A study on monitoring tools and applications that can aid small- and medium-scale ecosystem restoration implementers to track their progress

Tools and Applications for Ecosystem Restoration Monitoring

United Nations Decade on Ecosystem Restoration 2021-2030

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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EXECUTIVE SUMMARY

Locally led ecosystem restoration projects often face financial and technical constraints to implement a holistic monitoring approach which measures a diverse range of ecological and socio-economic indicators. Acknowledging the resource constraints in locally led projects, the study explores the emergence of digital monitoring tools designed for ease of use on standard devices.

The study was developed for local ecosystem restoration implementers that are looking for ways to establish a monitoring approach for their project. The study analyses 11 freely available digital tools for ecosystem restoration monitoring regarding their functionalities, technical requirements, and user-friendliness. A key focus is on their potential to record multiple indicators that reflect the multilayered outcomes of restoration including climate, ecologic and socio-economic benefits Each tool and the respective analysis results are presented as easy-to-read "tool-profiles". In a second step, the study analyses the tools' alignment with globally proposed indicators for a consistent monitoring approach under the UN Decade on Ecosystem Restoration.

Ultimately, the findings aim to provide insights into the effectiveness of freely available digital monitoring tools in supporting comprehensive and globally consistent ecosystem restoration monitoring, offering a valuable resource for local practitioners, but also policymakers and other stakeholders involved in restoration initiatives.

1. ECOSYSTEM RESTORATION MONITORING

The **UN Decade on Ecosystem Restoration** marks a significant global effort to address the urgent need for restoring and conserving the planet's ecosystems. To ensure the success of this monumental initiative, ecosystem restoration monitoring assumes paramount importance. Monitoring serves as a fundamental tool for assessing and evaluating the progress, effectiveness, and impact of restoration activities undertaken – in general and in particular during the UN Decade. By systematically tracking the outcomes of restoration projects, such as changes in biodiversity, ecosystem functions, and habitat quality, we can gather crucial data and insights. This data not only informs global restoration implementers if they are on track to meet the 2030 goals of the UN Decade, but it also builds the foundation for adaptive management strategies. Ultimately, evaluating this data helps us to document and communicate Best Practices and replicate and upscale successful restoration approaches.

Furthermore, ecosystem restoration monitoring holds immense significance for the successful implementation of the new **Kunming-Montreal Global Biodiversity Framework (GBF)** of the **Convention on Biological Diversity (CBD)**. This framework sets ambitious targets for halting biodiversity loss, promoting ecosystem resilience, and restoring degraded ecosystems. In Target 2, the Parties to the CBD have agreed to "ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity". In order to assess the progress and effectiveness of restoration efforts undertaken to achieve this target, monitoring plays a critical role. The information received from monitoring enables policymakers, scientists, and other stakeholders to make evidence-based decisions, identify areas for improvement, adjust strategies accordingly, and ultimately ensure that the objectives of the CBD Global Biodiversity Framework are met.

2. INTRODUCTION TO THIS STUDY

Ecosystem restoration monitoring plays a vital role in assessing the progress and effectiveness of restoration initiatives aimed at revitalizing degraded ecosystems. Moreover, regular monitoring is an important part of every ecosystem restoration project as it can indicate if the project is on track to meet its goals, or needs readjustment (see Figure 1). However, the complexity of ecosystem restoration, which does not only consider ecological health, but also the socio-economic well-being of local communities and other stakeholders can make the monitoring of different outcomes challenging. Monitoring ecological as well as socio-economic aspects requires a wide range of indicators (see Figure 2) and measurement approaches. Plus, the choice of indicators that best provide information about the progress made towards certain restoration goals depends on various factors, e.g. the type of ecosystem, the initial degree of degradation, and the kind of restoration measures implemented[1]. Furthermore, to gain meaningful monitoring results, it is necessary to take spatial as well as temporal measurements. Localizing the intervention area and the recording of spatial data (e.g. plot data with GPS recording) allows to connect restoration measures to positive impacts in the target area. The ability to record data over time, on the other hand, is crucial for making comparisons with the baseline situation. Recording temporal and spatial data and measuring the different indicators can be highly time and cost intensive as they might require mixed approaches. These can be approaches which combine data collection in the field and computer-aided data analysis, for example using geographical information systems (GIS) and remote sensing. However, restoration projects, especially locally led projects often have limited financial and human resources. Therefore, projects often need to find a balance between the completeness of the indicators (indicators that reflect ecological as well as socio-economic outcomes of the project) and the robustness of the data (amount of high-quality data that can be collected for each indicator). Additionally, smaller and locally led projects might be limited in their choice of indicators because they do not have the necessary technical equipment and training possibilities which are needed for complex data recording and analysis (e.g. computers with high computing capacities and storage space, costly GIS programs, relevant expertise on spatial analysis and remote sensing). These sort of challenges and restrictions can lead to fragmented monitoring approaches that can negatively affect the project's work in several ways:

i. As the project is not able to comprehensively capture all changes occurring in the ecosystem, it is more challenging and possibly takes more time to identify successful practices and to make necessary adjustments to ongoing activities.
ii. It is harder for the project to prove and communicate all its positive outcomes. This can negatively affect its likelihood to receive further interest and funding from donors.
iii. As the project might not use standardized indicators (see Box 1 for more information on standardized indicators developed for the UN Decade on Ecosystem Restoration) it is more difficult for the project to upscale its work, e.g. by collaborating with other projects and by integrating its restoration area into larger landscape approaches.

1 For an example of a guide to selecting appropriate indicators that meet the project objective, see 'Road to Restoration' and the AURORA tool, both produced by the World Resource Institute (Buckingham et al., 2019).

Lastly, there is often a mismatch between the monitoring indicators used at the local and national level. This makes it difficult to integrate locally led restoration projects into national and international reporting since international reporting standards cannot be applied – like the ones of the new Global Biodiversity Framework (GBF) which was agreed upon by the Parties on the Convention on Biological Diversity (CBD) in December 2022.

To tackle these challenges, over the past years digital monitoring tools and applications (apps) which can be used easily on available devices like standard smartphones or tablets have emerged. They aim to integrate globally used (headline) indicators and standards while trying to lower the burden of complex recording for locally led restoration projects. This entails that many of the tools are open source and freely available, easy to understand and use – without prior knowledge or training, and they are designed in

FIGURE 1:

General workflow of monitoring for ecosystem restoration projects (Geosys, 2023)

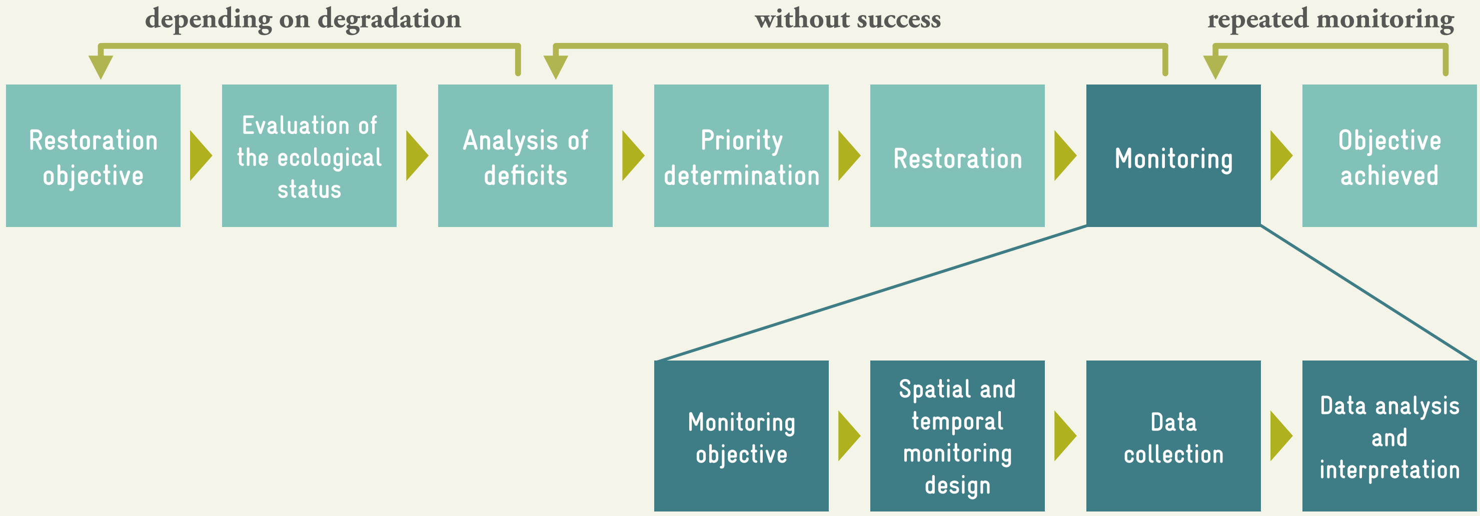


FIGURE 2:

