# Tech to Track

## Harnessing the potential of spatial data & digital technologies to prioritise nature and climate action

**White paper**
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## About SPACES

**SPACES is an emerging coalition that mobilises spatial intelligence to support governments, businesses, financial institutions, funders, and investors in achieving climate and nature goals.** SPACES is coordinated by the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and SYSTEMIQ, working with UNDP, IIASA and IIS, among other partners. It aims to support the use of spatial intelligence in achieving national climate and nature objectives, by implementing and accelerating spatial planning in countries.

For more information, please visit www.spacescoalition.org, or contact info@spacescoalition.org

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## About this report

This paper aims to inspire decision-makers in both the public and private sector to use spatial intelligence as an enabler for integrated nature and climate action. It showcases 'emerging' data sources and digital technology in the nature and climate space and their use in providing spatial intelligence to decision-makers. All specific tools and solutions mentioned are examples and not exhaustive of all that is (increasingly) available.

**Authors of this work are** Floor van Dam, Boipelo Tshwene-Mauchaza, Kollie Tokpah, Scarlett Benson, Naseer Chia, Lera Miles and Gergana Nikolaeva Daskalova.

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Rafael Loyola (**IIS**), Piero Visconti (**IIASA**), Marion Marigo, Christina Supples (**UNDP**), Tara O'Shea (**Planet Labs**), Anna Colina Segalà (**Dendra**), Douglas Yu, Mike Morris (**NatureMetrics**), Aurel Stenzel, Martin Pompéry (**SINE Foundation**), Vizzuality team, Andrew Sowter, Kevin Porter (**Terramotion**), Caleb Midgley **(Descartes Labs**), (**TRASE team, Stockholm Environment Institute**), Bernhard Seeger (**University of Marburg**), Hjalmar Kuehl (**Dresden University, Senckenberg**), Kristen Snyder, Alina Peter, (**Grumeti Fund Trust**), PJ Stephenson (**IUCN**), Mark Mulligan (**Department of Geography, King's College London**), Nicolas Loncle, Liesbeth Huisman, George Darrah (**Systemiq**)

**Editing and design:** Matt Kaplan

**Design:** Alan J. Tait

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# Executive summary

**Climate change and the destruction of nature are two dual crises increasingly drawing the attention of governments, businesses and finance.** Nature is critical for climate resilience and adaptation. There is growing agreement that swift and integrated action must be taken to avert catastrophe. This was a priority area at COP26, remains firmly on the agenda for COP27, and features heavily in the EU Taxonomy and the G7's Nature Compact. Nature-based solutions could contribute more than 30% of the emission reductions and carbon capture needed to reach net zero by 2050, as required by the Paris Agreement. The Global Biodiversity Framework, to be agreed and adopted by all members of the UN Convention on Biological Diversity (CBD) at COP15 in December 2022, therefore aims to set ambitious targets towards "nature positive" that will require vastly more conservation and restoration efforts, including delivering on a commitment to protect or conserve at least 30% of the planet by 2030 ("30×30"). A growing number of businesses and financial institutions want to aim for nature positive outcomes across their spheres of influence, which will require profound changes to business practices and international supply chains. Their businesses depend on it. More than 50% of global Gross Domestic Product (GDP) is moderately or highly dependent on nature and the goods and services it provides.

**To enable governments, businesses and finance to act, spatial intelligence needs to be available to help prioritise and track location-specific actions for nature and climate.** Measuring climate impact requires tracking impacts on one, location-agnostic indicator: the release of greenhouse gases. However, it is much harder to measure the impacts of actions taken on nature. This requires collecting location-specific data across several variables, such as freshwater availability, soil health and biodiversity intactness, to name a few. This data can subsequently be translated into spatial intelligence to optimise integrated action. Spatial intelligence is defined as the use of location-specific data, tools, analysis, and visualisation to inform decision-making. It can be used to map agriculture, biodiversity and the risk of natural disasters among other uses, to identify areas that require protection, restoration and sustainable management.

**Today, governments, businesses and finance lack the data to track progress towards 'nature positive' and 'net zero' emissions.** Although spatial intelligence is essential for success, current available data is too sparse, often of poor quality, limited in scope (e.g. covering only a few species), out of date, not collected regularly, and too difficult to access. Many countries and businesses therefore do not know their natural capital and cannot track biodiversity loss. Indigenous Peoples and Local Communities (IPLC) cannot easily demonstrate the value they bring to natural capital stewardship. Financial investors and insurance companies cannot develop financial products to divert capital flows towards nature positive activities and to raise new funds for international nature and climate finance. Carbon markets do not systematically include nature.

**Fortunately, technology is transforming the collection of on-the-ground data, alongside a revolution in the application of satellite technologies and data science to monitor the state of our planet.** In the next few years it will be technically feasible to expect public and private actors to track and estimate the nature and climate impact of their activities. There is currently a growing involvement of corporate technology incumbents (e.g. Microsoft, Google) and an explosion of the number of start-up companies in this space. The scientific community, Non Governmental Organisations (NGO), and volunteers, and for-profit companies are together paving the way for a nature and climate-monitoring revolution that supports and supplements efforts by local communities, countries and businesses to track nature and climate impact. This is an essential first step towards reducing and compensating impacts. The tools that make this possible fall into four categories:

**On-the-ground measurements.** On-the-ground (or 'in-situ') data in the context of nature and climate goals describes data which is collected in its original place. Examples include population surveys, sensors (networks), the sampling of environmental DNA to understand which species are available in a specific location, or other field measurements of biodiversity and ecosystem services.

**Remote sensing.** Sensors carried by satellites, airplanes and drones can provide high resolution images of infrastructure, land use, and ecosystems from space, which simplify detecting where and when change takes place, from an illegal dam installation to deforestation.

**Processing and analysis.** The sheer volume of information provided by newly developed sensors and high-definition imaging cannot be processed manually. Artificial intelligence systems that are capable of learning how to process vast quantities of data are filling the gap. Major recent advancements in data processing enable easier data management and processing, especially when combined with drastic increases in computer processing power and improvements in cloud storage.

**Sharing and accessibility.** A range of online platforms and encryption tools make it easier and safer to share spatial data and analysis, which strengthens transparency and safeguards from the duplication of work by different actors.

**Three urgent challenges must be overcome** to unlock the potential of new spatial data and digital technologies to support nature and climate action:

1. **Private and public investment is needed to identify and close data gaps, and to unlock sustainable funding for frequently updated spatial nature and climate data.** The private sector must be incentivised to adequately value and fund the collection and use of spatial intelligence through an enabling regulatory and financial environment. Where legislation, regulating and incentivising the private sector to increase nature and climate action and monitoring still leaves significant gaps, governments and philanthropies could subsidise the cost of long-term data collection or data access.

2. **The data community needs to agree and adopt data measurement and quality standards to ensure delivery of high-quality, comparable, and interoperable data in formats suitable for the private and public sector.** Such standards require flexibility to encourage innovation and to allow for local adaptation, while remaining robust and evidence-based to build trust in government and business data.

3. **Companies and civil society organisations must be encouraged and incentivised to share the nature and climate data they generate through public databases.** If done well, this can lead to an explosion in available real-time data on biodiversity and ecosystem. A trusted, secure data architecture is needed to facilitate the integration of multiple sources and types of spatial data, and enable data access without compromising sensitive information or legitimate commercial interests.

Tremendous environmental challenges lie ahead, and the solutions will need to consider the specificities of each situation and location. Nonetheless, these innovative technologies can provide the necessary tools for people to act in a ‘net zero emitting’ and ‘nature positive’ manner. It is critical data is funded and collected, is standardised and therefore usable and trusted, and is made accessible and widely shared – the future of people and the planet depends on it.

# Spatial intelligence: using data for nature, climate and people

Spatial intelligence is the use of spatial data, tools, analysis and visualisation to strengthen decision-making. It can help businesses understand, manage and monitor their impacts and dependencies on nature, climate and people, and can help countries with their spatial planning practices.

Spatial intelligence can better support businesses and countries if data collection, analysis and visualization are designed to target decision-making needs. Social, economic, environmental and governance objectives need to be identified, and challenges and opportunities to align these need to be explored. **Engagement with stakeholders throughout the process highly increases the chances of a successful outcome.**

## Data collection

### Remotely sensed data

Satellites, aircrafts and drones can be used to measure and monitor key variables and trends from a distance.

### Field data

Data collected "on-the-ground" using individual or networks of sensors (e.g. audio), camera and live traps, citizen science, field surveys and sampling (e.g. environmental DNA) etc.

## Spatial data are processed

### Data processing

Adjustments to spatial data are often needed to account for different formats and resolutions, before they can be aggregated, integrated, filtered, processed and stored.

### Data analytics

Analysis changes data into information e.g. mapping different solutions or modelling scenarios. Advances like artificial intelligence help analyse data more efficiently, identify spatial patterns and provide richer insights.

## Possible scenarios are visualized, a decision is made and actions are implemented

### Visualization

Visualising analysed spatial data can be a powerful engagement and decision-making tool, identifying effective actions.

### Data accessibility

Spatial intelligence has to be transparent, accepted, affordable and accessible by its users (mindful of privacy and confidentiality).

### Action

Spatial intelligence can help to select locations to implement actions for nature, climate and people, monitor progress and channel finance.

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*Figure 1: Illustration defining what spatial intelligence is.*

# 1

# Introduction

**The world is facing both a nature and climate crisis, which requires integrated, concerted and urgent action.**[1] Nature is the foundation of our economy with more than 50% of global Gross Domestic Product (GDP) (USD 44 trillion) moderately or highly dependent on nature and the goods and services it provides.[2,3] Five primary drivers are causing biodiversity loss and ecosystem decline: land use and sea-use change; overexploitation of natural resources; climate change; pollution, and the spread of invasive species. Damages to ecosystem services are costing the global economy more than USD 5 trillion (or 6% of GDP) every year.[4] Imminent action is needed, delaying efforts and actions to tackle biodiversity loss doubles the cost relative to acting now.[5] There is a small and rapidly closing window of opportunity to avert the most catastrophic impacts of these intertwined crises. This urgency is underscored by the risk of irreversible tipping points, such as the Amazon Forest dieback, beyond which it will be impossible to recover from the damages caused to ecosystems and the essential services they provide.[6]

**Awareness of the gravity of the situation is increasing, with governments, businesses, and civil society committing to tackle the nature and climate crises.** The United Nations Framework Convention on Climate Change (UNFCCC) COP 26 delivered a Glasgow Climate Pact that emphasises the importance of nature's conservation and restoration of nature to tackle climate change. The draft of the Convention on Biological Diversity's (CBD) post-2020 global biodiversity framework (gbf) also highlights the need for nature-based solutions in addressing climate change.[7] More than a thousand companies with annual revenues of USD 4.7 trillion are calling on governments to adopt policies that will reverse nature loss in this decade.[8] Additionally, the Nature Action 100 (NA100) initiative, including institutional investors and their representatives, was recently launched to engage with companies and policymakers on nature. Businesses are also starting to set targets and disclose their nature and climate impacts, making use of guidance and frameworks currently being drafted by the Science Based Target Networks (SBTN) and the Taskforce on Nature-related Financial Disclosures (TNFD), among others.

