetically distinct populations, those with adaptive value, species with long evolutionary histories) which have high conservation value. **Identification of ecosystems of high ecological integrity** • eDNA sequence data are used for assessing community composition which is a major factor in ecological integrity. **Monitoring effectiveness of management** • eDNA sequence data are used for monitoring microbial and other communities as an indicator of ecosystem functionality and effectiveness of management.
Target 2 Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.	**Identification of degraded ecosystems** • DSI is used for assessing community composition and functional roles to determine the extent of ecosystem degradation (which species and functional roles have been lost from the system). **Restoring ecosystems** • Selection of communities to restore ecosystem functionality requires DSI. • DSI is required to identify traits that enable survival under specific conditions (local adaptations) for the re-introduction of keystone species (e.g. reforestation programmes). **Monitoring effectiveness of restoration, ecosystem functioning** • DSI is used for assessing community composition and functional roles at regular intervals to determine whether re-introduced communities and species have established and are resulting in the required functionality. • DSI is used to assess and monitor whether there is gene flow between fragmented habitats after corridors have been restored to enhance connectivity.
Target 3 Ensure and enable that by 2030 at least 30 percent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, ...	**Identification of areas of high biodiversity value for spatial planning** • Analysis and mapping of DSI for species is used to identify areas with unique genotypes (genetically distinct populations, those with adaptive value, species with long evolutionary histories) which have high conservation value. • Surveys using eDNA analysis are carried out to collect spatial data to determine localities where threatened or other important species occur. • DSI provides an understanding of which populations are naturally isolated, which ones require gene flow to maintain genetic diversity and which areas allow this gene flow (connectivity, establishment of protected area networks). • DSI enables determination of dispersion distances (e.g. how far the larvae of fish move from parents) to ensure that protected area boundaries are appropriate. **Monitoring management and conservation effectiveness** • DSI is used to monitor genetic diversity, threatened species presence, gene flow, community structure and ecosystem functioning (e.g. pollinator networks, food webs, prey composition, microbial community structure).

Target 4 Ensure urgent management actions to halt human induced extinction of known threatened species and for the recovery and conservation of species, in particular threatened species, to significantly reduce extinction risk, as well as to maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence.	**Maintaining and restoring genetic diversity** • DSI is required for – understanding genetic diversity within and between populations for threatened and other species (e.g. species with low genetic diversity and impacts of this on extinction risk) – understanding adaptive potential at the gene level – planning interventions to retore and maintain genetic diversity (e.g. selecting populations or individuals for restoration efforts). – monitoring genetic diversity for target species and populations to track changes and impacts of interventions. **Ex situ collections** • DSI for samples / material held in gene banks is required to ensure genetic diversity is represented, and to identify gaps to inform expansion strategies. **Monitoring distribution of threatened species** • Metabarcoding of eDNA is used to detect the presence of threatened species in freshwater and marine ecosystems and other habitats where direct observation is challenging.
Target 5 Ensure that the use, harvesting and trade of wild species is sustainable, safe and legal, preventing overexploitation, minimizing impacts on non-target species and ecosystems, and reducing the risk of pathogen spillover, applying the ecosystem approach, while respecting and protecting customary sustainable use by indigenous peoples and local communities.	**Sustainable use of wild species** • DSI is used for monitoring levels of genetic diversity within populations, which is important for species where specific populations or characteristics are targeted for harvesting. **Legal harvesting and use** • DSI is used: – to identify harvested material to check if it is legal (which species?) (e.g. bulbs, dried leaves, seeds, fish) – in forensic investigations into illegal harvesting and trade (e.g. identification of species, populations and locations from which genetic resources were harvested) – in supporting legal trade through provision of parentage / evidence of origin passports for traded species. **Safe use and trade: reducing the risk of pathogen spillover** • DSI is used to identify pathogens and parasites (fungi, viruses, bacteria and protozoa) associated with harvested and traded resources and to track their source.
Target 6 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, and eradicating or controlling invasive alien species, especially in priority sites, such as islands.	**Tracking pathways of introduction of alien invasive species** • Analysis of DSI from different locations across the distribution of the alien invasive species facilitates the identification of potential pathways of introduction and can be used to identify the site of origin for individual specimens or populations. **Preventing introduction of alien invasive species** • DNA barcodes are used at ports of entry to countries to verify the identity of imported goods and any associated pests and pathogens. • eDNA using a metabarcoding approach is used for monitoring programmes to detect new invasive species in an area or habitat. **Eradication and control of alien invasive species** • The selection of potential microbial biocontrol agents involves the use of DSI.