A list of possible indicators to measure ecosystem restoration success (Geosys, 2023)

Diversity	Vegetation structure	Ecological processes	Quality of Ecosystem services	Economic factors	Social factors
» Richness » Functional diversity » Genetic diversity	» Vegetation height » Biomass » Wood density » Basal area » Litter structure	» Nutrient cycling » Carbon dynamics » Soil development » Pollination	» Nutrient cycling » Carbon dynamics » Soil development » Pollination	» Diversification of income » Creation of jobs » Tourism	» Strengthening role of women » Safety » Education

a way that they can also be used in remote locations with limited access to the internet. However, the questions remaining are

1. How extensively can these tools support the measurement of a wide variety of complex ecological and socio-economic indicators? and
2. In how far do the tools align with the (headline) indicators proposed for a globally consistent monitoring approach?

To answer these questions, this study analyzed 11 freely available monitoring tools regarding their general functions, technical requirements and user-friendliness. In a second step, it examined in how far the indicators measured by the tools align with globally proposed (headline) indicators and can therefore help to build a globally consistent monitoring approach under the UN Decade on Ecosystem Restoration.

BOX 1

MONITORING APPROACHES AND INDICATORS IN THE UN DECADE ON ECOSYSTEM RESTORATION

One aim of the UN Decade on Ecosystem Restoration is to capture all ecosystem restoration efforts worldwide and to build a comprehensive knowledge and monitoring system that accounts for different approaches in different ecosystems (terrestrial, freshwater, coastal and marine ecosystems) and on different levels (local, national, regional). Recording and monitoring the extent of all ecosystem restoration efforts worldwide is not only crucial to track if international commitments and pledges are being fulfilled. What is even more important: It helps us to understand how restoration and which sort of restoration measures can contribute to stopping the loss of biodiversity and to counteracting climate change. The crucial role of ecosystem restoration in safeguarding climate, biodiversity and socio-economic wellbeing can only be mainstreamed into political decision-making worldwide, if concrete positive outcomes can be showcased to decision-makers through reliable monitoring approaches.

To build a robust monitoring approach there is a need for globally agreed **headline indicators** that can be consistently and comprehensively recorded. The **UN Decade Task Force on Monitoring** is developing such a monitoring approach called the **Framework for Ecosystem Restoration Monitoring (FERM)**. It provides key geospatial information related to the biophysical, and the socio-economic dimension for all terrestrial, coastal and marine ecosystems. Moreover, the platform also has functionality for uploading national and sub-national data, enabling integration of geospatial data locally, regionally, nationally, and globally. Through the **FERM Registry**, which will be interoperable with other restoration monitoring platforms, restoration stakeholders and national entities can share their information on restoration progress (including impact stories) at different scales. The dashboard is currently under development and will allow easy visualization of the restoration progress made in the UN Decade (FAO & UNEP, 2023). As part of the FERM development, the Task Force also compiled a **universal set of indicators** that builds upon the indicators of the globally adopted Sustainable Development Goals (SDGs) (FAO & UNEP, 2022). By using the SDG indicators, the Task Force seeks to lower the reporting burden for countries as most countries already have an SDG monitoring system in place.

Additionally, to bridge the gap between locally led ecosystem restoration monitoring and national monitoring frameworks which are used by countries for international reporting, Gann et al. (2022) have developed a set of indicators in their **Restoration Project Information Sharing Framework** which can be used by all restoration projects regardless of if they work on the local, national, regional or global level. This set of indicators aligns with the **10 Principles for Ecosystem Restoration to Guide the United Nations Decade 2021–2030** (FAO et al., 2021; hereafter referred to as the 10 UN Decade Principles). The latter are best-practice principles that detail the essential tenets of ecosystem restoration that should be followed by all ecosystem restoration activities in order to maximize net gain for native biodiversity, for ecosystem health and integrity, and for human health and well-being – across all biomes, sectors and regions.

BEST PRACTICE FOR THE USE OF OPEN SOURCE (OS) MONITORING TOOLS

Football for Forests (F4F) is an initiative of different NGOs that uses the broad impact of football to restore Colombian forests. F4F uses the data collection tool KoboToolbox to gather data from all stakeholder groups involved in the restoration activities – a quite diversified user group from restoration professionals to farmers. KoboToolbox has different input options, simple and understandable language, and intuitive navigation. With these features the data collection forms can be customized easily and allow monitoring of the different phases of a restoration intervention. KoboToolbox enables users to collect and store different types of data. Besides the input of numbers and text in forms, it is possible to capture photos and videos. The digital data collection forms work on both, mobile devices, and the web browsers of desktop computers / laptops.

During the planning phase, F4F records geodata of protected areas and areas to be restored. Restoration measures, including tree planting are then documented by taking time-stamped and geotagged photos. After planting, annual monitoring is conducted to estimate the survival rate of planted seedlings and document plant growth.

The captured data can be stored offline on the device, which was an important criterion for F4F, as the various field sites are usually very remote and without internet connection. Once internet is available, the data can then be uploaded to an online database. KoboToolbox offers various choices for storing the collected data on a central server. It provides existing servers that are already configured for information from KoboToolbox (e.g. Humanitarian Server hosted by UN Office, Non-Humanitarian Server hosted by KoboToolbox). This option is especially relevant if there is no experienced technical support in the project, as installing KoboToolbox on own servers requires advanced server administration and programming skills. However, using own data storage allows for full data sovereignty, higher flexibility and better adaptability to the project requirements. For restoration monitoring which is done over an extended period of time, storing data independently of a tool's hosting organization might be preferred in order to guarantee long-term data storage and availability. The F4F team decided to install KoboToolbox on its own server for the sake of greater flexibility and data security.

Furthermore, the F4F team emphasizes the good user support, the continuous development and an active user community, which exchanges experiences and offers help in the Kobo forum. In addition to these benefits, Ivan Palmegiani of the F4F technical development team summarizes the philosophy of free and open source software as follows: "I advocate free and open source software (FOSS) for reproducible research and for environmental/ social impact. So, the fact that KoboToolbox falls into this category was a big plus for me. In addition, the fact that such a comprehensive set of features is provided free of charge to impact organizations is a very good and cost-effective option for initiatives like F4F."

3. STATE OF THE ART MONITORING TOOLS FOR ECOSYSTEM RESTORATION

Open source software development, cloud-based services and an increased availability of free of charge satellite data provide new technological possibilities for monitoring ecosystem restoration activities. Tools like software development kits (SDK), e.g. provided by Google, have made it much easier to develop and build apps, including apps that can support the monitoring of ecosystem restoration. These new apps come with key advantages. They are easy to handle – without intense training and can be applied on already existing devices like smartphones. Moreover, they offer automated data storage and processing options, which make them time-efficient and cost-effective.

However, the wealth of different tools and apps available can make it difficult for restoration implementers to maintain an overview of the different purposes and functions. Picking the tool that fits best to the project's monitoring purposes can become challenging.

For restoration implementers, answering the following questions can help them select the appropriate tool for their monitoring purposes:

- Can the tool help to record the kind of data which is needed to report against the indicators of the restoration project?
- How much time is available to configure the tool?
- What programming skills are available?
- What kind of hardware is available?
- What are the security/data protection requirements for the recorded data?
- Which languages are provided by the tool? Can the tool also be used by illiterate persons?
- Is there an end date for the monitoring or should it ideally be an open-ended long-term recording? Can the tool support the monitoring over the desired timeframe?
- Is there internet availability in the field or can collected data only be uploaded once the person recording the data has returned to an area with internet availability?
- Is it "only" about the data recording or should the tool also support data analysis?

The World Resources Institute (WRI), in collaboration with other partners, has developed a Restoration Monitoring Tool Guide to support restoration implementers to pick the monitoring tool(s) that are most suitable for their project. It is available online at **https://restorationmonitoringtools.org/**.
For this guide, WRI has pre-selected and tested 22 tools. Some of them are proprietary and fall under standard GIS solutions, while others are open source and run only on mobile devices. Users can also submit their own suggestions for tools that could be added in the future. This study complements the Restoration Monitoring Tool Guide by analyzing tools specifically targeted to small and medium-sized ecosystem restoration implementers.