**The achievement and operationalisation of the global targets, and the understanding of trade-offs inherent within them, require new applications of spatially explicit technologies, data and tools to support spatial planning by governments and use of spatial intelligence by businesses.** Location matters: 30% of land area could conserve more than 60% of carbon stock, over 65% of clean water provision, and meet conservation targets for more than 50% of terrestrial vertebrates and vascular plants.[9] Governments need to understand the marine, freshwater and terrestrial environments their populations rely on to effectively protect, manage and restore them. The use of spatial planning by governments is Target 1 in the first draft of the post-2020 gbf and enables other targets to be achieved.[7]

Businesses setting science-based targets, or assessing nature and climate-related financial risks and opportunities, need spatial data and tools to better understand their location-specific impacts and dependencies on nature and climate in specific locations across their supply chains and the surrounding land and seascapes. Similarly, the financial sector requires this intelligence to inform investment, engagement, and divestment activities. For the private sector (business and finance), the application of spatial intelligence is codified in the SBTN guidance and TNFD beta framework.[10,11]

**The SPACES coalition aims to mobilise spatial intelligence to support governments, businesses, finance, funders, and investors in achieving nature and climate goals.** This paper highlights how the world is undergoing a spatial data revolution with technological innovation exponentially increasing the availability, accessibility, usability, and interpretability of the spatial data actors need. To date, the lack of awareness of the availability and accessibility of the emerging spatial technologies, data and tools is hampering the ability to effectively take nature and climate action. This paper aims to increase awareness of the opportunities presented by emerging data technologies and develops a shared understanding of the conditions needed to unlock this potential. The sections are set out as follows:

- **II. Potential impact of spatial intelligence:** Describes how data and technologies support integrated spatial planning and spatial intelligence processes that can help deliver action and results for nature, climate and people.
- **III. Status and trends of spatial technologies:** Provides an overview of the emerging and expected technological advancements in the nature and climate space along the ‘data value chain’ towards spatial intelligence.
- **IV. Unlocking the potential:** Gives insights on what is needed to mobilise these emerging technologies in this space.

# 2

# Potential impact of emerging spatial data and technologies

**Spatial intelligence is the use of spatial data, tools, analyses, and visualisation to strengthen decision-making.** It can be used by a range of actors to support action on nature and climate. Incentives for the uptake of spatial intelligence by these actors are increasing and are likely to increase further in the next couple of years.

**Governments – national and sub-national – can leverage new data and technologies through improved ability to better understand nature and climate impacts in their jurisdictions, and inform spatial planning processes to prioritise nature and climate action, in line with target 1 of the draft global biodiversity framework.** Integrated spatial planning is a central element of a successful national planning strategy for climate, nature, and people. It can for instance be used to clearly 'rank' areas that are more or less valuable for conservation practices, making it possible for offsetting entities to target protection and restoration of those areas. The technological advancements discussed in Section 3 are expected to make each of these elements cheaper, more precise and easier to use for governments. Non-governmental organisation (NGOs) and intergovernmental organisations (IGOs) often have increasing capacity to conduct spatial planning activities with countries at (sub)national scale and in the landscapes they support. A companion piece illustrates in more detail how spatial planning can help governments to operationalise nature targets, integrate nature and climate policies, mobilise finance, and monitor targets already set.

**Businesses will benefit from these opportunities, as it becomes easier to combine supply/value chain data and operations data with spatial data on nature and climate.** Businesses can use spatial intelligence to support the delivery of their nature and climate commitments, which supports them in understanding their impacts and dependencies on nature and climate in specific locations across their supply chains and associated landscapes. Increasingly spatial intelligence enables businesses to move from identifying risks to taking action and tracking progress, to achieving results. It also gives more specific insights, making it possible for businesses to transition from using modelled economic data on product locations and impacts towards using accurate details on product origins.

Businesses need spatial intelligence to:

- Understand risks and opportunities related to both nature and climate, as well as their overlaps with other business risks and opportunities
- Track and disclose progress towards nature positive outcomes and net-zero carbon emissions Raise green finance and lower the cost of capital through carbon markets, biodiversity credits and access to capital linked to environmental, social and governance (ESG) criteria

- Better engage with local communities and align business strategies with national policies, for example through stakeholder consultations and alignment with national spatial planning efforts
- Get ahead of external scrutiny of their supply chains and operations by ensuring they have the spatial intelligence to pinpoint and remedy negative impacts from their business operations

**The finance sector can deploy new spatial data and technologies to create products and services that support nature positive actions.** Using spatial intelligence allows financial institutions to avoid operational, regulatory, and procedural risks that come with non-compliant investments; to align investments with nature positive outcomes; to design sustainable landscapes investment funds and facilities; and to understand risks to protected areas, biodiversity, and ecosystems, also giving transparency on when certain clients operate, or have plans to operate, in protected areas or biodiversity hotspots. Financial institutions can use tools like the Integrated Biodiversity Assessment Tool (IBAT) and Trase Finance to screen the value of biodiversity and ecosystem services of current and prospective project areas for clients in near real-time. An overview of already existing data and tools for the finance sector includes the TRADE Hub 'trade tools navigator' and data systems such as ENCORE.[12,13]

Further applications for spatial intelligence for businesses and finance are highlighted in WBCSD's paper on Spatial intelligence and business: data application for a nature-positive and net-zero future and the WEF's paper Location Matters: Using spatial intelligence for business action on nature and climate.

3

# Status and trends of spatial technologies: Emerging data and technologies to drive nature and climate action

**Innovations in technology across the data value chain mean that all stakeholders – from citizens to governments to farmers and financial institutions – could have unprecedented access to spatial intelligence.** It is increasingly possible to collect spatial data at scale and with greater granularity and frequency.[14] New computing methods are enhancing our ability to filter, process, store, aggregate, integrate, and visualise this data, 'translating' it into spatial intelligence. New ways to make spatial intelligence more accessible and sharable are unlocking the potential for driving decision-making and action across large and diverse groups of stakeholders. Figure 2 highlights how a combination of technologies along the 'data value chain' is creating opportunities for tailored solutions to specific spatial intelligence demands. Appendix B gives a more specific overview of how new forms of spatial data and technologies can contribute to mapping specific *Nature's Contributions to People*.

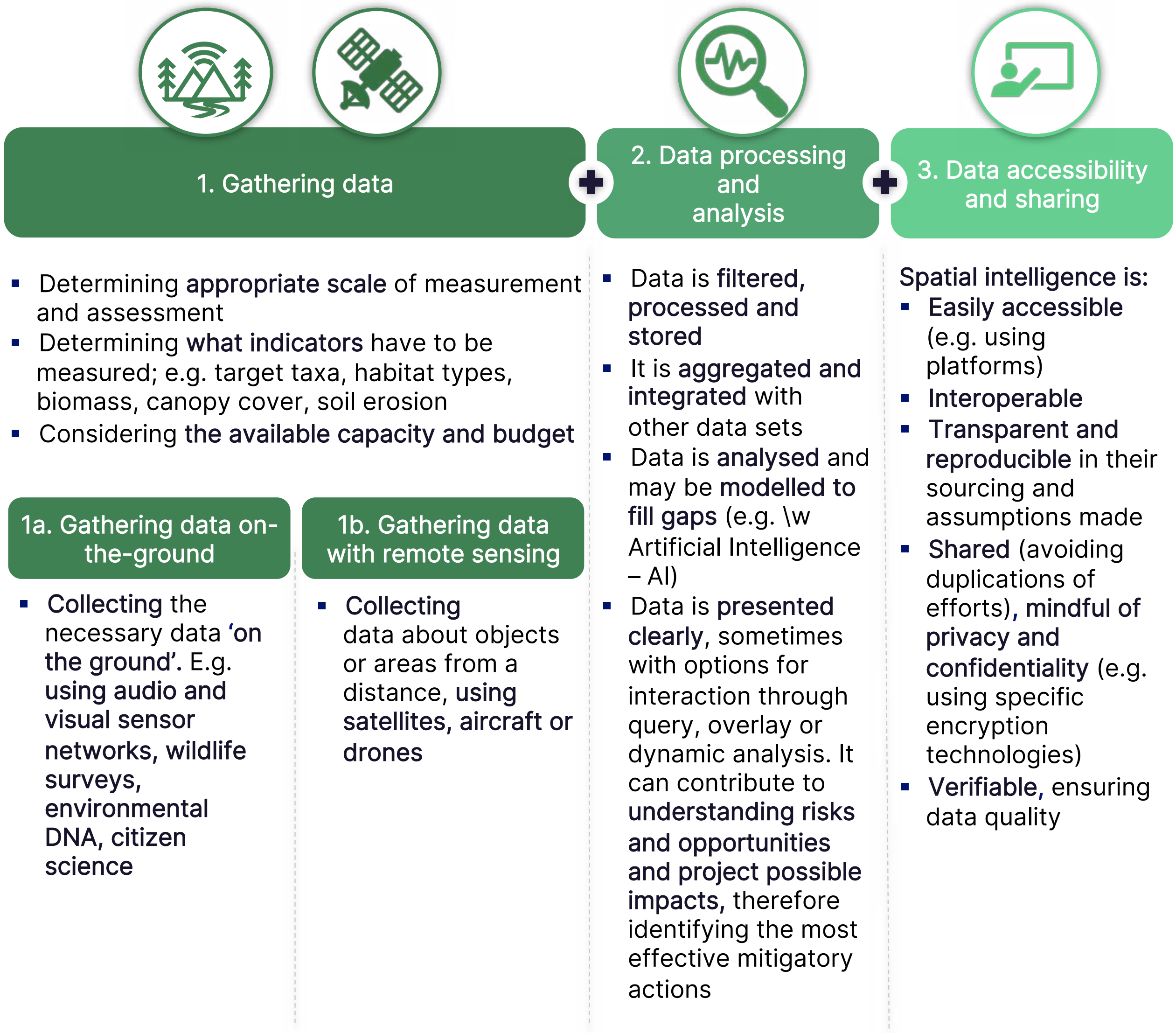


*Figure 2: The 'data value chain' from data collection to sharing*

# (1a) On-the-ground measurement

**On-the-ground (or 'in-situ') data in the context of nature and climate goals describes data which is collected in its original place. Examples include population surveys, sensors (networks), the sampling of environmental DNA, or other field measurements of biodiversity and ecosystem services.** Advancements in this area are increasing the coverage, speed, and precision of measurements, as well as the ability of non-technical stakeholders to collect data. These types of on-the-ground measurements are needed to monitor and track 'smaller scale' dimensions such as pollination, which 75% of global crops depend on.[15] Advances include:

- **Sensors:** Different types of on-the-ground (in-situ) sensors can contribute to more automated, frequent, and standardised monitoring of the state of the environment. Appendix A gives an overview of the different types of sensors, including visual, atmospheric and acoustic sensors. Increasing battery life and efficiency has reduced both the size and price of sensors. They can now even be placed on small insects making it possible to monitor the species and their usefulness as pollinators, pest control and nutrient cycling agents.[16] In addition, sensor utility is enhanced due to the increased ability to connect multiple sensors in a network or 'internet of things', leading to more automated and standardised sampling and better holistic insights.[17,18] This is for instance relevant for monitoring natural flood management, ecosystem services (e.g. FreeStation.org) or forest fires (as highlighted in the example below).