Target 7 Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: (a) by reducing excess nutrients lost to the environment by at least half, including through more efficient nutrient cycling and use; (b) by reducing the overall risk from pesticides and highly hazardous chemicals by at least half, including through integrated pest management, based on science, taking into account food security and livelihoods; and (c) by preventing, reducing, and working towards eliminating plastic pollution.	**Assessing the impact of pollution on biodiversity** • DSI is used to identify / understand and monitor impact of pollutants at the level of genes and chromosomes (e.g. mutations). **Monitoring impacts of pollution on ecosystems** • DSI is critical for monitoring impacts of pollutants on microbial and microfaunal communities in marine, freshwater and soil ecosystems. **Reducing the impact of pollutants** • DSI is used in biotechnology to develop biodegradation products for pollutants (e.g. oil degrading bacteria in ocean environments, and heavy metal absorbing microbes in contaminated soils), and for the development of biocontrol agents for pests to reduce the use of pesticides.
Target 8 Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation, and disaster risk reduction actions, including through nature-based solutions and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.	**Increasing resilience of ecosystems / species** • DSI is required to understand the genetic basis of resilience to climate change impacts such as increasing temperatures, drought tolerance, pest and pathogen spread. This knowledge is essential for management and mitigation of climate change impacts on species and ecosystems. **Minimising and mitigating impacts: monitoring marine and soil microbial diversity** • DSI is used to assess and monitor marine microbial and plankton communities to understand changes in response and contribution to climate change and ocean acidification. • DSI is used to assess and monitor soil biodiversity which plays a significant role in carbon sequestration.
Target 9 Ensure that the management and use of wild species are sustainable, thereby providing social, economic and environmental benefits for people, especially those in vulnerable situations and those most dependent on biodiversity, including through sustainable biodiversity-based activities, products and services that enhance biodiversity, and protecting and encouraging customary sustainable use by indigenous peoples and local communities.	**Ensuring sustainable use for the benefit of local communities** • DSI is used for forensic investigations into illegal / unregulated fishing and other large-scale harvesting (e.g. timber products) that impacts on environmental benefits and use by indigenous and local communities. • Verification of product origin can be done using DNA sequencing to detect mislabelling of products. **Support for indigenous communities in product development** • DSI can be used to predict or explain medicinal properties of plants or beneficial traits in harvested food plants used by indigenous peoples which can increase benefits or food security.
Target 10 Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches, contributing to the resilience and long-term efficiency and productivity of these production systems, and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services.	**Ensuring sustainable management** • DSI is used for measuring and monitoring biodiversity in productive systems, especially microbial / microbiota in soils, and primary producers and plankton communities in aquatic ecosystems. • Analysis of eDNA is used to detect parasites and pathogens in aquaculture facilities. • Metabarcoding is used for monitoring populations and communities of beneficial Insects such as pollinators as well as pests and disease vectors in agricultural and forestry systems. **Long-term efficiency in productivity and food security** • DSI is used for understanding the genetic basis of crop and livestock adaptation which is needed for breeding programmes. • DSI is used for the identification of crop wild relatives with potential for crop improvement and for identifying beneficial genes / gene combinations in crop wild relatives. **Developing biodiversity friendly practices** • DSI is used to identify appropriate communities of soil microbes for fertilizer inoculants. • DSI is used in development of new biocontrol agents for crop pests.