4. METHODS

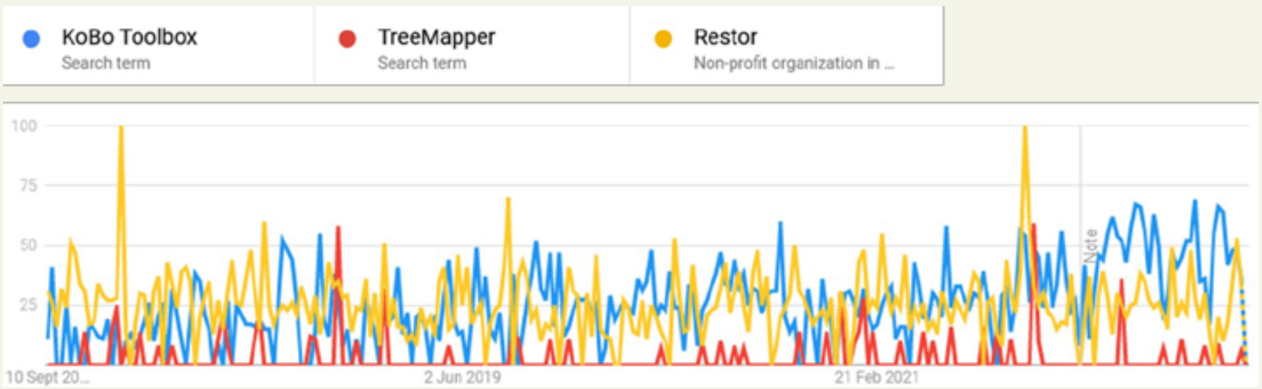
4.1 Selection of tools and apps for testing

The study tested 11 tools that can support the monitoring of terrestrial ecosystem restoration. Tools were selected based on three criteria:

i. They have to offer a graphical user interface (GUI) in English and preferably in Spanish.
ii. They have to be freely available and/or open source, without any licensing fees for their use.[2]
iii. They have to be applicable globally, and cannot only be restricted to a certain country or region.[3]

To ensure the selected tools were indeed relevant for the target group, the selection was reviewed with partner organizations implementing restoration projects in the field[4]. Additionally, restoration implementers from Central America and Africa were asked about their monitoring experiences and their needs regarding monitoring tools. This was done at a capacity building workshop series (Restoration Academy) during which participants were asked to fill in an online survey (please see "Survey Results" in the Appendix for more information on the Restoration Academy and the results of the survey). The selected tools were then also compared with the tools evaluated in WRI's Restoration Monitoring Tool Guide. Besides considering the target group when selecting the tools, it was also taken into account if they could potentially support the monitoring of indicators suggested by restoration (monitoring) guidelines central to the UN Decade's monitoring efforts, especially the Restoration Project Information Sharing Framework (Gann et al., 2022) and the 10 UN Decade Principles (FAO, 2021) (see Box 1 for more information on the UN Decade' monitoring approach). Finally, Google Trends was used to confirm the popularity of each selected monitoring tool (Figure 3).

FIGURE 3
Verification of relevance of selected monitoring tools using Google Trends



2 It is possible that costs are incurred, e.g. for the use of data storage. If this licensing costs were discovered during testing, it is indicated in the test matrix (see pages 13 and 14 for the matrix).

3 For this reason, the Regreening Africa app was not included in the testing procedure. However, it is still included in the considerations in chapter 3.

4 The authors of this study have conducted interviews with representatives of GEO schützt den Regenwald e.V. and NABU Africa.

The selected monitoring tools can be divided into three groups:

i. Tools for general data collection (recording different types of data, for example during field visits, inventories, or interviews)
ii. Tools specifically designed for data collection to track reforestation/trees, with focus on data collection in forest ecosystems
iii. Tools for rapid assessment and presentation (analyzing and displaying existing data sets, for example remote sensing images)

TABLE 1
Tested tools grouped by their main uses

General data collection	Data collection to track reforestation/trees	Rapid assessment and presentation
» KoBo Toolbox/KoBo Collect » Open Foris Collect Mobile/Open Foris Collect » CyberTracker » SMART » QField	» TreeMapper » TREEO » Greenstand Tree Tracker » Forest Watcher	» Restor » Explorer.land

4.2 Test criteria

All selected tools were tested against the following criteria, which can be divided into three main groups: i. General, ii. Functionality, iii. Monitoring

TABLE 2
Test criteria grouped into three main groups

i. General	ii. Functionality	iii. Monitoring
» License type » Requirements for the operating system » General user friendliness » Possibilities to customize user interface	» Possibilities of data input (forms, geospatial data, photos) » Data storage (data storage on the device, cloud-based data storage) » Date visualization and export	» Possibility to record spatial units » Possibilities to track progress over time

All apps were tested with both Android and iOS operating systems. All desktop-based tools were tested on Windows with different browsers (Chrome and Firefox). To test the data collection abilities and the specific built-in data availability of the selected tools, a virtual forest in an inner-city area was simulated. The test procedure was largely identical for all tools presented. Some of the evaluated tools are "self-guided", meaning they don't require direct contact with the host organization to initiate the monitoring activity (e.g. TreeMapper, KoBo Collect, SMART Collect). Users of these tools are often relatively free to design monitoring categories and survey designs according to their project's needs. However, this also requires users to have more in-depth technical knowledge. Because the status of "self-guiding" can change over time, this information was not included as a test criterion.

5. RESULTS

This chapter gives a brief overview of each tested tool (5.1) and shows all test results (5.2). Consulting 5.1 and 5.2 can help restoration implementers to decide on a monitoring tool most useful to their project's restoration and monitoring approach. Since the tools are usually subject to constant development, there may have been some innovations during compilation that are not included here. Therefore, the website of the tool provider should be read thoroughly before finally taking a decision.

5.1 Short description of tested tools

Name	Description	Notes
KoboToolbox (desktop programme) and **KoboCollect** (app for mobile devices)	KoboToolbox is a tool to collect spatial data with user defined variables. The creation of forms for data collection can be done in a personal account on the web interface. Created forms can be shared and downloaded to the mobile app KoboCollect to collect data in the field. KoboCollect can be used offline. Collected data can then be uploaded as soon as an internet connection is available.	
Open Foris Collect Open (desktop programme) and **Foris Collect Mobile** (app for mobile devices)	Open Foris Collect is a desktop-based program to create surveys, for example for field-based inventories, and manage collected data. To conduct the survey, the created survey scheme can be imported to Open Foris Collect Mobile, which is an app for mobile phones.	
CyberTracker	The CyberTracker app was designed to record conservation-related field data, including animals, plants and human activities. The app can first be customized on a desktop computer and then installed on a smartphone.	The new release (June 2023) offers a variety of connections with other monitoring tools, including SMART. This could be advantageous when different stakeholders use different monitoring tools.
SMART	The SMART platform consists of a set of software and analysis tools designed to help protect and manage conservation areas and wildlife. Through different tools it supports field-based data collection and analyzes. SMART Mobile is a mobile application which is designed for remote data collection. It relies on the SMART DESKTOP program which can be downloaded to a computer.	
QField	QField is a mobile app that supports data collection during fieldwork. It works as an addition to the desktop GIS software QGIS. Geodata can be prepared in QGIS and used in the QField app.	QGIS with "QField sync"-plugin needs to be installed on a computer to use the app.