**Sensor (networks) – Forest fire detection and acoustic monitoring for biodiversity.**

Sensor networks can now detect forest fires in hours instead of days, which allows for better allocation of resources to prevent the large-scale destruction of forest ecosystems which has been increasing in the last couple of years.[19,20] Wireless sensor networks from the start-up Dryad can detect new forest fires in California within 60 minutes and send alerts to local authorities who can intervene before the blazes grow out of control.[21] Using radio technology, a large area can be covered as existing network coverage is not needed and data can easily be stored and quickly integrated in 'the cloud'.[22] This method to detect forest fires makes it possible to prevent economic damages and negative nature and climate impact. In 2019, forest fires generated 7.8 billion tonnes of $CO_2$ (almost 20% of the annual global emissions from the burning of fossil fuels).[23]

The AudioMoth 'device', a low-power, open-source acoustic monitor, also uses sensor networks. It can collect information on wildlife populations by recording the calls of specific target species. It can simultaneously serve as an alert system when the sound of human exploitation (like the blast of a shotgun or the roar of a chainsaw) is detected.[24]

The introduction of biodegradable sensors allows data to be collected and reduces the environmental footprint of field surveys as, after use, the sensors degrade into by-products that do not harm the environment. Biodegradable sensors allow data collection in the most remote locations on Earth without risks to surveyors and minimum impacts on the area under study.[25]

The main barriers that limit the potential for sensor (networks) are the knowledge and costs to install sensors, the need for resources to store and process the large amounts of data that sensor networks produce, and the need to complement and calibrate sensor data with observer-based methods, which are time-consuming and costly. Many sensors require human presence and interpretation – they are a means to increase available data for expert interpretation, but can often not be fully automated without field verification. Therefore, it will be critical to identify where these types of data collection efforts are needed most, increase the capacity to install such sensors, optimise the processing and storing of sensor data, and improve cost-effectiveness and efficiency of on-the-ground measurement to calibrate sensor data.

- **Environmental DNA (eDNA):** eDNA metabarcoding is a transformative technology that enables rapid species inventories to be made from trace DNA released by organisms.[a] It brings together traditional field-based ecology with high-throughput molecular methods and advanced computational tools, with the potential to revolutionise global conservation. Taxonomic experts are no longer needed to carry out time intensive field-based surveys. If their genetic markers are known, a sample of eDNA is all that is required to identify the presence of hundreds of species in an area. Innovations are bringing down the costs, allowing eDNA from waterbodies, and increasingly from soils and air, to be collected, processed and analysed more quickly and comprehensively. This allows for the detection of species and advances biodiversity assessment and monitoring (as highlighted in Figure 3).[26] The use is expected to grow in the coming years, as its effectiveness is increasingly being recognised and accepted by regulators.[b] Additionally, in-field eDNA detectors may soon have the capability to automatically collect data, making it easier to consistently sample developments in an area.[27]

While the potential for eDNA is extremely encouraging, the technologies and lab resources for the sequencing and analysis of genetic material are not yet widely available, mirroring old inequities in conservation research. Additionally, millions of species have not yet had their DNA sequenced and annotated. To address this, resources are needed to create and house growing reference databases. Even when species can be detected, there can be uncertainty around their precise location (e.g. eDNA from a fish can 'flow' to different locations and can remain in the water for a long time; even terrestrial species' DNA can be transported through a watershed). Ongoing research is therefore important to improve the precision of measurements.[32]

[a] SYSTEMIQ believes that emerging technologies such as eDNA can catalyse transformational action for nature, and is supporting the further development of these services through impact investing and venture capital.

[b] Currently, eDNA is currently only explicitly accepted in the UK and Sweden as a valid methodology for regulatory monitoring. Some countries (including most of the EU) are currently in the process of evaluating its merits compared to conventional methods.

### Example of eDNA – the eBioAtlas project

The eBioAtlas project, a collaboration between the International Union for Conservation of Nature (IUCN) and NatureMetrics, gathers eDNA data at scale. The project aims to support conservation, unlock investment, and inform global biodiversity policy by improving knowledge on freshwater species distribution. By working together with companies and training local communities to collect eDNA samples, the eBioAtlas team will develop a globally standardised sampling and analysis protocol and create a "global atlas of life in the world's river basins and wetlands".[28] The results will be made freely available to non-commercial users and will be designed to interface with the IUCN Red List of Threatened Species, used by many businesses when measuring the biodiversity impact of their activities. The eBioAtlas team will also screen water samples to identify pandemic risk (by detecting the presence of particular pathogens or zoonotic disease vectors).[29]

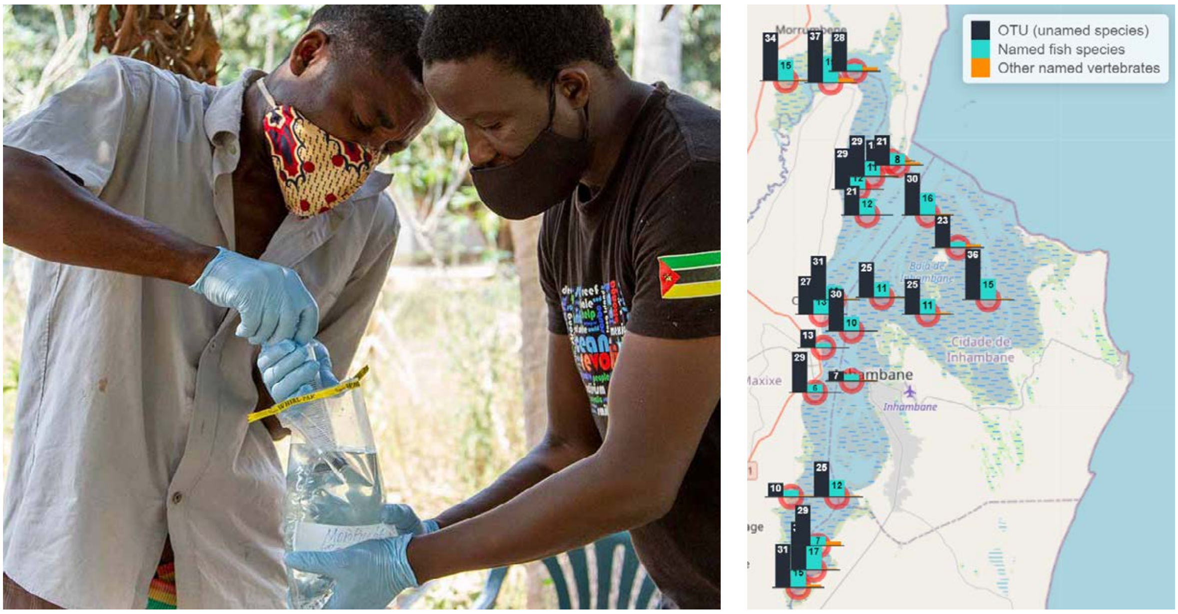


*Figure 3: Two Mozambique locals collecting a freshwater eDNA sample (left) to be able to map (right) the different species detected in different locations.[30,31]*

*Disclaimer: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.*

- **Citizen science:** Citizen science is a fundamental part of geospatial data collection. Over 80% of biodiversity observation data in Europe are estimated to be collected by dedicated volunteers.[33] As citizens around the world are becoming increasingly concerned about the state of nature and more of them have access to mobile applications, citizen science can play a critical role in the data infrastructure required for integrated planning for nature, climate and people.[34] It can be used to obtain finer scale socio-economic data when compared to the scientific community. To unlock this potential, citizen science data collection activities need to be scaled up and further standardised following the example set for species observation networks, which have often adopted the Darwin Core standards[35], and have been complemented by many of the new emerging technologies such as mobile applications (apps) and low-cost sensors.[36] The latter is crucial, as citizen science is particularly powerful when it is combined with methods that require limited training and do not rely upon (expensive) equipment.[37,38]

### Example of citizen science – Indigenous communities

The Cofán people in Ecuador use drones, camera traps and satellite map apps daily to monitor their territory covering over 55,000 hectares. This enabled them to detect 52 mining concessions that had been granted without consultation. By sending photos, videos and coordinates to prosecutors as evidence, the community won a trial against the Ecuadoran government for violating their right to a healthy environment.[39] Additionally, in the Peruvian rainforest, researchers trained and paid representatives of 36 communities in the use of smartphone applications and satellite data to patrol their forests monthly and verify reports of suspected deforestation. Compared with 37 other communities where this programme was not implemented, they saw 52% and 21% less deforestation in 2018 and 2019, respectively.[40] These examples illustrate how indigenous knowledge, shared and used for centuries, can be strengthened by the latest technology, and how citizen science can fill data gaps at scales and resolutions not achievable through professional activities alone.

### Examples citizen science – Global database

iNaturalist uses a ‘computer vision’ model to automatically identify species from photographs, passing validated observations directly to the Global Biodiversity Information Facility (GBIF) database.[41] This database, built by iNaturalist’s network of 2 million users, is then used by the scientific community in their research to map the current and future status of biodiversity around the world.[42] This demonstrates the power of combining mobile applications and citizen science. It also illustrates a potential risk of data bias. Data should be analysed with care as most mobile phone users live in urban areas and travel to limited locations - data should be analysed with care.[43] Organisations like Cyber Tracker try to counter this bias by developing mobile phone tools that indigenous communities can use to manage and record adjacent biodiversity. This product includes an icon user interface to enable non-literate expert trackers to gather complex biodiversity data.[44]

## (1b) Remote sensing

**Remote sensing is "the science of gathering data about objects or areas from a distance", using sensors on satellites, or mounted on aircraft or drones.**[45] Compared to on-the-ground data, remote sensing makes it easier to cover larger areas. The entire globe can now be monitored at high resolution (up to 10 metres for openly available datasets). With this information, it is possible to easily monitor the status and threats to key ecosystems, such as the Amazon rainforest, covering 40% of the South American continent.[46] The latest developments in remote sensing technology are providing insights across a wider range of nature indicators, not only focusing on large scale land use changes but also on increased quality measurements - for instance, the ability to measure soil health. Both the resolution (spectral and spatial) and temporal frequency of measurement are increasing across the board. The question will no longer be what resolutions are possible, but rather what resolutions are needed for specific applications. This is largely due to the increased deployment of satellites (Figure 4) and the use of different types of remote sensors.