Target 11 Restore, maintain and enhance nature's contributions to people, including ecosystem functions and services, such as the regulation of air, water and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and/or ecosystem-based approaches for the benefit of all people and nature.	**Maintaining and restoring ecosystem services to people and nature** • DSI is used for – assessment and monitoring of microbes in aquatic and soil ecosystems that play a major role in climate regulation. – assessment and monitoring soil biodiversity for management of soil health and can be used to identify communities for restoration purposes. – for monitoring pollinator diversity. – for monitoring freshwater invertebrates that serve as indicators of the status of freshwater ecosystems. **Nature-based solutions and approaches** • DSI is used to identify microbial communities for wastewater treatment, and for the development of soil microbial inoculants to increase fertility.
Target 12 Significantly increase the area and quality, and connectivity of, access to, and benefits from green and blue spaces in urban and densely populated areas sustainably, by mainstreaming the conservation and sustainable use of biodiversity, and ensure biodiversity-inclusive urban planning, enhancing native biodiversity, ecological connectivity and integrity, and improving human health and well-being and connection to nature, and contributing to inclusive and sustainable urbanization and to the provision of ecosystem functions and services.	**Biodiversity inclusive urban planning, ecological connectivity and integrity** • DSI is required for the inclusion of genetic diversity of priority species and gene flow considerations into urban planning. • DSI is used to assess microbial communities in aquatic other ecosystems as a measure of ecosystem integrity. **Improving human health** • DSI is used to detect zoonotic and other pathogens and disease vectors and sources or origins of these in urban and densely populated areas. **Provision of ecosystem functions and services** • eDNA analysis is used to monitor freshwater invertebrates that serve as indicators of the status of freshwater ecosystems. • DSI is used to identify microbial communities for wastewater treatment.
Target 13 Take effective legal, policy, administrative and capacity-building measures at all levels, as appropriate, to ensure the fair and equitable sharing of benefits that arise from the utilization of genetic resources and from digital sequence information on genetic resources, as well as traditional knowledge associated with genetic resources, and facilitating appropriate access to genetic resources, and by 2030, facilitating a significant increase of the benefits shared, in accordance with applicable international access and benefit-sharing instruments.	DSI is central to increasing use and benefits from biodiversity (essentially covered in all other targets).
Target 14 Ensure the full integration of biodiversity and its multiple values into policies, regulations, planning and development processes, poverty eradication strategies, strategic environmental assessments, environmental impact assessments and, as appropriate, national accounting, within and across all levels of government and across all sectors, in particular those with significant impacts on biodiversity, …..	**Poverty eradication strategies** • DSI is used for ensuring sustainable use (genetic diversity, product verification, forensics, supporting legal trade), and for the development of new products that could contribute to poverty eradication. **Environmental impact assessments** • DSI is used to assess biodiversity and to detect threatened species or communities for EIAs. **Measuring and monitoring impacts of sectors on biodiversity** • Metagenomic and metabarcoding of eDNA are used to measure impacts on biodiversity and on mitigation measures implemented.