Name	Description	Notes
Tree Mapper	In the Tree Mapper app data about planted trees can be recorded. For mapped areas it shows the area and density of trees per hectare. An export of the data as GeoJSON[5] file is possible.	The app is currently in its beta version and monitoring functions will be added soon. An application programming interface (API) for developers is currently being developed and will be added soon.[6]
TREEO	With the smartphone app TREEO, smallholders / farmers can track tree growth and calculate timber volume, CO2 removals, and the prices of individual trees or entire stands.	
Greenstand Tree Tracker	The mobile app supports users to keep track of their trees by taking periodic geotagged photos. Uploaded tree data is verified by Greenstand and then appears on Greenstand's Web Map.	The mobile app is specifically designed for users with low literacy. Greenstand also offers an open market platform where "Impact Tokens" can be purchased from tree growers.
Forest Watcher (app for mobile devices) and **Watcher Web** (web application)	Forest watcher is a mobile app to monitor forest disturbance. It allows offline use of global deforestation and fire alerts from the web platform Global Forest Watch. A forest change alert function can be activated. Forest Watcher Web syncs with the Forest Watcher mobile app and allows for greater customization. This includes customizing report templates, reviewing reports created in the field and managing forest monitoring teams. Content can be exported as GeoJSON files.	
Restor	Restor is a map-based online platform that allows projects to present their restoration area. It provides datasets (incl. on carbon, biodiversity, water and land cover) to assess restoration potentials and aid restoration planning. Polygons can be drawn to mark the restoration area and time series of satellite data are available to monitor project progress. Additionally, ground data and photos can be added (information is added by organizations and not verified by restor).	Organizations can set up a profile. A mechanism to connect restoration implementers and potential donors is under development. The Restor platform will be integrated into the FERM.
explorer.land	explorer.land is a map-based online platform that allows projects to present their restoration area. Projects can draw polygons and mark different land-uses or import already existing geodatabases. Monthly updated satellite images are provided to show landscape change. Thematic data layers available include deforestation, tree cover, soil carbon and tree biomass density.	An additional mobile story mapping app can be used to capture and upload geolocated news posts.

→ 5.2 Overview of test results

5 Geodata can be stored in different formats. A historic and widely spread format is the "shape file" format. The format is suitable as an exchange format, but for enrichment, editing and analysis, modern data formats such as "GeoJSON" offer greater advantages.

6 For a holistic monitoring approach, it if often necessary to record different data in different formats (e.g. geospatial data as polygons and measurement data in a numeric format). Accordingly, the data is stored in different locations, such as excel spread sheets and geospatial databases. To link the different information, a "data gateway" called API (application programming interface) is required. The existence of an API increases the flexibility of monitoring approaches. For example, it might allow to add new monitoring indicators (and respective data) to existing data collection methods.

KOBO TOOLBOX/KOBOCOLLECT

GENERAL

INFORMATION

Website: https://www.kobotoolbox.org/	**Affiliated organization/ Partners** –	**Thematic focus:** Design of surveys and questionnaires

LICENCE

Licence: open source	**Pricing:** free	**Registration:** Name, E-Mail

OPERATING SYSTEMS (OS)

Windows	macOS	Linux	Android	iOS	Web
–	–	–	✓	–	✓

GENERAL USER FRIENDLINESS

User forum: https://community.kobotoolbox.org/	**Web support:** https://support.kobotoolbox.org/	**Starting the App: Setup:** quite easy, form creation needs some time with logics (skip, validation)
Supported languages: English, French, Spanish, Arabic, Hindi, Kurdish, Chinese	**Information and guidance for user**[7]**:** good	**Starting the App: IT Knowledge required:** not needed, unless it should run on own server
	Customization Design (logos, colors etc.) ✓	**Intuitive GUI:** mostly

FUNCTIONALITY

DATA INPUT

Attributes for capture[8]**:** everything possible in form	**Photos:** ✓	**Spatial data:** points, lines, polygons	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud / locally	**Data transfer (cable, wireless):** via Internet

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs: yes, reports in web interface	**Spatial data export:** GeoJSON	**Print map** ✓

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	Load/show previous data –

OPEN FORIS COLLECT

GENERAL

INFORMATION

Website: https://openforis.org/tools/collect/	**Affiliated organization/ Partners** –	**Thematic focus:** General data collection in field-based biophysical, socio-economic or biodiversity surveys

LICENCE

Licence: Open Source	**Pricing:** free	**Registration** –

OPERATING SYSTEMS (OS)

Windows ✓	macOS ✓	Linux ✓	Android –	iOS –	Web –

GENERAL USER FRIENDLINESS

User forum: https://openforis.support/#gsc.tab=0	**Web support** –	**Starting the App: Setup** –
Supported languages: app will use language of the user's web browser	**Information and guidance for user**[7]**:** medium	**Starting the App: IT Knowledge required** –
	Customization Design (logos, colors etc.) –	**Intuitive GUI:** only in web browser

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	Photos –	Spatial data –	Works offline ✓

DATA STORAGE

Data saved (cloud/locally): locally	**Data transfer (cable, wireless)** –

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	Spatial data export –	Print map –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	Load/show previous data –

OPEN FORIS COLLECT MOBILE

GENERAL

INFORMATION

Website: https://openforis.org/tools/collect-mobile/	**Affiliated organization/Partners** –	**Thematic focus:** General data collection in field-based biophysical, socio-economic or biodiversity surveys using mobile phones

LICENCE

Licence: Open Source	**Pricing:** free	**Registration** –

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** ✓	**iOS** –	**Web** –

GENERAL USER FRIENDLINESS

User forum –	**Web support** –	**Starting the App: Setup** –
	Information and guidance for user[7]**:** good	**Starting the App: IT Knowledge required** –
Supported languages: multilingual	**Customization Design (logos, colors etc.)** –	**Intuitive GUI** ✓

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos** ✓	**Spatial data:** points	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): locally	**Data transfer (cable, wireless):** cable, via internet (when server installed)

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	**Load/show previous data** –

CYBERTRACKER

CyberTracker

GENERAL

INFORMATION

Website: https://cybertracker.org/	**Affiliated organization/ Partners** –	**Themathic focus:** Mobile data capture and visualization for conservation purposes

LICENCE

Licence –	**Pricing:** free	**Registration:** E-Mail

OPERATING SYSTEMS (OS)

Windows ✓	macOS –	Linux –	Android ✓	iOS ✓	Web –

GENERAL USER FRIENDLINESS

User forum: –	**Web support:** –	**Starting the App: Setup:** easy
	Information and guidance for user[7]**:** bad	**Starting the App: IT Knowledge required** –
Supported languages: English, can be used by illiterate persons	**Customization Design (logos, colors etc.)** ✓	**Intuitive GUI:** –

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] ✓	**Photos:** ✓	**Spatial data:** points	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud	**Data transfer (cable, wireless):** via Internet

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** ✓

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	**Load/show previous data** –

SMART

GENERAL

INFORMATION

Website: https://smartconservationtools.org/Download/SMART-7-Release	**Affiliated organization/Partners:** WWF, WCS, Wildlife Protection Frankfurt Zoological Society, Zoological Society of Landon, Zoo North Carolina, PANTHERA, re:wild	**Themathic focus:** Wildlife

LICENCE

Licence: Open Source	**Pricing:** free	**Registration** ✓

OPERATING SYSTEMS (OS)

Windows ✓	**macOS** ✓	**Linux** ✓	**Android** ✓	**iOS** ✓	**Web** –

GENERAL USER FRIENDLINESS

User forum: https://impactsmart.azurewebsites.net/SMART-Approach/Community	**Web support** –	**Starting the App: Setup** –
	Information and guidance for user[7]**:** good	**Starting the App: IT Knowledge required** –
Supported languages: Over 100 languages	**Customization Design (logos, colors etc.)** –	**Intuitive GUI** ✓

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos:** SMART mobile: yes	**Spatial data:** SMART mobile: points	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud / locally	**Data transfer (cable, wireless)** –

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	**Load/show previous data** –

QFIELD

GENERAL

INFORMATION

Website: https://qfield.org/	**Affiliated organization/ Partners** –	**Thematic focus:** Spatial data

LICENCE

Licence: Open Source	**Pricing:** free	**Registration** –

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** ✓	**iOS** ✓	**Web** –

GENERAL USER FRIENDLINESS

User forum: https://github.com/opengisch/qfield/discussions https://gis.stackexchange.com/questions/tagged/qfield?sort=newest	**Web support:** https://docs.qfield.org/	**Starting the App: Setup** –
	Information and guidance for user[7]: good	**Starting the App: IT Knowledge required** –
Supported languages: English	**Customization Design (logos, colors etc.)** –	**Intuitive GUI:** mostly

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] ✓	**Photos** ✓	**Spatial data:** points, lines, polygons	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud / locally	**Data transfer (cable, wireless):** cable

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** ✓	**Print map** ✓

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ✓	**Load/show previous data:** Possible but higher computer literacy necessary

7 Information and guidance might be offered in form of user manuals, video tutorials, helpdesks, or active user forums.

8 In this category, it is assessed if the tool offers possibilities to save complementary information in addition to geospatial data.

