such as Nutrient Network[2], field studies with natural diversity or land-use gradients[3] and research infrastructures such as eLTER[4]. A shared measured variable for all of these is above-ground plant biomass as a proxy for plant production, an essential component of ecosystem functioning (next to other structural characteristics, e.g. cover or growth height). The most common way to determine above-ground biomass is to harvest the plants (there are also alternative non-destructive methods, which are, however, error-prone if used incorrectly[5]). Actual estimates of productivity—measuring rates of biomass change vs. standing pool size – requires longer time-series of biomass over the seasons than is possible with destructive harvesting. In addition to its coarse time resolution, destructive sampling also is very coarse in terms of capturing spatial variation of vegetation structure. Newer, more modern techniques allow finer-scale temporal and spatial measurements using 3D scans and computationally processing the resulting digital point clouds (e.g., terrestrial laser scanning [TLS])[6]. The disadvantage is that the equipment and software are very expensive and the work in the field is cumbersome and time consuming.

A middle way that combines the positive aspects of both methods (i.e., cheap and fast, easy to implement, non-destructive) is to use smartphones and freely available 3D scanning apps (without special fields of application). Almost everyone nowadays has a smartphone, and the technology has improved enormously in recent years. Cameras with at least 40 megapixels, multiple lenses, image stabilisers and autofocus are standard for modern smartphones, and take high-resolution photos that rival those of SLR cameras. Some models even have a LiDaR (Light Detection and Ranging) sensor that can measure infrared light reflected from surfaces to create 3D images. As well as the hardware, software and apps have also developed significantly. There are now freely available apps such as *Scaniverse*[7] (completely free), *Polycam,* or *3d Scanner App*™, which allow 3D scans of above-ground vegetation. The applications are simple to use: one opens the app, scans the plot (takes about 20 seconds, depending on the size), then the app processes the captured images/videos (takes about 0.5-1 minute, depending on the size) and finally outputs a 3D animation, as shown in figure 1 and 2, as well as under https://doi.org/10.5281/zenodo.10610071. In this way, it is possible to easily scan the above-ground vegetation at daily, weekly, or monthly intervals, convert it into biomass, and thus get an even more accurate picture of the plant communities without high cost and disturbance of the system. This approach has many advantages, even beyond the simple determination of biomass: repeated or even automated sampling over the growing season allows for estimates of the rates of biomass production; the 3D point clouds allow the quantification of the structure and spatial variation of vegetation; captured wavelengths can be decomposed to quantify phenological patterns based on the colour changes; spectral data can be used to directly estimate species composition and diversity (with suitable ML/AI methods). Moreover, this method opens up numerous possibilities for citizen science, i.e., people can collect data and provide important additional quantitative and qualitative information[8, 9]. Another conceivable use would be for teaching, in order to better explain structural interrelationships.

Of course, the use of smartphones for biodiversity research is in its early stages and requires “ground-truthing” to calibrate 3D images into accurate biomass estimates, and to test reproducibility and comparisons to traditional methods, as well as scaling opportunities to various more remotely-sensed imaging methods. Other challenges include the fact that only small areas can be scanned at the moment (e.g., no forests) and that the resolution of the 3D scans is not very high; thus, it is necessary to further develop apps. In particular, software is needed that allows virtual sampling of plants/leaves, automatic quantification of leaf distributions and other individual/species-based analysis methods.

Because of the growing necessity for more and higher-quality biodiversity data, we see that harnessing these emerging technologies as an opportunity to meet the challenges of monitoring biodiversity change, opening up new questions and novel data to old questions, as well as a way to increase inclusion and access to biodiversity science. Biodiversity research needs to evolve and open up, establishing state-of-the-art methods as the standard that everyone can use.

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Figures

Fig. 1) Result of scanning a research plot with smartphone and the app *Scaniverse*. The photography (a) and the scan (b) were taken in the *DivResource* experiment[10] at the UFZ research station in Bad Lauchstädt (Germany). 3D animations can be found in Fig. 2 and under https://doi.org/10.5281/zenodo.10610071.

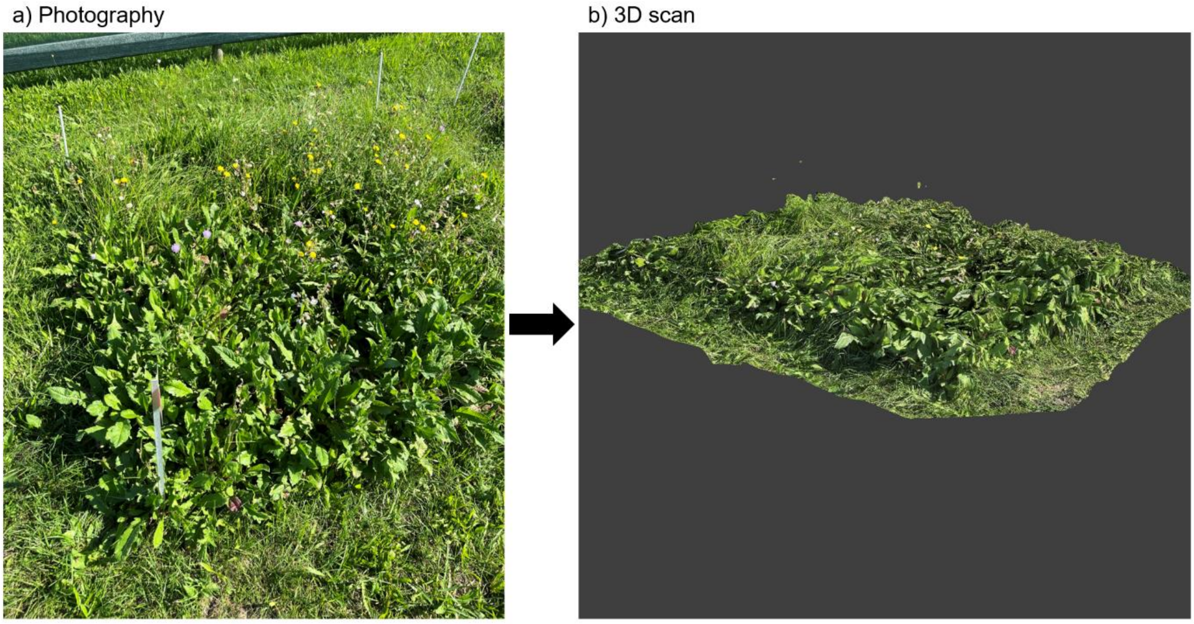

Fig. 2) 3D animations of scanned research plots with smartphone and the app *Scaniverse*. The scans were taken in the *DivResource* experiment[10] at the UFZ research station in Bad Lauchstädt (Germany). Note: trust the document to see the 3D animation (yellow bar at the top of the PDF).

2a) plot B2A23

2b) plot B6A70