Target 15 Take legal, administrative or policy measures to encourage and enable business, and in particular to ensure that large and transnational companies and financial institutions: (a) Regularly monitor, assess, and transparently disclose their risks, dependencies and impacts on biodiversity, including with requirements for all large as well as transnational companies and financial institutions along their operations, supply and value chains, and portfolios; (b) Provide information needed to consumers to promote sustainable consumption patterns; (c) Report on compliance with access and benefit-sharing regulations and measures, as applicable; in order to progressively reduce negative impacts on biodiversity, increase positive impacts, reduce biodiversity-related risks to business and financial institutions and promote actions to ensure sustainable patterns of production.	**Monitoring, assessing and disclosing dependencies and impacts on biodiversity** • DSI is used to: – measure and monitor impacts on biodiversity at genetic, species and ecosystem levels – identify and verify dependencies on biodiversity along value chains by analysing biological content of products. **Providing information to consumers and ensuring compliance with access and benefit sharing regulations** • DNA barcoding, metagenomics and metabarcoding are used for verification of natural product content (what species) and geographic origin (where does the product come from).
Target 16 Ensure that people are encouraged and enabled to make sustainable consumption choices, including by establishing supportive policy, legislative or regulatory frameworks, improving education and access to relevant and accurate information and alternatives, and by 2030, reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption and substantially reducing waste generation, in order for all people to live well in harmony with Mother Earth.	**Reducing the footprint of production** • DSI is used: – in crop breeding programmes to increase productivity and / or nutritional value without increasing area or natural resources required, or the negative impacts of cultivation (e.g. pest management). – in biotechnology to develop new food products that have less impact on the environment and that have longer shelf life. **Reducing food waste** • Microbial genomic data are used to identify pathogens and contaminants at various points along supply chain that contribute to food spoilage.
Target 17 Establish, strengthen capacity for, and implement in all countries, biosafety measures as set out in Article 8(g) of the Convention on Biological Diversity and measures for the handling of biotechnology and distribution of its benefits as set out in Article 19 of the Convention.	**Biosafety measures** • Managing and controlling risks associated with GMOs requires DSI to know what the genetic modifications were involved and monitoring whether there is unintended change over time. • Monitoring risks and impacts requires DSI to track whether there is gene flow or hybridisation between modified organisms and wild species and populations. **Benefits from biotechnology** • DSI is essential for Parties to participate in and benefit from biotechnology research.
Target 18 Identify by 2025, and eliminate, phase out or reform incentives, including subsidies, harmful for biodiversity, in a proportionate, just, fair, effective and equitable way, while substantially and progressively reducing them by at least $500 billion per year by 2030, starting with the most harmful incentives, and scale up positive incentives for the conservation and sustainable use of biodiversity.	**Identifying which incentives are harmful for biodiversity** • DSI may be required to support decisions about which incentives have harmful impacts at gene, species and ecosystem levels.

Target 19 Substantially and progressively increase the level of financial resources from all sources, in an effective, timely and easily accessible manner, including domestic, international, public and private resources, in accordance with Article 20 of the Convention, to implement national biodiversity strategies and action plans, mobilizing at least $200 billion per year by 2030	**Increasing financial resources** • DSI is required for biotechnology, which results in new or improved product development. • DSI supports legal trade in biodiversity.
Target 20 Strengthen capacity-building and development, access to and transfer of technology, and promote development of and access to innovation and technical and scientific cooperation, including through South-South, North-South and triangular cooperation, to meet the needs for effective implementation, particularly in developing countries, fostering joint technology development and joint scientific research programmes for the conservation and sustainable use of biodiversity and strengthening scientific research and monitoring capacities, commensurate with the ambition of the goals and targets of the Framework.	• Capacity building and development in generating and application of DSI is essential for conservation, sustainable use, and monitoring of biodiversity. • The development of innovation increasingly involves generation and use of DSI. • DSI enables the identification of unique diversity which can help identify projects for community empowerment.
Target 21 Ensure that the best available data, information and knowledge are accessible to decision makers, practitioners and the public to guide effective and equitable governance, integrated and participatory management of biodiversity, and to strengthen communication, awareness-raising, education, monitoring, research and knowledge management …..	• DSI is a major component of best available data that is required for decision-making, management, monitoring; and is also a critical component of much biodiversity-related research. • DSI is an essential component of information systems and observatory centres for large scale monitoring programmes.
Target 22 Ensure the full, equitable, inclusive, effective and gender-responsive representation and participation in decision-making, and access to justice and information related to biodiversity by indigenous peoples and local communities ……,	• DSI may be required as legal evidence in support of protecting environmental human rights of indigenous / local peoples (e.g. measuring / monitoring negative impacts on ecosystem services or proof of ownership of genetic resources).
Target 23 Ensure gender equality in the implementation of the Framework through a gender-responsive approach, where all women and girls have equal opportunity and capacity to contribute to the three objectives of the Convention, including by recognizing their equal rights and access to land and natural resources and their full, equitable, meaningful and informed participation and leadership at all levels of action, engagement, policy and decision-making related to biodiversity.	• DSI in open access repositories is equally accessible irrespective of gender.