TREEMAPPER

GENERAL

INFORMATION

Website: https://www.plant-for-the-planet.org/de/treemapper/	**Affiliated organization/Partners:** Plant-for-the-Planet	**Themathic focus:** Trees / reforestation

LICENCE

Licence: open source	**Pricing:** free	**Registration:** E-Mail

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** ✓	**iOS** ✓	**Web** ✓

GENERAL USER FRIENDLINESS

User forum –	**Web support** –	**Starting the App: Setup:** easy, nice user experience
Supported languages: English, German, Spanish, French, Italian, Portuguese	**Information and guidance for user[7]:** bad	**Starting the App: IT Knowledge required** –
	Customization Design (logos, colors etc.) –	**Intuitive GUI:** ✓

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos:** ✓	**Spatial data:** points, polygons	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud	**Data transfer (cable, wireless)** via Internet

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export:** GeoJSON	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots: not yet	**Load/show previous data** ✓

TREEO

GENERAL

INFORMATION

Website: https://treeo.one/	**Affiliated organization/Partners:** Fairventures Digital GmbH	**Themathic focus:** Reforestation

LICENCE

Licence –	**Pricing:** free	**Registration** –

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** ✓	**iOS** –	**Web** –

GENERAL USER FRIENDLINESS

User forum –	**Web support** –	**Starting the App: Setup** –
	Information and guidance for user[7]**:** medium	**Starting the App: IT Knowledge required** –
Supported languages: English, Luganda, Bahasa, Spanish	**Customization Design (logos, colors etc.)** –	**Intuitive GUI:** mostly

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos** –	**Spatial data** –	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud / locally	**Data transfer (cable, wireless)** –

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots –	**Load/show previous data** –

GREENSTAND TREE TRACKER

GENERAL

INFORMATION

Website: https://greenstand.org/	**Affiliated organization/Partners:** Greenstand	**Themathic focus:** Trees

LICENCE

Licence: Open Source	**Pricing:** Use for tree tracking free, with option to buy more advanced services	**Registration:** Name, email

OPERATING SYSTEMS (OS)

Windows	macOS	Linux	Android	iOS	Web
–	–	–	✓	–	✓

GENERAL USER FRIENDLINESS

User forum –	**Web support** –	**Starting the App: Setup** –
Supported languages: English, Swahili	**Information and guidance for user**[7]: bad	**Starting the App: IT Knowledge required** –
	Customization Design (logos, colors etc.): customized web map for extra price (case-by-case basis)	**Intuitive GUI** –

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos** ✓	**Spatial data:** geotagged photo	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud	**Data transfer (cable, wireless):** via internet

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots –	**Load/show previous data** –

FOREST WATCHER

GENERAL

INFORMATION

Website: https://forestwatcher.globalforestwatch.org/	**Affiliated organization/ Partners:** Global Forest Watch	**Themathic focus:** Forest (disturbance) monitoring

LICENCE

Licence –	**Pricing:** free	**Registration:** Name, E-Mail

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** ✓	**iOS** ✓	**Web** ✓

GENERAL USER FRIENDLINESS

User forum: https://www.globalforestwatch.org/help/	**Web support:** https://globalforestwatch.org/help/	**Starting the App: Setup** –
Supported languages: English, Spanish, French, Portuguese, Bahasa, Dutch, Malagasy	**Information and guidance for user**[7]**:** good	**Starting the App: IT Knowledge required** –
	Customization Design (logos, colors etc.) –	**Intuitive GUI:** mostly

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] ✓	**Photos:** ✓	**Spatial data:** points	**Works offline** ✓

DATA STORAGE

Data saved (cloud/locally): cloud / locally	**Data transfer (cable, wireless)** –

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs –	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots –	**Load/show previous data** –

RESTOR

RESTOR

GENERAL

INFORMATION

Website: https://restor.eco/de/	**Affiliated organization/Partners:** ETH Zurich, Crowther Lab	**Themathic focus:** Area analyses

LICENCE

Licence: Proprietary	**Pricing:** free	**Registration:** Name, email

OPERATING SYSTEMS (OS)

Windows –	**macOS** –	**Linux** –	**Android** –	**iOS** –	**Web** ✓

GENERAL USER FRIENDLINESS

User forum –	**Web support:** https://intercom.help/restor/en/	**Starting the App: Setup** –
Supported languages: English, Spanish, French, Portuguese, Bahasa, Indonesian, Dutch, German	**Information and guidance for user[7]:** medium	**Starting the App: IT Knowledge required** –
	Customization Design (logos, colors etc.) –	**Intuitive GUI** ✓

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] –	**Photos** ✓	**Spatial data:** draw polygons	**Works offline** –

DATA STORAGE

Data saved (cloud/locally): cloud	**Data transfer (cable, wireless)** –

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs: yes (for predefined data)	**Spatial data export** –	**Print map** –

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots –	**Load/show previous data** ✓

EXPLORER.LAND

explorer.land

GENERAL

INFORMATION

Website: https://explorer.openforests.com/	**Affiliated organization/Partners:** OpenForests	**Themathic focus:** Nature-based projects in general

LICENCE

Licence ⊖	**Pricing:** Free, with option to buy more advanced features	**Registration** ⊖

OPERATING SYSTEMS (OS)

Windows ⊖	**macOS** ⊖	**Linux** ⊖	**Android** ⊖	**iOS** ⊖	**Web** ✓

GENERAL USER FRIENDLINESS

User forum ⊖	**Web support:** Helpdesk | Home (explorer.land)	**Starting the App: Setup** ⊖
Supported languages: English	**Information and guidance for user**[7]**:** good	**Starting the App: IT Knowledge required** ⊖
	Customization Design (logos, colors etc.) ⊖	**Intuitive GUI:** only in web browser

FUNCTIONALITY

DATA INPUT

Attributes for capture[8] ⊖	**Photos** ⊖	**Spatial data:** draw polygons	**Works offline** ⊖

DATA STORAGE

Data saved (cloud/locally): cloud	**Data transfer (cable, wireless)** ⊖

DATA VISUALIZATION AND EXPORT

Dynamic statistics/graphs ⊖	**Spatial data export** ⊖	**Print map** ⊖

MONITORING

SPATIAL UNITS	TRACK PROGRESS
Plots ⊖	**Load/show previous data** ⊖

After all tools had been tested in the same way (simulated virtual forest), one tool out of each of the three main use categories (Table 1) was picked for a more in-depth analysis. The selected tools were the ones that had performed best in their category, e.g. because they were most intuitive to use or offered a great range of features. The tools selected were:

- **KoboToolbox** (general data collection),
- **TreeMapper** (reforestation/trees), and
- **Restor** (rapid assessment/presentation).

All three tools are designed for different use cases, and each has its particular strengths. Each of the three tools are described in detail here:

KoboToolbox/KoboCollect:

The strength of Kobo Toolbox and Kobo Collect is that they allow the collection of a wide range of data for a diverse user group. As many restoration projects work with a diverse stakeholder group, it is important to be able to record data in a very simple but robust and standardized way. KoBoToolbox and KoboCollect offer many options for data input and data formats, including photo and video documentation. The standardized and customizable forms are easy to use and can be adapted to each project's needs. Data can be entered either via a desktop-based dashboard or the KoboCollect app. Furthermore, a variety of geodata formats can be utilized which helps projects to use the tool for different purposes. For example, while some projects want to record spatial data, other projects also want to create maps with the collected field data. Additionally, KoBoToolbox offers a robust API and REST (representational state transfer) services which allows other applications to access the data in real-time and enables further data processing and analyses. To build a robust monitoring system, it is crucial to be able to track progress over time. For this, KoboToolbox offers the possibility to compare baseline data (data recorded before the start of the restoration intervention) with data collected during the implementation phase and/or after the implementation phase. This relatively new feature can be tested in a beta version. KoboToolbox has the most transparent data storage of all tools tested, as data can be stored on Kobo's own server. Moreover, it offers a wide array of options to record geodata. All spatial elements (points, lines, polygons) can be used and stored locally in GeoJSON format. The app can be used offline when work is conducted in remote areas without internet access. Spatiotemporal statistics and monitoring results can then be created in the KoboToolbox web interface.

TreeMapper:

The TreeMapper app is especially tailored to tree monitoring and offers a wide range of forest-related indicators. This includes the calculation of stocking rates and the assessment of CO2 storage capacities for individual trees. The latter can be used if the restoration project is looking into possibilities to participate in the carbon market.

Like for KoboToolbox, a feature is being developed which will allow to compare collected data with baseline data (data recorded before the start of the restoration intervention). The analysis will be based on the data collected over the course of the restoration actions and thus will allow for conclusions about the progress and success of a restoration intervention over time. The export of spatial data in GeoJSON and APIs make it possible to share the geospatial data with other GIS software for further processing and analyses.