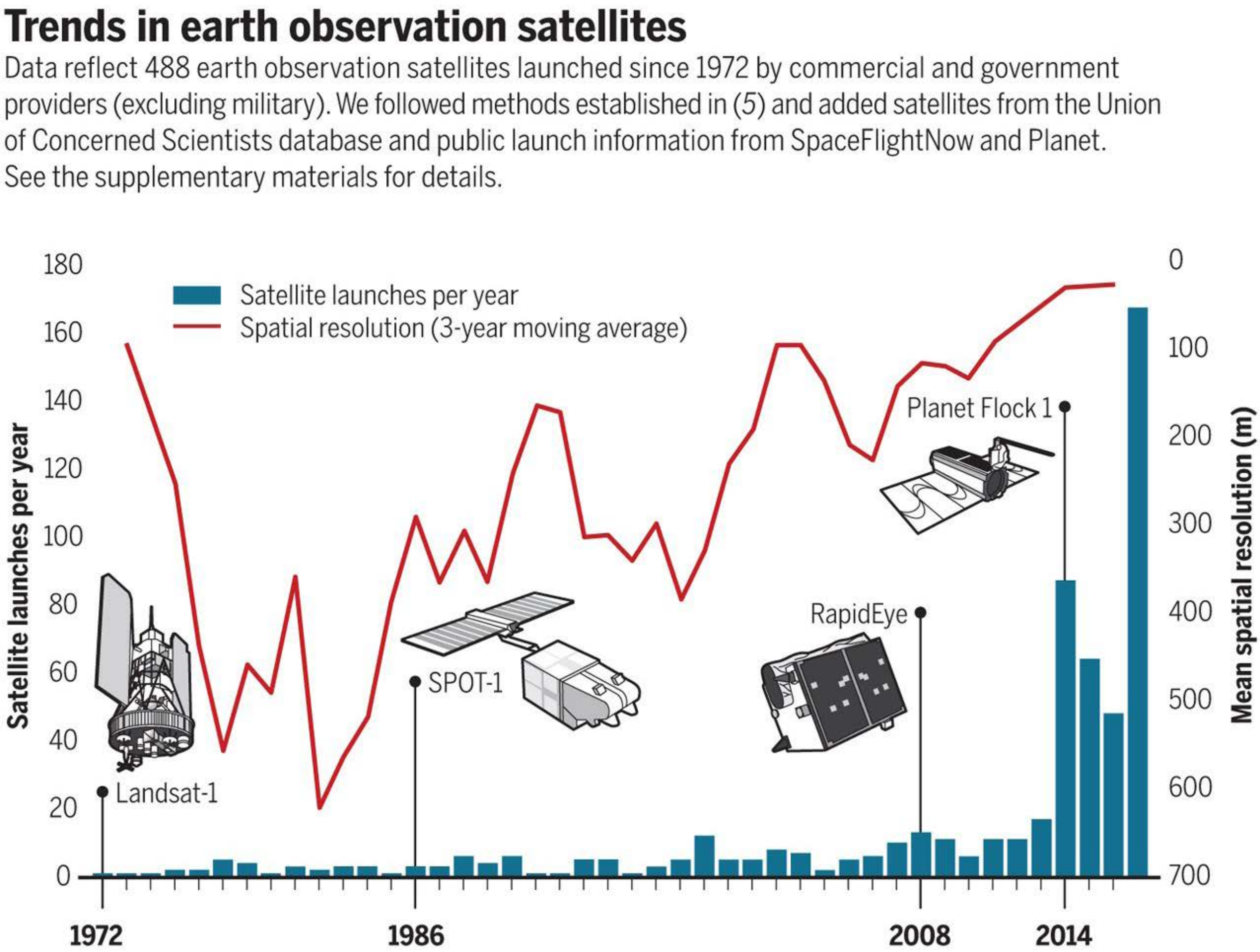


*Figure 4: Trends in earth observation satellites. Data reflect 488 earth observation satellites launched since 1972 by commercial and government providers (excluding military).* [47]

Key developments in remote sensing include:

- **Satellite remote sensing:** Earth observation satellites have historically had low spatial and low update frequency. Gradually resolutions have increased; where it was initially possible to detect fields at 100 m resolution, it is now possible to map specific tree species and illegal deforestation roads at 0.5 m resolution. The frequency of measurement also increased from having a picture available every 18 days to being able to quickly detect illegal poaching activities with images available every 4 minutes.[48] Increasing temporal, spatial and spectral resolutions of satellites, combined with increases in the speed of image processing thanks to cloud computing and Artificial Intelligence (AI), mean that resolution and frequency will soon no longer be significant barriers to the application of this technology in a sustainability context (such as near real-time monitoring of forests).[c,49]

  Increased availability of innovative satellite sensors has made it possible to measure nature and climate dimensions, which were previously 'unmeasurable'. Light detecting and ranging (LIDAR) allow measurements of vegetation structure using lasers to determine 3D structures. This makes it possible to assess (forest) biomass and carbon storage, important for measuring and (possibly) quantifying the Earth's Natural Capital.[50] Synthetic Aperture Radar (SAR) is a remote sensing technology that can collect nature and climate data in any weather conditions, day or night.[51] There are hundreds of use cases for this technology - from analysis of melting glaciers and the effect on sea levels to insurers using data to quantify flood losses.[52,53] Particularly interesting is the potential for monitoring global forests and deforestation rates, as SAR sensors allow the number of detections of changes in often cloudy tropical forests to be doubled.[54,55]

- **Aircraft/drone sensing:** Small unmanned aircraft systems typically consist of a lightweight aerial vehicle (i.e. a drone), an imaging payload, a controller, a navigational computer and a ground-based pilot. Such drones and other manned aircrafts can be mounted with sensors such as metric cameras, hyperspectral scanners and light detection and ranging systems (LIDAR).[59] The use of drones can provide more flexibility to target a specific area (compared to satellites) and improve accuracy and access to hazardous environments (e.g. also reaching an approximate depth of 6 km into oceans).[60,61] Drones can for example be used to track species such as turtles in nesting sites, saving time and not disturbing the animals directly. Drones can also be used in restoration activities such as seeding practices. In a recent restoration project in Panama drones only needed five minutes to release 750 seed balls in one hectare of land.[62]

[c] SPACES is developing a deep-dive on the role remote sensing can play when assessing impacts of land-use change on biodiversity and carbon stocks.

### Example remote sensing – Interferometric Synthetic Aperture Radar (SAR)

Interferometric SAR (InSAR) is a well-known satellite mapping technique that makes it possible to detect surface movements and ground displacement to millimetric accuracies. Terra Motion uses InSAR to take measurements over natural and vegetated surfaces, which can help to identify actively eroding peatlands and support targeted national restoration efforts.[56] Terra Motion has collaborated with the academic community to measure "bog breathing" to derive detailed information regarding the condition of the peat, from degraded to a near-natural state. In this context, "bog breathing" is defined as surface levels change of peatlands by cause of peat shrinkage and expansion due to water table changes. Terra Motion's method can strengthen monitoring and verification of restoration efforts and can be used to generate carbon credits through regular, robust quantification of reduced emissions from the restored peatland (Figure 5). Such technological advancements are critical in the fight against climate change, as peatlands contain about 25% of global soil carbon - twice as much as the world's forests - whilst only occupying 3% of the global land area.[57]

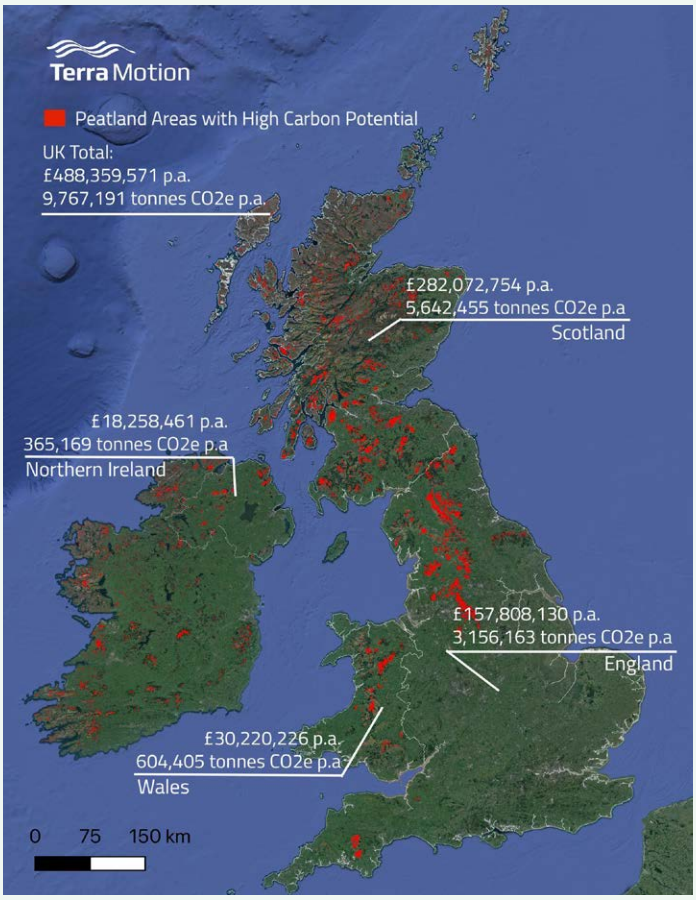


*Figure 5: Figure highlighting the possible value of carbon credits that could be generated if the highlighted peatlands would be restored, depicting the potential financial benefits of peatland restoration for climate change mitigation in the UK.[58]*

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Although there are many applications for remote sensing, satellites and other remote sensors are not a substitute for on-the-ground insights. They can help with monitoring, planning and prioritisation of specific locations, but local measurements and operations will always be needed to ensure appropriate location-specific action. Linking remote sensing results to on-the-ground action also remains a challenge. Research suggests that, despite substantial investments in remote-sensed applications, early deforestation alerts generated by forest monitoring systems in the Amazon rarely reach the most directly affected populations in time to deter deforestation, as insufficient resources for policing illegal deforestation are available.[63] Remote sensing is an important first step, but does not provide a complete solution.