Annex 2: List view of DSI and implementation of the 23 GBF targets

- DSI critical
- DSI useful but not critical
- DSI a component of the target

	Assessment / identification	Spatial planning	Monitoring impacts	Restoration	Product development	Legal/illegal use
Target 1: Reducing land and sea use change	DSI critical	DSI critical	DSI critical			
Target 2: Restoration of degraded ecosystems	DSI critical	DSI critical	DSI critical	DSI critical		
Target 3: Protect and conserve areas	DSI critical	DSI critical	DSI critical			
Target 4: Halting species extinction and reducing extinction risk	DSI critical	DSI critical	DSI critical	DSI critical		
Target 5: Harvesting and trade of wild species	DSI critical	DSI critical	DSI critical			DSI critical
Target 6: Managing invasive alien species	DSI critical	DSI critical	DSI critical		DSI critical	DSI critical
Target 7: Reducing negative impacts of pollution on biodiversity	DSI critical		DSI critical		DSI critical	
Target 8: Minimize impacts of climate change	DSI critical	DSI critical	DSI critical		DSI critical	
Target 9: Management of wild species	DSI critical		DSI critical			DSI critical
Target 10: Agriculture, aquaculture, fisheries and forests sustainably managed	DSI critical		DSI critical			DSI critical
Target 11: Restore, maintain and enhance nature's contribution to people	DSI critical		DSI critical		DSI critical	
Target 12: Urban blue and green spaces	DSI useful but not critical	DSI useful but not critical	DSI useful but not critical			
Target 13: Fair and equitable sharing of benefits from genetic resources and DSI						DSI a component of the target
Target 14: Integrate biodiversity & values into policies, regulations, planning & development processes	DSI critical	DSI critical	DSI critical			DSI critical
Target 15: Integrate legal, administrative or policy measures within business and financial institutions	DSI useful but not critical		DSI useful but not critical			
Target 16: Encourage and enable sustainable consumption choices	DSI useful but not critical				DSI useful but not critical	DSI useful but not critical
Target 17: Establish, strengthen capacity for and implement biosafety measures	DSI critical	DSI critical	DSI critical			DSI critical
Target 18: Identify and eliminate, phase out or reform incentives						
Target 19: Substantially and progressively increase the level of financial resources	DSI useful but not critical				DSI useful but not critical	
Target 20: Strengthen capacity building and technical and scientific co-operation						
Target 21: Ensure data, information & knowledge accessible to decision-makers, practitioners & public						
Target 22: Respecting rights and cultures of indigenous peoples and local communities						DSI useful but not critical
Target 23: Ensure gender equality*						

*DSI is used extensively by biologists in the natural sciences, and there is a gender gap that still needs to be addressed in this discipline (see Chui & Cesa. 2020. Gender Gap in Science. Chemistry International 42(3): 16-21. https://doi.org/10.1515/ci-2020-0306).

Annex 3: Examples of application or potential application of DSI for GBF targets from the scientific literature

There are thousands of scientific publications that include examples of how DSI can be used or has been used in the context of the sustainable use and conservation of biodiversity. In some cases, the application is direct and obvious, but in other cases, the application may be more obscure.

Some DNA sequencing technologies and approaches are relatively new but are developing further and improving at a rapid pace. Researchers have tested these technologies and verified their application for a range of functions but adoption in conservation or other areas of practice is still relatively limited. This is likely to change in the near future as the benefits in terms of cost effectiveness and efficiency are fully realised, and the reference sequence data sets expand.