Restor:

The desktop tool Restor has the most convincing rapid assessment options among all tools tested in the study. A mobile app for data collection in the field is neither offered nor planned. The focus of Restor lies on forest monitoring and reporting. The rapid assessment is based on remote sensing data which is pre-processed and provided by the Restor platform. The user can select an area of interest for their restoration actions and can see data on indicators like carbon storage capacity and biodiversity without having to collect data in the field. Parameters for carbon accounting can be approximated very easily, and the integration of different temporal resolutions of satellite images allows a visual analysis of land cover development. This is a good way of estimating and updating carbon parameters for a specific project area without having to perform a full inventory. This information is valuable but in terms of a monitoring tool, Restor can only be seen as an additional instrument. Furthermore, the application is proprietary and there are only few customizing options which might limit its usefulness for some user groups.

6. COMPATIBILITY WITH 10 UN DECADE PRINCIPLES

In 2021, several environmental organizations[9] developed an internationally recognized framework to track progress and trends in ecosystem restoration: **The Restoration Project Information Sharing Framework (RPISF)** (Gann et al., 2022).

It includes a set of 61 headline, core, and secondary monitoring indicators organized under the 10 UN Decade Principles, along with 32 project descriptors (metadata, project, and site variables) used to document general project information.

The monitoring indicators and project descriptors proposed by the RPISF can be shared among the many platforms and databases that collect, aggregate, evaluate, and provide access to data on ecosystem restoration. It can therefore serve as a valuable framework to standardize and harmonize monitoring approaches worldwide. However, it has not yet been tested which monitoring tools can contribute to collecting the relevant information for the respective headline indicators. Therefore, in Table 3 an attempt is made to evaluate which of the tools tested in this study (see Table 1) can support the reporting against the headline indicators proposed by the RPISF[10]. In accordance with the focus of this study only four of the 10 UN Decade Principles and their respective headline indicators were taken into account.

Table 3 shows 4 of the 10 UN Decade Principles and their respective headline indicators suggested by the RPISF (Gann et al., 2022). In the right column, tested tools are listed (see Table 2) that can support the monitoring of the suggested headline indicator.

TABLE 3
Tested tools grouped by their main uses

UN Decade Principles	Sample Project Goal (Source: RPISF)	Headline Indicator (Source: RPISF)	Tested app that can support reporting on headline indicator
Principle 1: Ecosystem restoration contributes to the UN sustainable development goals and the goals of the Rio Conventions.	Ensure that ecosystem restoration contributes to global goals for sustaining healthy and biodiverse life on Earth.	**Contributions to global commitments** Officially recognized contribution to national or regional commitments.	**Regreening Africa**[11]

9 The RPISF was co-developed by the Society for Ecological Restoration (SER) and Climate Focus, in partnership with the Global Restoration Observatory (GRO) network, and in coordination with the UN Decade on Ecosystem Restoration Monitoring Task Force and many other collaborators.

10 Table 5 is a simplified version of the Restoration Project Information Sharing Framework's indicator overview table. Due to the limited scope of this study, the columns "core indicator" and "secondary indicator" are omitted. To see the complete table, please follow the link: https://globalrestorationobservatory.com/restoration-project-information-sharing-framework/.

11 The Regreening Africa app was not included in the testing procedure described above, as a prerequisite for the study was that the tool can be used internationally. The Regreening Africa app is regionally limited to Africa.

UN Decade Principles	Sample Project Goal (Source: RPISF)	Headline Indicator (Source: RPISF)	Tested app that can support reporting on headline indicator
	Contribute to the implementation of ecosystem restoration at the largest scales that can be achieved.	**Extent of restoration** Extent of area undergoing restoration. (Also aligns with Principle 4.)	**Regreening Africa, Restor, explorer.land, Tree Mapper, QField, KoboToolbox, Open Foris Collect, Open Foris Collect Mobile**[12]
Principle 2: Ecosystem restoration promotes inclusive and participatory governance, social fairness and equity from the start and throughout the process and outcomes.	Ensure inclusive and participatory governance.	**Stakeholders engaged** Types and diversity of stakeholders engaged. **Stakeholder engagement activities** Types of stakeholder engagement activities implemented. Also aligns with Principle 8.	**Regreening Africa** (limited options: track households engaged, gender-disaggregated data collection possible), **KoboToolbox** **Regreening Africa** (limited options: trainings can be recorded), **KoboToolbox**
Principle 3: Ecosystem restoration includes a continuum of restorative activities.	Foster a wide range of restorative activities, singly or collectively, which aim to protect and repair degraded ecosystems across the social-ecological continuum.	**Categories of ecosystem restoration activities and approaches utilized** Major categories of restoration activities used in the restoration project or program (i.e., reducing societal impacts, remediation, rehabilitation, ecological restoration, other). A sub-indicator tracking categories or approaches to rehabilitation and ecological restoration is recommended for those projects.	**Regreening Africa** (limited options as it tracks tree planting, farmer managed natural regeneration (FMNR), nurseries and trainings)
Principle 4: Ecosystem restoration aims to achieve the highest level of recovery for biodiversity, ecosystem health and integrity, and human well-being.	Increase integrity, area, number, or viability of biodiversity identified by project targets within the focal restoration area.	**Biodiversity target status** Changes in biodiversity target status from pre-project baseline toward measurable project goals, accounting for leakage.	**Tree Mapper** (near future, limited options), **KoboToolbox** (near future, limited options), **SMART Collect** (limited options: species can be recorded but comparison between pre-project baseline and project goals only possible when data is exported to other programs), **Open Foris Collect, Open Foris Collect mobile** (limited options), **Restor** (limited options: baseline data on biodiversity is provided, but mechanisms to track changes over time have not been developed so far), **Cyber Tracker** (limited options: species can be recorded but comparison between pre-project baseline and collected data is not possible)

12 Restoration area can be recorded and/or reported in each tool listed. However, if these data uploaded by organizations to different platforms were to be used to assess the global area under restoration, double counting could occur. This is due to the fact that projects and their restoration area could be registered on multiple platforms at the same time.

13 This composite indicator also contains a set of "secondary indicators", which have been omitted here due to the limited scope of this study.

UN Decade Principles	Sample Project Goal (Source: RPISF)	Headline Indicator (Source: RPISF)	Tested app that can support reporting on headline indicator
Principle 4: Ecosystem restoration aims to achieve the highest level of recovery for biodiversity, ecosystem health and integrity, and human well-being.	Achieve the highest level of ecological recovery possible within the focal restoration area, given project and program-level goals.	**Ecosystem integrity** Change in ecosystem integrity status from pre-project baseline toward measurable project goals, accounting for leakage. [This is a composite indicator – see core indicators (C) below[13].]	**none**
		Native species richness (C) Change in richness of desirable native species from pre-project baseline toward measurable project goals.	**none**
		Invasive species (C) Change in invasive species abundance or relative abundance from pre-project baseline toward measurable project goals. Also aligns with Principle 5.	**Regreening Africa** (limited options: a ratio between native and exotic tree species can be calculated)
		Beneficial connectivity of native ecosystems (C) Changes in beneficial connectivity between native ecosystems from pre-project baseline toward measurable project goals.	**none**
	Achieve and sustain the greatest net gain possible for ecosystem goods and services and human health and wellbeing within the focal restoration area, given project and program-level goals.	**Social-economic benefits** Change in delivery and sustainability of social-economic benefits from restoration from pre-project baseline toward measurable project goals, accounting for leakage. [This is a composite indicator – see core indicators (C) below.[14]]	**TREEO** (limited options), **KoboToolbox**

14 This composite indicator also contains a set of "secondary indicators", which have been omitted here due to the limited scope of this study.