## (2) Data processing and analysis

**Collecting data is an important step; but without processing, analysing and interpreting it, data cannot be translated into usable information. This becomes even more important as the amount of data to be processed increases.** To quote EO Wilson: "We are drowning in information, while starving for wisdom".[64] Advancements are reducing the time and effort needed for data filtering, (pre-) processing, storing and analysis. As a result, what currently requires huge computing time, resources, expertise, and a team in place, can increasingly be done by a single operator on a desktop connected to 'the cloud' (using an internet connection).[19] These advancements are represented in the plethora of useful tools and platforms for processing data, such as Microsoft Planetary Computer, the FAO Collect Earth tools, and the Google Earth Engine (GEE). On such platforms, users can both easily find nature and climate data and analyse this data from their laptop using 'distributed computing environments'. There are several key advancements in this area:

- **Automatic classification:** Artificial intelligence and machine learning technologies such as neural network algorithms can recognise underlying relationships in a dataset through a process that mimics how the human brain works.[65] This allows instant and automatic classification, and the detection of patterns in land use and biodiversity data that even "elude the most sophisticated human analysis".[66]
- **Edge computing to speed up processing:** The paradigm 'edge computing' brings computation and data storage closer to the source and improves response time.[71] It can be used to quickly process the huge amounts of data produced by hundreds of networked sensors. Simply put, computing and storage resources are deployed at the location of each sensor rather than centrally. This leads to less raw data having to be stored - raw data is erased after summary results have been generated – leading to faster processing times.

### Example analysis – image classification

Near real-time data and predictive capacity improve the opportunities to detect activities such as deforestation and wildlife poaching. As data collection becomes easier, it also becomes possible to collect land use data more continuously at shorter time intervals, and with shorter feedback times. It is then possible to better track business activities, monitor wildlife, and enforce regulations. For example, algorithms have been developed to classify images captured in the Lopé National Park in Gabon: the software is capable of analysing images in a matter of hours, allowing eco-guards to quickly identify any warning signs in the animal population and act quickly to prevent poaching. The effectiveness of this new solution is enhanced by the software's ability to operate without an internet connection, which is often difficult to access in remote areas.[67]

### Example analysis – GEDI biomass data

The Global Ecosystem Dynamics Investigation (GEDI) is a LIDAR instrument aboard the International Space Station designed to measure vegetation which can be used to estimate aboveground biomass at billions of points around the world.[68] This data is difficult to process due to its volume. Descartes Labs has therefore designed an "empirical model" that can estimate carbon from a single optical satellite image, meaning that fewer processing steps are needed (Figure 6). The model is 'trained' on GEDI biomass data and is used for carbon change tracking over time (which is highly relevant for the carbon market).[69]

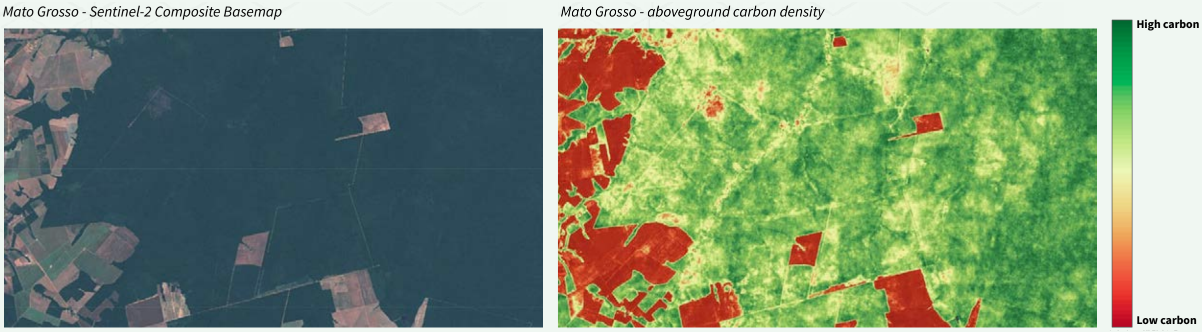


*Figure 6: A base map (left), and an aboveground carbon density map (right).[70]*

- **Predictive and prescriptive modelling:** Scenario modelling is a mature discipline. It can be used to model 'what-if' scenarios, making it possible for organisations to plan for different potential outcomes and project the nature and climate impacts of different options for action.[72] Artificial Intelligence (AI) and machine learning (ML) offer new computational tools that allow actors to move from descriptive (describing what has happened) to predictive (describing what is most likely to happen) and prescriptive analytics (recommending actions one can take to affect these outcomes). This enables opportunities for planning and risk management.[73,74] Their use can help predict where deforestation might occur based on historic trends or infrastructure development in surrounding areas, and automatically recommend actions to prevent deforestation.

- **Integration of nature, climate, asset and supply chain data:** Integrating different datasets increases insights on the interrelated aspects of nature and climate to help create more effective, comprehensive and long-lasting interventions, and support prioritisation. Interoperability of different datasets is critical here to make sure datasets can easily be integrated. Although specific elements can increasingly be automated, integrating data from various sources and in different formats into usable forms of intelligence remains a time intensive task. The potential benefit of solving these issues, however, is enormous. Recent research concluded that, for biodiversity, the "integration of distribution databases could lead to increased taxonomic coverage that corresponds to 23 years' advancement in data accumulation".[75]

  The impact of integrating nature and climate data with supply chain data is also large.[76] Innovations are ongoing to create more integrated virtual models of the physical world, building on spatial decision and policy support systems.[77] In this category, the Digital Twins concept has promising implications for sustainability. These 'dynamic maps' are constantly updated in response to new data and present virtual models of a real-world object, machine, or system that can be used to assess how the real-world counterpart is performing, diagnose or predict faults, or simulate how future changes could alter its behaviour.[78]

  Digital twins can enable the integration of asset and supply chain data with Earth system data (collected using both remote sensing and on-the-ground data) to improve monitoring, prediction analytics and scenario analysis to inform action on nature and climate.
- **Data visualisation:** Data visualisation and storytelling (through graphs, maps and dashboards) are critical mechanisms for engaging audiences on the nature and climate crises.[81] Several initiatives make satellite remote sensing data easily available via online portals, such as the US National Oceanic and Atmospheric Administration's Coral Reef Watch (providing current reef environmental conditions and heat stress to identify areas at risk from bleaching), and the World Resources Institute's Global Forest Watch (presenting forest cover as maps and dashboards and producing weekly deforestation alerts).[82] The latter is a public-private partnership with a collaboration between different actors, including Norway's International Climate & Forests Initiative and private satellite images provider Planet Labs.[83]

## (3) Data sharing and accessibility

For spatial intelligence to be useful, it must be accessible to its users. There is currently a large digital inequality in the availability, access, and use of data and technology. The market has generally shifted from directly selling unprocessed data, towards making various datasets available on platforms and marketplaces, and now to selling 'analysed information as a service' directly tailored to end-users. Platforms or marketplaces help connect data and combine a flexible interface with varying functions that can be tailored to specific end-users.[84] Examples include Global Forest Watch, a platform which offers free and real-time data on forests bringing all the key datasets together in a common platform (Figure 7).

A premium service, Global Forest Watch Pro, goes further by providing analysis and dashboards to businesses on a property, supply shed and portfolio level.[85]

### Example analysis - Digital twin

**Governments can use digital twins and other software advancements to enhance the understanding of interactions across systems and enable a better understanding of interdependencies among various national commitments.** Predicting interaction between “natural phenomena and human activities” is essential as governments try to manage the ‘multi-dimensional human needs driving competing demands for finite land areas’. By 2030, the European Union project Destination Earth (DestinE) aims to develop a digital twin of the Earth to monitor and predict such interaction.[79] On a national scale, Singapore recently completed work on the world’s first digital twin of a whole country. Satellite data were transformed into a digital model of the country (e.g. illustrating infrastructure and/or land use). This integrated digital twin infrastructure is already helping Singapore respond to challenges such as the rollout of renewable energy. This includes being able to measure how much and where solar photovoltaics (PV) should be installed and how best to meet their solar energy commitment by 2030. Additionally, the digital twin is also used to respond to the impact of climate change, as the terrain model supports national water agency resource management, planning, and coastal protection efforts.[80]

**Spatial intelligence is increasingly designed for a wider (non-expert) audience.** UN Biodiversity Lab (UNBL), for example, is a platform that provides free access to approximately 400 spatial data layers from the best global available datasets to a wide, non-technical, audience, where users are not required to have any GIS and data processing skills. Decision-makers within the Government of Haiti use this spatial data and aerial imagery from UNBL to monitor protected areas.[86] The Climate Council has recently launched another shining example of a tool that has engaged a broader population through its simple interface. Their new and interactive Climate Risk Map of Australia shows the risk of climate-fuelled extreme weather events, such as bushfires and floods, to properties in electorates, local government areas (LGAs), and suburbs all around the country. On the website, users can directly send the Climate Risk Map of Australia to their federal candidates, “urging them to put the spotlight on climate action before the next election”.[87]

**Data sharing and integration of data sources among platforms are critical.** A company can for instance only measure its complete footprint (e.g. including scope 3 emissions which an organisation indirectly impacts in its value chain) if it has insights into its suppliers’ footprint. Data sharing is technically possible. Application Programming Interfaces (APIs) can for example be used to enhance connections and interoperability between databases. There are however several challenges to data sharing. Firstly, one must ensure interoperability to make it possible to integrate multi-source data. This can for instance be done through consistent use of measuring methods and data structures. Secondly, an architecture must be in place to allow data sharing; the central question of who ‘owns’ data must be addressed to ensure credibility, maintain openly accessible datasets and secure funding and respect data privacy and sensitivities.

**Data privacy and confidentiality remain a barrier to data sharing.** Governments and companies need to ensure that confidential data is protected from unauthorised access. As part of the solution, new technologies, such as cryptography, federated learning and distributed ledger technology (e.g., blockchain[90]), make it easier to respect data privacy and confidentiality. Such forms of data sharing make spatial intelligence more widely and easily available.