A sample of potential and actual applications of DSI in the context of the GBF targets is provided below, but a comprehensive list and explanation is beyond the scope of this document.

Genomics and gene editing for improving crops: crop wild relatives	
Compared to the domesticated population, tremendous genetic diversity persists among crop wild relatives (CWRs). Advances in genomics have accelerated the identification of valuable CWRs for use in crop improvement and CWRs have provided breeders with several 'game-changing' traits or genes that have boosted crop resilience and global agricultural production. Expansion of sequence information on wild genomes in combination with precise gene-editing tools provide a fast-track route to transform CWRs into ideal future crops. Bohra et al. (2022) provide several examples of the use of CWRs in breeding, such as disease and pest resistance improvement in wheat, rice, potato, tomato, cassava, sunflower, banana and lettuce; yield improvement in wheat and rice; and improving tolerance to abiotic stress in rice, tomato, barley and chickpea. They also document how sequencing technology and DSI have been and could be used in future crop improvement through CWRs. The application of CWRs in breeding has been also shown to deliver huge economic returns in agricultural industries worldwide, with their annual contribution to the world economy estimated at around US $186.3 billion in 2020 (Tyack et al., 2020).	**Target 4** **Target 10** **Target 16**
Genetic diversity and restoration of threatened species: panthers	
A classic example of the importance of genetic diversity and how genetic data have been used for recovery of threatened species is the translocation of eight individual females from nonendangered populations of the Texas panther (*Puma concolor stanleyana*) to south Florida where the threatened Florida panther (*P. c. coryi*) showed negative impacts of inbreeding. While the two subspecies were genetically distinct, there was evidence that historically there had been some gene flow between them, and introducing the more genetically diverse individuals reversed the negative effects of inbreeding in the threatened species, resulting in an immediate increase in population numbers, fitness, and survival (Hostetler et al., 2013).	**Target 4**
Environmental DNA (eDNA) metabarcoding has revolutionized biodiversity monitoring and invasive pest biosurveillance programs.	
To prevent invasive alien species from successfully invading a new habitat and for subsequent management, early detection is critical, but this requires regular and accurate monitoring. Current freshwater monitoring methods rely on sight or capture of specimens followed by morphological identification either in the field (i.e., fish) or using a microscope. These methods often miss species that are not easily sampled, or that are small, and they are time consuming and not easily implemented over large areas. Furthermore, cryptic, or closely related taxa, juvenile or damaged specimens may not be identified correctly, or only identified to a coarse taxonomic level, which may lead to incorrect or unsuccessful detection of invasive species. Using eDNA to identify invasive alien species from simple water sample collection is a growing trend and 'game-changer' regarding biomonitoring. Currently, eDNA approaches are being used as part of a monitoring strategy for invasive fish in the Great Lakes region of the US and Canada (Jerde et al., 2013), and metabarcoding has been investigated for screening ballast water for the introduction of invasive species to freshwater and marine ports (Zaiko et al., 2015). Studies in various other parts of the world have shown that using eDNA is an effective method for detecting alien invasive species in freshwater and marine environments.	**Target 5** **Target 6**

Using eDNA for conservation planning

DNA sequence data have been used to link larval fish to parents, which provides an indication of dispersal distance, which is an important consideration for marine protected area design to ensure that larvae do not disperse into areas that are heavily fished. Understanding dispersal of larvae is also important to determine the benefits of marine protected areas for sustainable use of harvested species. For example, researchers were able to use genetic data to link the larvae to parents for the squaretail coral grouper fish in Papua New Guinea to determine how far larvae disperse from a small community marine protected area that included the grouper spawning area. They showed that at least 50% of larvae disperse up to 14km from the protected area, into the communal fishing area, replenishing the available stock. This study (Almany et al., 2013) showed the benefits to the community that had set aside some of its fishing area for the protected area.	**Target 3** **Target 5**