UN Decade Principles	Sample Project Goal (Source: RPISF)	Headline Indicator (Source: RPISF)	Tested app that can support reporting on headline indicator
		Food, water, fuel security (C) Changes in food, water, fuel security from pre-project baseline toward measurable project goals.	**Regreening Africa** (limited options: intended usage of tree species can be recorded, but comparison to pre-project baseline is not possible) **KoboToolbox**
		Other social benefits (C) Changes in other social benefits from pre-project baseline toward measurable project goals.	**KoboToolbox**
	Achieve and sustain the greatest net gain possible for climate change mitigation, adaptation, and risk reduction within the focal restoration area, given project and program-level goals.	**Carbon sequestration** Estimated change in sequestered aboveground carbon, soil organic carbon, and blue carbon equivalents from pre-project baseline toward measurable project goals, accounting for leakage. Also aligns with Principle 7.	**Greenstand Tree Tracker, explorer.land, TREEO, Tree Mapper, Forest Watcher, Restor**

With regard to Principle 1, the majority of the tested tools can be used to report against the second headline indicator "Extent of restoration". However, only a few tools offer the option to directly feed collected data into monitoring schemes that track progress on global commitments (headline indicator 1 for Principle 1). A positive example is the **Regreening Africa app**. It allows for data collected with the app to be uploaded to a central server, which adds the recorded measure and/or its effects as a contribution to the commitments of the African **Great Green Wall Initiative**.[15]

Principle 2 focuses on the inclusive and participatory governance, social fairness and equity of ecosystem restoration processes. The suggested headline indicators focus on recording the diverse range of stakeholders and stakeholder engagement activities that could possibly be part of an ecosystem restoration activity. Most of the tested tools have a strong focus on farmers, but do not by default include other stakeholders such as private businesses, government bodies, and educational facilities. Since surveys can be customized in KoboToolbox, this is the only tool that allows for the inclusion of all stakeholders. However, the decision on which actors and which activities to include depends on the person designing the survey.

It should also be mentioned that the way the tools are designed can lead to the exclusion of stakeholders in the monitoring process itself. Although the tools are for free, they always require a smartphone and, in some cases, internet access. To increase access for all user groups it could be beneficial to offer extensions of the tools that can be run on local computers.

15 For more information on this, please visit: https://international-partnerships.ec.europa.eu/news-and-events/stories/mobile-application-helps-african-farmers-manage-and-restore-their-land_en.

This would allow for collected geodata to be stored and further processes without access to the internet. For example, data from GPS devices used in the field, could be passed to the desktop application via Bluetooth or cable. However, if the necessary technical equipment (smartphone, internet) is available, the tools can support the development of a monitoring approach and the monitoring itself for restoration implementers with different technical expertise. The "self-guided" tools such as TreeMapper, KoboCollect, SMART Collect require a higher level of technical understanding but also allow free choice of desired monitoring indicators and collection methods. They also provide greater data sovereignty. Restoration implementers with less technological knowledge can turn to tools with a guided user interface that allow for less customization. The Greenstand app and the CyberTracker app are user-friendly for people with low literacy skills, but some knowledge is still required to set them up.

Principle 3 puts an emphasize on the fact that ecosystem restoration includes a continuum of restorative activities. Again, only the Regreening Africa app offers (limited) options to report on different types of restorative activities, including FMNR and nurseries.

Principle 4 focuses on the restoration of biodiversity and ecosystem integrity, as well as social-economic benefits and carbon sequestration. Although most of the monitoring tools can record biodiversity (headline indicator 1 for Principle 4) by recording the status of existing flora and fauna (e.g. number of trees, forest cover, number of species, etc.), only KoBo Toolbox and Tree Mapper will soon allow for the comparison of data collected over time. For both tools beta versions are being developed which were not yet available when this study was conducted. The TreeMapper app is additionally developing a feature that will not only allow for comparison against a pre-project baseline but also for comparison with a no-intervention scenario. This will be possible by using paired baseline-plots. In all other tools it is not possible to compare results from earlier (baseline) surveys with results from the current monitoring period. Thus, changes of biodiversity and ecosystem integrity over time, as well as increasing social-economic benefits cannot be tracked.

Many tools provide options to measure the carbon sequestration potential of restored areas (headline indicator 9 for Principle 4) (Greenstand Tree Tracker, explorer.land, TREEO, Tree Mapper, Forest Watcher). Especially in the context of forest monitoring, many tools offer the possibility to accredit the forest as a carbon sink. Several tools provide the ability to account for planned new plantings as well. This is first done virtually by showing a footprint of the predicted carbon storage due to future actions taken and can then also be linked directly to carbon accounting companies in various tools (Greenstand Tree Tracker, explorer.land, Tree Mapper, Forest Watcher). However, as measuring and trading carbon storage is often only available through the host organization of the tool, cooperation and communication with other projects might be required and the provided data might be published on the host organization's platform. This can lead to conflicts in the collection of sensitive data (such as land tenure, protection status and/or user groups).

The biggest challenge at the local level is to document the social-economic benefits (headline indicator 6 for Principle 4). Only the TREEO app and the Regreening Africa app offer limited options to calculate the value of plants and report intended uses of newly planted plants. However, a comparison with a pre-project baseline is not possible. Due to customization options, KoboToolbox theoretically allows the collection of data on social-economic indicators, but it requires a high effort by the person responsible for the survey design and implementation to formulate appropriate questions and repeat the survey in order to allow for comparison over time.

The strength of the tested tools lies primarily in local data acquisition. In some cases, reporting options (e.g., Restor) are included, but these remain the exception so far. None of the tools combine the necessary features to report on all headline indicators assigned to the 10 UN Decade Principles.

7. RECOMMENDATION

KoboToolbox and KoboCollect performed best in the tests. The option to save the data on own servers allows the user to access data from older surveys even after a longer period of time. This option is not available in any of the other tested tools. In addition, KoboToolbox is very flexible and can be used for various monitoring purposes.

Despite the fact that comparing data over time is crucial for any robust monitoring approach as it allows to track changes and evaluate the effectiveness of the implemented restoration measures, only two of the tested tools (TreeMapper and KoboToolbox) are developing features that will allow the comparison of recently collected data with previous data records (e.g. baseline data).

Thanks to the intuitive user interface and options for data visualization, all tested tools are relatively easy to use for restoration implementers with different levels of technological knowledge. Extended training periods are not required. This ease of use and free access to the tools can especially help smaller organizations and projects to set up a monitoring system. However, it also carries the risk that there is no standardization for indicators and measurement methods, making it difficult to compare monitoring results within and across projects and restoration sites. As outlined in the Restoration Project Information Sharing Framework (Gann et al., 2022) the use of monitoring indicators and measurement methods that can be shared among the many platforms and databases already available for ecosystem restoration monitoring is critical to track and compare global process. It would be desirable to include these considerations and suggestions in respective user guidances for the tools.

Most of the tools are strongly tied to their provider's organizations. This carries the risk that cloud storage of the data may not be offered on an ongoing basis. It is therefore strongly recommended that all restoration implementers keep a backup of all recorded data on their own server system or hard disk.

Overall, the tools only support the monitoring of a limited number of indicators suggested to track the multiple benefits of ecosystem restoration which include climate benefits, biodiversity benefits, and socioeconomic well-being. While most tools offer the ability to track carbon mitigation potential, they lack options to track more complex metrics such as (positive) changes in climate adaptation, increase in biodiversity, and improvements in livelihoods (e.g. through increased or diversified income). In addition, the tools are very focused on trees and tree planting. Other terrestrial ecosystems such as peatlands, grasslands, and savannahs are often neglected (exceptions are the SMART and CyberTracker, which allow monitoring of species in all ecosystems). As noted above, most of the tools tested do not allow comparison of recently collected data with previously collected data (e.g. baseline data) and therefore do not allow restoration implementers to track changes over time. For the tools tested to better contribute to the monitoring goals of the UN Decade on Ecosystem Restoration and to showcase the positive impacts of restoration on the health and well-being of the planet and its inhabitants, they should consider three issues:

1. Including a wider range of indicators that reflect the multiple benefits that ecosystem restoration offers
2. Including data and monitoring options for a wider range of ecosystems
3. Enabling the comparison of data and tracking of changes over time

Finally, it should be mentioned that the study was conducted over a period of 6 months and even within the test period, many tools have undergone fundamental or groundbreaking developments. It is therefore recommended to compare favored tools online before taking a final decision.