## Example accessibility - Marxan

Marxan is a freely available Systematic Conservation Planning (SCP) software, which helps decision-makers identify and manage priority sites for conservation (Figure 8).[88] SCP takes the big data tables generated by new data collection technologies and converts them to a single site ranking by conservation value, which is much more usable for decision-making for making maps. takes the big tables Marxan software has been used in over 180 countries for protected area design and management. A project called Democratizing Marxan is bringing Marxan's open-sourced spatial planning software to 'the cloud', making the Marxan platform accessible to a non-expert audience that can now easily use Marxan in the form of a website.[89]

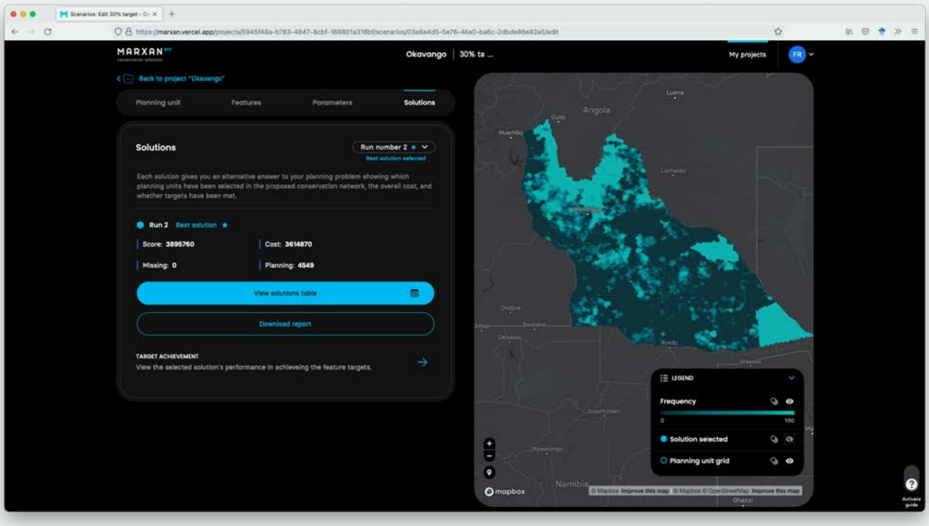


*Figure 8: An example optimisation of conservation areas near the Okavango River in Angola using Marxan. Marxan (http://marxansolutions.com) helps practitioners identify which areas have the greatest impact by weighing variables such as species extent, habitat types, and cost.*

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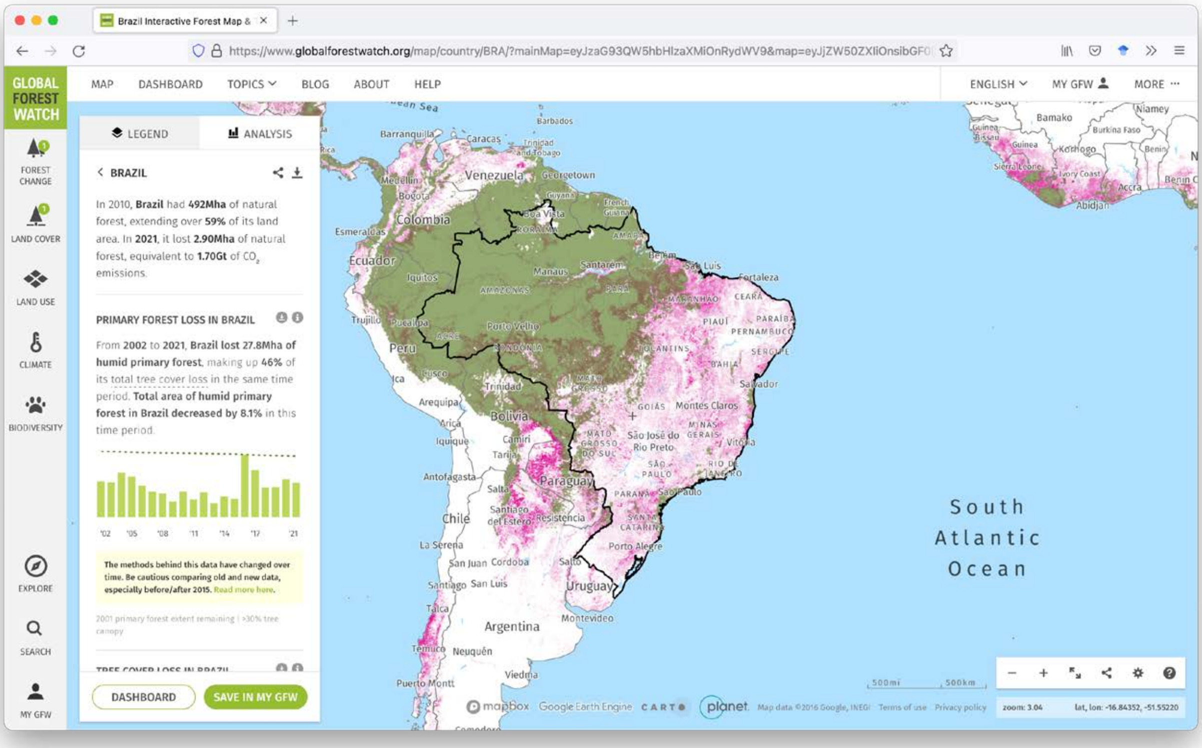


*Figure 7: forest loss in Brazil between 2000 and 2021 shown in Global Forest Watch. Global Forest Watch (http://globalforestwatch.org) provides in depth data and tools for monitoring and taking action on forests globally.*

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## Example data sharing - PACT

The partnership between the World Business Council For Sustainable Development (WBCSD) and the SINE Foundation has demonstrated the possibility of a functioning data sharing model. This group works closely with leading international companies, including BASF, Nestle and Unilever, to develop standards for calculating and sharing product-level emissions data along complex value chains. The group, which includes large tech companies like IBM, Microsoft and SAP, jointly decided that traditional, closed platforms for sharing this data were inappropriate in this case. Instead, the platform is designed to become a data commons - an open network for data collaboration. The SINE Foundation is leading the technical implementation of the commons, which includes the overarching architecture as well as data standards, programming interfaces and cryptography. The system is “open source” so that the technical components are fully transparent. Nevertheless, each company has sole sovereignty over its data. Other participants can only access data in encrypted form but use it to make necessary calculations. The control architecture includes rules for the provision and use of data, as well as for verification and conflict resolution.

4

# Unlocking the potential: how to increase uptake of spatial intelligence to deliver action on climate, nature and people

**While technological innovation is exponentially increasing the availability, accessibility, usability and interpretability of spatial intelligence, there is limited application and uptake of spatial intelligence technologies by the public, civil society, and private sectors to date**. Biodiversity and nature data is often patchy and out of date, is irrelevant at certain local scale, with limited integration of different data layers. This reduces the accuracy of national spatial planning strategies and business mapping of nature and climate impacts to drive action. New technologies present opportunities for countries to more frequently collect nature and climate data, integrate and translate these different data layers into intelligence, and make them accessible to decision-makers. Likewise, new technologies also present opportunities for businesses to track their value chains and estimate their overall nature and climate impact. In the future scenario planning is also likely to become easier.

**This section explores the cross-cutting conditions that need to be addressed to enable high-quality spatial data collection, analysis and intelligence that drives nature and climate action.** SPACES proposes three conditions:[91,92]

1. **Incentives and Price:** Both the private sector and government agencies should be incentivised to adequately value, collect, and use spatial intelligence by an enabling regulatory and financial environment. This will require striking the right balance between freely available spatial intelligence and intelligence available at price, provided by (private) companies and other organisations with guarantees of long-term provision, update and price control.

2. **Quality, Standardisation & Usability:** Spatial intelligence should be integrated, consistently updated, fit-for-purpose and actionable. It should be usable for its specific audience, considering different needs and levels of expertise. Users should have the minimum technical expertise to be able to adequately assess the quality of information.

3. **Accessibility & Acceptability:** Spatial intelligence is easily findable and accessible to all stakeholders. It will need to be trusted and accepted by key stakeholder groups. Ideally, it will be developed in collaboration with local partners, considering the current strong preference for use of nationally and proprietary generated (and owned) spatial intelligence.

The framing of these three conditions allows more in-depth exploration of the barriers that need to be addressed, and the role that different system actors can play in addressing them.

## 4.1 Incentives & Price

**Although technological innovations are resulting in declining cost curves, governments, businesses, and financial institutions do not always have sufficient budgets and capacity set aside to allow spatial intelligence to sufficiently inform their nature and climate strategies.**[19,93] This lack of sufficient funds leads to a huge dependency on the scientific community, NGOs and volunteers to develop and apply spatial data. These actors often work with short-term funding windows meaning that there are often no resources to maintain and update datasets and websites with the latest technologies. This is either done voluntarily or not done at all, leading to fragmented, non-interoperable and infrequently collected data.[d,19,94] This is unfortunate, as near real-time tasked intelligence allows for adaptive management, and leads to flexible decision-making.

**Businesses should be incentivised to adequately value and fund the collection and use of spatial intelligence through an enabling regulatory and financial environment.** High-quality spatial intelligence will succeed only if an increasing amount of private funding is unlocked and directed towards the right resources for spatial intelligence collection and use. Businesses are increasingly incentivised to better understand the impact of where operations and supply chains are located. Supply chain transparency is for example gaining more legislative ground via various local legislation (e.g. Germany - Lieferkettensorgfaltspflichtengesetz) and the upcoming Corporate Sustainability Due-Diligence Directive (EU). Initiatives and frameworks, such as TNFD, SBTN and the International Sustainability Standards Board (ISSB), can complement such legislation and regulation. Where legislation, regulating and incentivising the private sector to increase monitoring and driving action on nature and climate still leaves significant gaps, governments and philanthropies could subsidise the cost of long-term data collection or data access, in particular for users with a lower capacity to pay.[95]

**There is a need for sustainable business models and corresponding markets to collect and apply spatial data sustainably and uniformly.**[96] An example of such a business model could be the use of nominal fees, where alliances (such as the UN Net Zero Banking Alliance) collectively invest in spatial intelligence and collectively benefit from integrated data, standard user interfaces, and universal use-cases. Such business models should support spatial intelligence providers from the scientific community, NGOs, volunteers and private (for-profit) companies. The scientific community cannot supply all the spatial intelligence needed, and all actors must be involved to enable the highest quality spatial intelligence, finding the right balance between a market in spatial intelligence solutions and open access to publicly funded spatial intelligence. In some cases, a premium could be beneficial as it could increase funding flows. Spatial intelligence providers can only scale-up if they can monetise their specifically tailored offerings built on top of (publicly) available data.[97] The growing involvement of corporate technology companies in conservation technology (e.g. Microsoft, Google) is already shifting these financing dynamics substantially.[98]

[d] Previous research showed that "Common issues that reduce the quality and usability of data across technological tools are the short-term nature and design of monitoring systems. Many projects last 1–3 years when at least ten years is usually required for conservation impact and for detecting ecological change".

## 4.2 Quality, Standardisation & Usability

**Spatial data and intelligence should be high-quality, actionable and reliable. They should be relevant to users, of a suitable spatial and temporal resolution, frequently updated, with sufficient geographical and thematical coverage and be comparable and interoperable through time and topic. They must be constantly assessed for accuracy.**[99] Quality is still lagging; only 5% of data sets on biodiversity threats are "freely available, of a suitable spatial resolution, up to date, repeated and assessed for accuracy", and other data sources are not likely to be better.[100] Additionally, there are political and technical challenges in ensuring 'interoperability' of datasets. Spatial intelligence is often fragmented, and users often have to collate data from various sources. This leads to a lack of integration, making it difficult to attain a holistic overview of the different interdependencies at play. The world needs (updated) data quality and measurement standards that ensure high-quality, comparable, and interoperable data.

**Data and intelligence should also be usable for their specific audience; it should be understandable and should come with technical support or training to be able to use it.** Historically, spatial intelligence tools were mostly produced by academia and NGOs. They were not often designed in a way that governments, businesses or financial institutions found easy to use. This is changing, as larger tech incumbents are leveraging their existing capabilities to expand into the field of nature and climate; start-ups with a specific nature and climate focused offering are also emerging. Co-design is key: spatial intelligence providers, both public and private, must better tailor data and intelligence to specific end-user needs through a collaborative development process.[101] Geographical and sectoral factors should be considered here too, such as attention to limited internet or electricity access in some areas.[102] Aside from visualising, packaging, and co-designing spatial intelligence in a way which makes it usable by end-users, decision-makers' knowledge and capabilities can also be increased. Users should have minimum technical expertise to adequately assess the quality of information they are integrating into their decision-making process.