Metagenomics to monitor and restore microbial community structure and function and clean up oil spills

Soil microbes are involved in the decomposition of soil organic matter, they regulate carbon stocks and nutrient cycles, and facilitate plant nutrient uptake. Changes in soil microbial community composition and related functions can alter soil ecosystem services. Soil microorganisms have recently become of interest in restoration ecology to re-establish biodiversity and functions in degraded ecosystems globally (Averill et al., 2022). However, detailed research showed that attempting to rescue degraded soil biodiversity by adding complex microbial communities strongly depends on the nature and strength of species interactions. Successful restoration could be achieved only with the right combination of competitive species which allows community resilience. The authors of this research (Koziol et al., 2022) used an experimental approach for prairie ecosystems in the USA, involving multiple molecular techniques and analyses of the sequence data to determine which species were present in degraded soils, to identify the community for introduction, and to assess the microbial community composition after introduction.	**Target 1** **Target 2** **Target 4** **Target 5** **Target 7** **Target 8** **Target 10** **Target 11** **Target 12** **Target 14**
The condition of the ocean is largely determined by the activities of microscopic plankton cells that harvest the energy that supports the food chain. Microbes turn CO2, H2O, and nutrients into organic compounds. They dissolve, transform, and deposit large quantities of minerals. They control the composition of the atmosphere and influence climate on a global scale. If microbes change their activities and cycles, life on land will experience the consequences. Oceans are changing rapidly and are under threat from both natural and man-made stressors, including rising seawater temperatures, ocean acidification, over-exploitation of resources and pollution. Baseline census data on the identity and function of marine microbes provide a benchmark against which microbial community changes can be assessed. Genomic approaches are essential for baseline data on microbes, and for monitoring future changes and are being used globally by various organisations and large-scale monitoring or observation projects, including in the Atlantic and Pacific Oceans (Biller et al., 2018).	**Target 1** **Target 2** **Target 4** **Target 5** **Target 7** **Target 8** **Target 10** **Target 11** **Target 12** **Target 14**
Numerous studies have shown that populations of known oil-degrading bacteria are common in ocean environments. Biodegradation of petroleum, which is a highly complex mixture of hydrocarbons, requires a complex community of microorganisms. Knowledge about microbial community composition and diversity aids in understanding and prediction of petroleum biodegradation by microbial communities and is therefore an important component of oil spill response decision-making process. Characterization of the microbial community in the Gulf of Mexico following the Deepwater Horizon spill in 2010 provided insights about the succession of microbial taxa involved in petroleum biodegradation. Genomic sequencing was used to survey the microbial composition of sites and to identify the species responsible for biodegradation of petroleum (Kostka et al., 2021)	**Target 7**

Using DNA sequence data for product verification and forensic investigations

A study of shark traded in the seafood industry in Australia (Cundy et al., 2023) used DNA sequence data to show that 70% of the samples tested were mislabelled, and some samples represented three different threatened shark species. Similar results have been obtained from sequence data in Brazil, Singapore, Indonesia and the United Kingdom.	**Target 4** **Target 5** **Target 9**

Synthetic biology and positive impacts on the environment

Impossible Foods recognized that blood, specifically the iron-containing heme, is important for the taste and experience of eating a hamburger. A yeast species was engineered to produce soy leghemoglobin, which improves meaty flavours and aromas when added to a plant-based burger. Compared to a beef patty, the Impossible Burger requires 96% less land and produces 89% fewer greenhouse gases. Worldwide, their products are available in over 30,000 restaurants and 15,000 grocery stores (Voigt, 2020). Digital sequence information was critical for the development of this new product.	**Target 10** **Target 16**

DSI SCIENTIFIC NETWORK SANBI Biodiversity for Life South African National Biodiversity Institute

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