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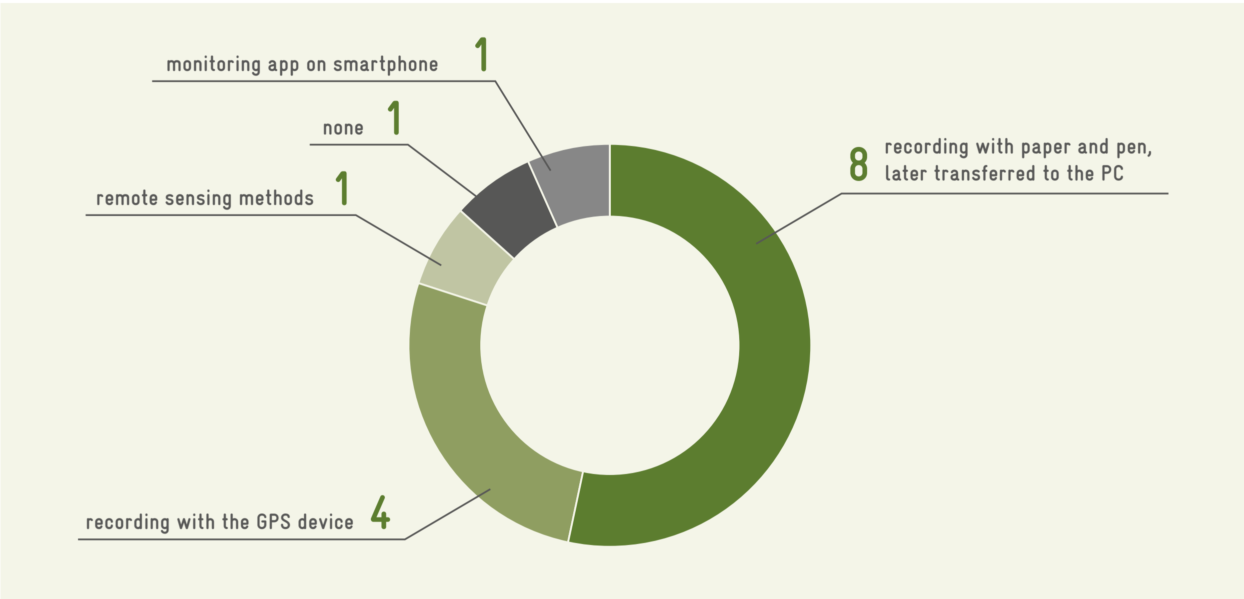
APPENDIX

Survey Results

In order to analyze and suggest monitoring tools suitable for the experiences and preferences at the local and national implementation level, ecosystem restoration implementers from Central America and East Africa were surveyed. The (online) survey took place as part of the Restoration Academy, a workshop series developed and implemented by the GIZ projects DEER[16], FDV/REDD+ Landscape[17] (Central America) and AREECA[18] (Africa). The Restoration Academy supports local and national restoration implementers to contribute to and benefit from the UN Decade on Ecosystem Restoration (2021–2030) and upscale their current work[19]. It focuses on knowledge exchange, dissemination of best practices, and network and capacity building.

The results of the online survey show that monitoring is currently mostly done with pen and paper and the collected data is then transferred to a computer. In some cases, GPS devices are also used to collect data in the field. Only in very rare cases are smartphone apps used.

What tools have been used for monitoring in the project so far?



One of the most important indicators collected during the monitoring process is vegetation structure. The focus is on observing changes in vegetation over a certain period of time. Especially for the observation of changes, the comparability of the collected data is important and thus a uniform recording method.

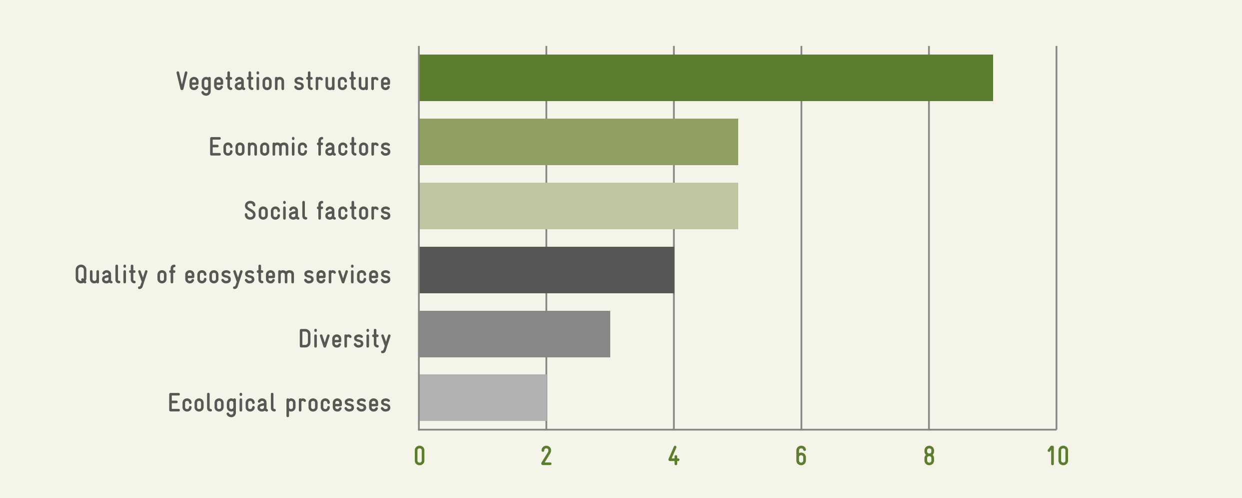
16 "Support for the Design and Implementation of the UN Decade on Ecosystem Restoration"

17 "Forest Landscape Restoration in Central America and the Caribbean and implementation of the Green Development Fund for Central America (REDD Landscape)"

18 "Large-scale Forest Landscape Restoration in Africa"

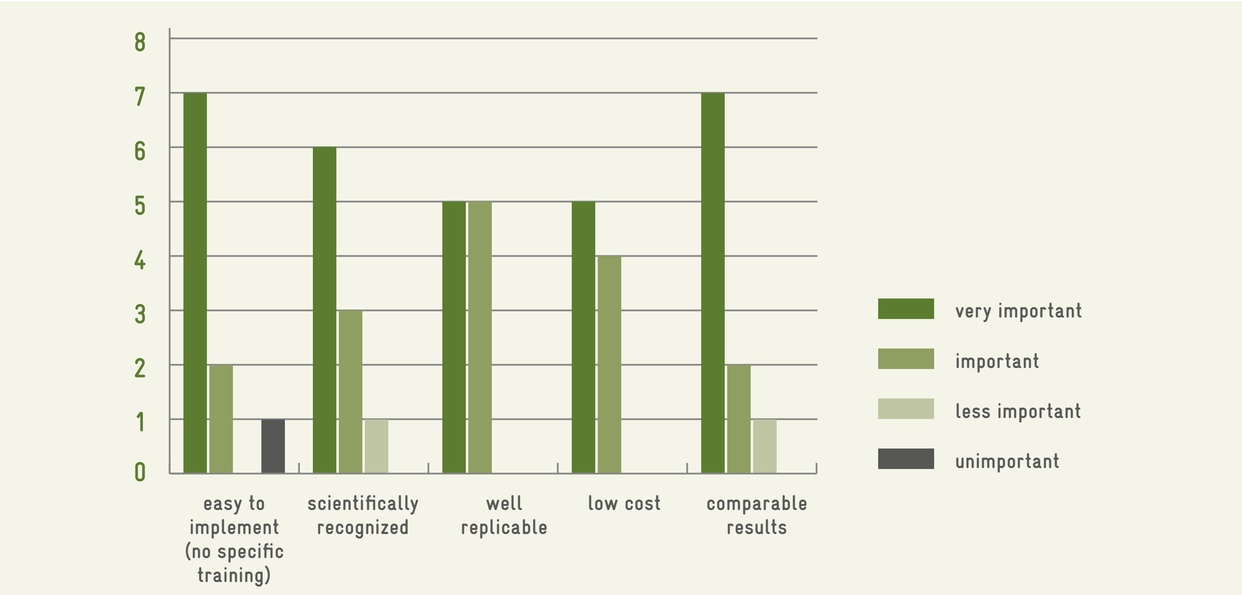
19 https://www.decadeonrestoration.org/stories/welcome-restoration-academy (visited 19.04.2023)

What indicators are recorded in your project?



When restoration implementers were asked about the aspects most important to them when deciding on a monitoring approach most interviewees noted that the approach should be easy to implement and that it should be possible to obtain comparable data and results.

Which aspects are most important when deciding on a monitoring approach?



When asked about a possible incentive for continuous monitoring (even after the project end) the following answers were provided:

- Recording could show efficiency and success of the restoration attempt and as a consequence attract more funding and/or mobilize volunteers
- Capacity building
- Involvement of other stakeholders, including communities and farmers. Participatory monitoring approaches can be a tool to involve and educate other stakeholders and create ownership by visualizing successes that are beneficial to all.
- Continuous earning from the project
- Better/more accurate result