## 4.3 Accessibility & Acceptability

**Spatial intelligence should be sufficiently accessible to stimulate use, with simple systems making spatial intelligence available online in different formats (e.g. direct downloads, web services, platforms).** Increasing accessibility and 'findability' of forms of spatial intelligence could reduce the "huge level of duplication of effort, with different organisations often developing similar data sources or data mapping platforms to each other".[103] The private sector can play an enormous role here, as they for instance collect nature and climate data for their Environmental Impact Assessments (EIA's). There is great potential here, as private companies for instance only account for 0.3% of all records published in the well-respected biodiversity data platform GBIF. Making a greater effort to publicise data sources, through regulatory pressures, public-private partnerships or specific licenses can be an important enabler of mainstreaming spatial intelligence into decision-making.

Additionally, guidance should be translated for non-English speakers, to ensure better access and understanding, which help to increase the geographical and taxonomic (i.e., the number of species covered by the relevant studies) coverage of biodiversity data by respectively 12-25% and 5-32%.[104,105] To support data sharing, the right data architectures will be needed. Platforms must be advanced to collate, curate, analyse and assess data from multiple sources and domains. Sufficient resources for data storage and maintenance will be key here.

**Increasing accessibility of spatial intelligence within organisations is also important, as many organisations are using spatial data and intelligence, but for a limited set of specific purposes.** Such existing spatial intelligence could be leveraged to its full potential by stimulating data sharing and more holistic platforms for data integration across a (public or private) organisation.

**Even if spatial data and intelligence are accessible, spatial intelligence for nature and climate must still be trusted and accepted to be used.**[106] Such acceptance often has institutional, policy, demographic, geographical and socio-economic drivers. There is still a large potential for improvement in this area.[107] Spatial intelligence is more likely to be seen as authoritative if it has been subject to peer review, or a UN process such as an Intergovernmental Panel on Biodiversity and Ecosystem Services assessment. The ability to take parallel independent samples can also build trust and acceptance. A mine and a community could for instance both take exactly the same set of eDNA and sensor samples to ensure credibility of data. Traceability or 'open-sourcing' is key when it comes to translating this data into intelligence. This means that the original data used and the 'data trail', laying out how the data has been translated by different users to arrive at its final format, should be clear.[108]

5

# Call to action

**Collaborative action is needed to ensure spatial data is funded and collected, is standardised and therefore usable and trusted, and is made accessible and widely shared. Only then can the growing potential of new spatial intelligence and technologies be unlocked to further drive nature and climate action.** Businesses (including private investors and insurers), governments, data collectors, technology providers, tool developers, standards bodies, the scientific community and society at large can all help to further drive nature and climate action through the use of spatial intelligence. Actors should work together to kickstart action now and improve precision and ambition over time as science develops further. The insights one could already obtain when wisely integrating existing data sources could already be enormous. Government and businesses could start with determining which forms of spatial intelligence they specifically need to drive nature and climate action and sustainable spatial planning practices. What 'proof' and information are needed to kickstart nature and climate action? In parallel, spatial intelligence providers, both public and private, could help co-design the solutions these groups so desperately need, ensuring the quality and acceptability of these solutions as they adhere to the standards and framework being developed by a wider international community.

**Three urgent challenges must be overcome** to unlock the potential of new spatial data and digital technologies to support nature and climate action:

1. **Private and public investment is needed to identify and close data gaps, and to unlock sustainable funding for frequently updated spatial nature and climate data.**
    - Investors and companies must be incentivised to better understand where their operations and supply chains are located. Regulations (such as the EU Deforestation Law) are needed to incentivise this.
    - Collaboration (within and between sectors) is needed to determine which data is needed, which public and private actors are best placed to collect which data, and which platforms are best placed to host this data.
2. **The data community needs to agree and adopt data measurement and quality standards to ensure delivery of high-quality, comparable, and interoperable data in formats suitable for the private and public sector.**
    - Current data providers, technology companies, standards bodies, regulators, corporate users, investors, and civil society could adjust and design data quality and measurement standards (e.g. Darwin Core, ISO certifications) and regulation to ensure high-quality, comparable, and interoperable data.
    - The international community could congregate and expand on existing "data and tools overviews and assessment" to ensure all available spatial intelligence can easily be found and its quality is 'assessed'.

- Spatial intelligence providers could co-design products specifically with users, and always include resources for capacity-building for the users to ensure the product is adequately used in the long term.
- Mechanisms need to be in place to incentivise the market to innovate. Practice and reporting standards could for instance reassure potential users that new spatial intelligence technologies will be accepted by regulators.

3. **Companies and civil society organisations must be encouraged and incentivised to share the nature and climate data they generate through public databases.**
   - Businesses and governments could better understand what spatial data and/or capacity they already have access to internally, ensuring data is integrated across their business units and ministries.
   - Privately and publicly held data could be released into accessible platforms, following all relevant processes for data protection, privacy policies, licensing and security for countries, people and endangered species. Specific sectors/regions could kickstart this through specific data sharing projects (e.g. West Africa Cocoa Farm Dataset to be published by the end of 2022).
   - Data sharing should be incentivised. Potentially designing regulatory mechanisms to channel privately collected spatial intelligence into the public space. Initiatives and frameworks, such as TNFD, SBTN and the International Sustainability Standards Board (ISSB), can complement such national policies and regulation. Similarly, financial investors and insurance companies can push for data to be made accessible.
   - In some circumstances spatial data could move away from commercial subscription models, and the for-profit market could focus on building specifically tailored products on this (publicly available) spatial data available through API's.

Tremendous environmental challenges lie ahead, and the solutions will need to consider the specificities of each situation and location. Nonetheless, these innovative technologies can provide the necessary tools for people to act in a 'net zero' and 'nature positive' manner. It is critical data is funded and collected, is standardised and therefore usable and trusted, and is made accessible and widely shared – the future of people and the planet depend on it.

# Appendix

# A. Overview of the different types of 'on-the-ground' sensor measurements[109]

- **'Direct' measurements**
  - Observer based methods - 'Human eyes and ears' (e.g. field surveys)
  - Active sensors
    - **Physiology and energetics sensors** (e.g. body temperature)
    - **Visual sensors:** e.g. camera traps both on land and underwater with 'Baited Remote Underwater Video Stations', animal tagging with an antenna or tags, biologging with sensors located on or inside an animal
    - **Thermal sensors**: e.g. scopes, goggles, rifle scopes; This is particularly under some conditions (e.g., at night, with cryptic background or when species are hidden by vegetation)
    - **Acoustic sensors:** active recording of a species' sound
  - Passive sensors
    - **Vibration sensors:** can be used to detect vibration created by smaller objects at more local scales, such as the vibrations emitted by elephants[27]
    - **Thermal sensors:** e.g. cameras, and airborne thermal sensors
    - **Sensors for body position and movement:** e.g. pressure sensors can measure altitude of a bird during migration)
    - Acoustic sensors
      - Sound recording/landscape audio analysis[5] both on land and in oceans (acoustic loggers). Can be used to detect threats such as forest degradation. Sensors can be left unattended in the field for extended periods, either recording sound at pre-programmed intervals or in response to acoustic triggers
      - e.g. active sonar is used to detect fish schools and can estimate biomass in fisheries studies, these sensors can also map depth (bathymetry)
    - Visual sensors
      - Aerial (drones, airplanes)
      - On-the-ground (cameras, radar, lidar, tracking with radio-frequency triangulation)
- **Environmental and atmospheric sensors**
  - Environmental parameter measurements which include measurement of salinity, temperature, wind, wlope, water quality, magnetic field, gas concentration, air quality, moisture content in soil or air[27]. These sensors can also be active or passive. Examples include the use of a Weddell seal with a satellite relay data logger on its head with CTD (conductivity, temperature, and depth) sensors
- **Museum/ herbarium data**
  - Museum collections (to determine reference points and present day distributions
- **Supportive data gathering tech**
  - Which includes drones and other autonomous vehicles

## B. How can Nature's Contributions to People be better monitored and managed using the new and expected data opportunities?

By combining the technological advancements of the different technical dimensions mentioned in section 3, a world of opportunities is emerging for spatial intelligence and planning for nature & climate. Here we select 5 of 'nature's 18 contributions to people'[e] to highlight some of these opportunities.

| 1. Climate regulation | |
|---|---|
| The rationale for measuring climate regulation | The atmospheric concentrations of $CO_2$ have increased by 47% since 1750 and concentrations of $CH_4$ and $N^20$ have also increased. This unprecedented increase in emissions is affecting every region of the world, with anthropogenic activities causing many of the observed changes in weather and climate.[110] Deforestation, forest degradation and the management of forests are major sources of $CO_2$ emissions, almost offsetting land-based carbon sequestration. The urgency to address climate change through nature-based solutions requires effective forest monitoring systems that reduce uncertainties and other constraints, as well as provide spatial detail with real and near-term data.<br><br>Climate regulation is an ecosystem service provided by nature (atmosphere, habitats, soil and sediments, and species) through carbon storage and sequestration in soils, vegetation, and the oceans.[111] This geochemical process is not the only regulator of climate. Biophysical mechanisms that mediate energy and water at the land surface are also used by ecosystems to regulate climate. The incoming solar radiation is balanced by energy released from the land surface in an equilibrium state. The amount of solar radiation that the land absorbs is determined by its reflectivity (i.e. albedo). We can assess physical climate regulation by ecosystems by estimating the relative influence of changing land cover vs large-scale atmospheric circulation on local heat and moisture budgets.[112] i This approach has demonstrated that ecosystem biophysical climate regulation has a significant influence on air temperature and moisture in boreal and tropical regions. |
| Current data gap | Defining emission factors, monitoring of fluxes, sometimes measuring carbon emissions in the air and measuring above the ground storage and sequestration of carbon stock (including land use change impacts) are all possible. Fluxes of carbon and methane between the Earth's surface and the atmosphere can be estimated by combining in situ and satellite observations with computer models. However, datasets often incompletely cover the precise location and impacts on emissions.[113] In addition, most studies on climate regulation services are focused on biogeochemical services, ignoring biophysical forcings from land use change (e.g. changes in albedo, effects on rainfall). |

[e] This study uses Nature's Contribution to People to identify certain KPI's for nature & climate. Other existing frameworks could have also been used to identify such KPI's, such as ecosystem services. The 18 categories of Nature's Contributions to People (NCP's) are defined by the IPBES as "all the contributions, both positive and negative, of living nature to the quality of life for people". In this paper, five of these NCP's are used to describe the opportunity of the new technologies.

| | |
|---|---|
| The opportunity of new technologies to fill this gap and barriers that remain | With new technological advancements in sensor networks and data analysis, it becomes possible to measure non-carbon GHG emissions (especially methane) at high precision and frequency.[114] With LIDAR satellites, 3D images can be generated, making it possible to measure above the ground sinks of carbon (e.g. forest biomass). The use of GHG flux model estimates based on improved satellite data from for instance, GEDI, ICESTAT-2 and BIOMASS address the lack of consistent time series on forest growth which affects estimations of annual trends in gross removals and net fluxes.[115] Additionally, underground carbon sinks can also be measured using the latest advancements in data analysis.[116,117] Generally speaking, datasets are more integrated, complete, contain more precise & real-time data, can be measured at a regional scale, and have detailed forecasts.[118] With an integrated climate regulation index (CRV), estimated biogeochemical parameters and predicted biophysical processes can effectively quantify climate regulation services.[119] The climate regulation index uses observed climate data and simple land surface models to determine the ecosystem effect on climate via biophysical climate regulation.[120] To complement insufficient data for a particular region, the data can be averaged across spatially delineated ecoregions. |
| **2. Habitat quality and quantity (including species diversity)** | |
| The rationale for monitoring habitats | Biodiversity – the diversity of genes, species and ecosystems – is essential for the provision of all nature's contributions to people. The global biodiversity crisis is driven by habitat fragmentation, pollution, land use and land use change, invasive species, climate change, habitat succession, and catastrophic events – giving rise to the need to monitor habitats at global, regional, national, and local scales.[121] Hunting and trapping is the major threat to mammals and birds, prevalent in almost all geographies. Habitat monitoring is a process that tracks the habitats' conditions, and the ecosystems and habitats' various types to evaluate how they are changing, and understand the events causing habitat change over spatial and temporal scales – which has several benefits over species or site-specific monitoring. In addition, this approach provides insights into organisational levels of biodiversity – the characteristics of species and the association between species and habitats via field mapping.[122] Monitoring schemes may consider species composition, distribution (range, area), structure and function, and abundance, primarily through remote sensing and field surveys. |
| Current data gap | Remote sensing technologies (Sentinel-2, Landsat) are useful for monitoring land surface changes over time and mapping vegetation, providing an opportunity to identify changes in vegetation structure and the subsequent impact on species and ecosystem function. The status and structure of different global habitats and species can be measured, although spatial and temporal resolution and global coverage are sometimes lacking.[123] |
| The opportunity of new technologies to fill this gap and barriers that remain | Habitat loss can be measured with more precision, on a larger scale and in real-time. Habitat loss can increasingly be forecasted, enabling early interventions and leading to the easier definition of the most valuable, high-risk regions.[124] Another development is that 3D images make it possible to precisely estimate the amount of carbon that can be stored in forests.[125] Multi-spectra time series satellite images are used to detect and approximate the amount of harvested area and living trees in forests, but also map out the entire forest structure changes in terms of volume, canopy density, and stand density.[126] Large animals, such as African elephants, can also be monitored from space, making it easier to protect this critically endangered species. Cameras are used to capture moving photographs of large animals and birds, but also threats such as poaching.[127] Acoustic recording devices can monitor the presence, abundance, and distribution of bats, birds, wolves, and frogs in terrestrial environments. |

| 3. Pollination | |
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| The rationale for monitoring pollination | Pollinators and pollinating services are critical to the functioning of ecosystems; our food production, natural environment, maintenance of plants population and economy depends on pollinators.[128] Approximately 90% of flowering plants are pollinator-dependent and they are critical to ecosystem functioning – as they can create habitats and provide food products. 75% of global crops depend on pollination[129], and products from species of bees such as honey, pollen, venom, resin, and wax, have nutritional, health, medicinal, cultural and religious values.[130] Cocoa, an essential commercial crop in the world, fully depends on pollination by insects and other pollinators such as bats, birds, and rodents.[131] Over 500 plant species are reliant on bats to pollinate their flowers comprising species of banana, mango, durian, guava and agave. During pollination, pollen grains are transferred from one stigma to another through a biological process – enabling fertilisation and reproduction. However, the status and trends of pollinators are discouraging, the IUCN Red List mentions that 16.5% of vertebrate pollinators are threatened with extinction. Habitat loss, land use change, insecticide, disease and climate change are causing the decline of pollinators. Because they are under pressure, there is a growing national.[132] and international demand to understand the global status and trends of pollinators to inform sustainable management and protection strategies. Pollinator monitoring is the process of collecting information on the drivers and threats to pollinators, the destruction of plant-pollinator networks, and the effectiveness of methods to protect pollinators and manage their functions and services. Given the scarcity of data on the condition of wild pollinator populations on a national scale, well-designed monitoring will be invaluable in providing the consistent baseline data needed to shift to more targeted assessments or management decisions. DNA barcoding and citizen science are useful for pollination monitoring. |
| Current data gap | Pollinator status and ecosystem status are measured, with significant geographical and taxonomical data gaps.[134] The UK's Pollinator Monitoring Scheme is the only programme gathering systematic data on the abundance of insect pollinators at the national level – pointing out the substantial data gaps in pollination monitoring globally. |
| The opportunity of new technologies to fill this gap and barriers that remain | More types of species can be covered, at larger spatial scales, on a more continuous timescale. In addition, greater predictive power is possible, enabling real-time intervention.[135] For instance, using both AI methods and data from infrared sensors, the state of flying insect biodiversity can be quantified by clustering insect wingbeat signals.[136] DNA barcoding offers huge potential for generating data on pollinators – insects caught in a trap are identified from a barcode of their DNA and compared with the corresponding record in a database. Machine learning could be used to enhance computers' ability to recognise species from photographs, foraging patterns or sounds.137 Machine learning might also be used to reassemble ecological networks, possibly using DNA samples collected from animals and plants in the wild.[138] This might disclose how different species interact with one another, revealing changes in ecosystems swiftly and cheaply. |

| 4. Soil formation and protection | |
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| The rationale for monitoring soil formation and protection | The health and well-being of organisms depend on the complex processes that occur in soils. Soils play important roles in delivering all 18 Nature's Contribution to People and the UN Sustainable Development Goals. Local and small-scale agriculture accounts for roughly 40% of worldwide agricultural land area and supplies over 50% of global food and feed needs.[139] Sustainable management of agricultural land may involve enhancing soil biodiversity and increasing soil organic carbon (SOC), which is a key predictor of soil quality, soil health, and crop yield. Soil health is connected to human health – serving as a foundation for the supply of medicinal, genetic, and biochemical resources. Soils serve as a sink for atmospheric $CO_2$. The land that the soil helps form serves as a cultural environment for human activity, soils also regulate fresh and coastal water quality. However, soils are susceptible to degradation - inadequate soil management methods have resulted in decreases in soil carbon, biodiversity, and nutrients, as well as an increase in soil erosion, compaction, water pollution, sealing, crusting, and desertification. Therefore, there is a requirement for continuous monitoring of soils to inform policies for protection and sustainable management. |
| Current data gap | Soil condition and erosion can be mapped and modelled at a regional and country level, although this is expensive and time consuming due to the necessity for soil samples.[140] The ARIES Model, an adaptive modelling technology, uses information from literature in a Bayesian model of erosion as a metric of soil retention.[141] The InVEST sediment model and WaterWorld are also both useful for assessing ecosystem retention service, particularly in decision contexts that require ranking of sediment export areas, such as spatial prioritisation of conservation, development, or restoration activities. However, data on soil biological and physical properties are underrepresented and the monitoring indicators vary across countries.[142] |
| The opportunity of new technologies to fill this gap and barriers that remain | By combining satellite and direct sensor data, more precise predictions and estimations of soil state and biodiversity can be made on a global scale. Measurements are more cost-effective and continuous, with larger spatial and temporal resolution.[143] Small electronic devices equipped with sensors are useful for monitoring soil conditions to inform appropriate management decisions.[144] AI technologies (DL algorithms) for generating soil spatial products and the integration of in situ measuring systems with citizen science data.[145] |

| 5. Food and feed | |
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| The rationale for monitoring food and feed | Farming and fishing systems are under stress, with a growing challenge of providing food for 9 billion people by the middle of the century. There is an increase in food production worldwide, with variation in the quantity and trends in different regions. The harvested area and yields associated with crops have increased in similarity with meat and milk production. The potential of wild food to support livelihoods is apparent, especially in forest regions of developing countries, where wild foods are important for household food security. Information reported by the Poverty Environment Network (PEN) showed that over 75% of households in developing countries are engaged in wild food collection from land.[146] For the past 50 years, global fish harvests have increased by about 50%, while cultured (farmed) fish production has risen from tiny fractions of wild capture to 40% of worldwide seafood production in 2015. Temperature, oxygen, and pH variations, which are forecast to be different in different parts of the world, will affect fish catch potential in both magnitude and direction. Even though there are increases in food production worldwide, the ability of the natural environment to continue supporting food production is diminishing due to land degradation. Habitat and species loss are hindering ecosystem functioning, with the possibility of species going extinct and losing range area. Similarly, ocean fish stocks have decreased significantly due to overfishing, with limited opportunities to expand fisheries in the long term. Inequality in the distribution of calories is apparent, with the prevalence of malnutrition in Africa and other developing countries in the global south.[147] Therefore, there is a need for sustainable food production systems – from diversified agroecosystems to a sustainable fishery sector. |
| Current data gap | The harvested area and yields (also including fish catch potential) and vegetation type can be measured.[148,149] Food production and distribution estimates are controlled by governments, with limited access to start-ups and farmers, causing them to make inappropriate decisions. This includes globally consistent, multidecadal, cropland time-series data at locally relevant spatial resolutions (30m per pixel), where seasonal variation is considered. |
| The opportunity of new technologies to fill this gap and barriers that remain | Precision agriculture is possible with real-time sensing.[150] Crops typology can be identified with higher granularity, vegetation height can be mapped, and crop products can be tracked throughout the value chain.[151] With precision agriculture, farming activities can benefit from satellite data by identifying when specific crops should be harvested based on satellite observations, triggering automatic pest treatment using vector mapping, and even optimising irrigation based on weather data and crop monitoring.[152] Satellite imaging and GPS are useful in tracking fertilizer application – promoting the efficient use of fertiliser based on prevailing soil and climate conditions.[153] The utilisation of Information and Communication Technology (ICT) to predict agricultural yields and productivity also provides information for farmers to enhance profitability and economic sustainability of global food and feed. |
| **What are the exact impacts of technological advancements on the monitoring of ecosystem services?** | |
| | Technological advancements are having positive social and environmental impacts – allowing the monitoring of various ecosystem services, which is important for identifying trends and opportunities in the provision of those services and making appropriate management decisions. Existing examples include the tool Co$ting Nature, which enables ecosystem service trade-off analysis highlighting the potential impact of protecting ecosystems. |

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