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PERSPECTIVE

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A laboratory for conceiving Essential Biodiversity Variables (EBVs)—The 'Data pool initiative for the Bohemian Forest Ecosystem'

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Abstract

1. Effects of climate change-induced events on forest ecosystem dynamics of composition, function and structure call for increased long-term, interdisciplinary and integrated research on biodiversity indicators, in particular within strictly protected areas with extensive non-intervention zones. The long-established concept of forest supersites generally relies on long-term funds from national agencies and goes beyond the logistic and financial capabilities of state- or region-wide protected area administrations, universities and research institutes.
2. We introduce the concept of data pools as a smaller-scale, user-driven and reasonable alternative to co-develop remote sensing and forest ecosystem science to validated products, biodiversity indicators and management plans. We demonstrate this concept with the Bohemian Forest Ecosystem Data Pool, which has been established as an interdisciplinary, international data pool within the strictly protected Bavarian Forest and Šumava National Parks and currently comprises 10 active partners. We demonstrate how the structure and impact of the data pool differs from comparable cases.
3. We assessed the international influence and visibility of the data pool with the help of a systematic literature search and a brief analysis of the results. Results

primarily suggest an increase in the impact and visibility of published material during the life span of the data pool, with highest visibilities achieved by research conducted on leaf traits, vegetation phenology and 3D-based forest inventory.

4. We conclude that the data pool results in an efficient contribution to the concept of global biodiversity observatory by evolving towards a training platform, functioning as a pool of data and algorithms, directly communicating with management for implementation and providing test fields for feasibility studies on earth observation missions.

KEYWORDS

bohemian forest ecosystem, data pool, forest ecosystem science, remote sensing, remote sensing-enabled essential biodiversity variables

1 | INTRODUCTION

1.1 | Background

Reporting on the status of biodiversity calls for increased and intensified forest ecological research, inter-alia by integrating multi-source data over space and time at finer spatial resolution. The indispensable and mostly aggregate measures known as Essential Biodiversity Variables (EBVs; Pereira et al., 2013) are suggested as a result of implementation of intergovernmental science-policy platforms like the Group on Earth Observations Biodiversity Observation Network (GEO BON, http://geobon.org) and are conceptualized to support climate change assessment and enable attentive and integrated biodiversity monitoring (Jetz et al., 2019). These variables were initially stirred by the Essential Climate Variables (ECVs, https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables), were selected among a larger number of variables in terms of scalability, temporal sensitivity, feasibility and relevance, and define essential measurements to capture biodiversity change, while being complementary to one another. In particular, the EBVs are well compatible with common space-borne remote sensing estimations of biodiversity due to their feasibility for being spatially continuous, thereby enabling upscaling from local sampling to larger spatial domains (Pereira et al., 2013).

On the one hand, many biodiversity indicators (including the EBVs) are commonly relevant to be investigated on large-scale domains encompassing multiple ecosystem types (Dyer et al., 2017). On the other hand, only approximately 2% of the entire vascular plant species have been estimated to have any trait measurements at a regional level (Jetz et al., 2016). In this context, remote sensing data and methods offer new avenues for biodiversity monitoring across different spatiotemporal domains. For example, the remote sensing-enabled EBVs (RS-EBVs; Pereira et al., 2013; Skidmore et al., 2015) have been suggested for harmonizing remote sensing support for quantification of biodiversity traits, and have been stated to substantially support monitoring ecosystem function, structure, community composition and species traits (Vihervaara et al., 2017). In-situ data are additionally required not only for collecting information on quantity, quality and dynamics of vegetation traits, but also for calibrating, validating and simulating those traits using physically based remote sensing approaches. Quantification and monitoring ecosystem function at a local level, as well as linkages to global ecosystem functions, will become a reality with the launch of global imaging spectroscopy systems, as proposed by European Space Agency (ESA, https://www.esa.int/) and National Aeronautics and Space Administration (NASA, https://www.nasa.gov/; Ustin & Middleton., 2021). Nevertheless, enough representative test sites with a high level of ecological complexity are needed as focus regions for in-situ data sampling efforts to explore new remote sensing sensors and technologies and evaluate their usefulness for practical measurement of species traits and ecosystem functions (Skidmore et al., 2015).

1.2 | Supersites, long-term ecological research (LTER) sites and data pools: A conceptual differentiation

The diverse and partially geographical- and financially dependent trends of forest ecosystem research entail free/open sharing policies for in-situ and remote sensing data sources. One way to achieve this is through the establishment of supersites or data pools that enforce integrated data collection and multidisciplinary, synergetic research and practice. A supersite has been defined as a comprehensively equipped research area including multiple ecosystem categories and fluxes, thus conducting extensive experiments to collect information on many mechanistic processes is enabled, which leads to better understanding the ecosystem properties. If supersites are networked on national level, then international networks like long-term ecological research (LTER), European long-term ecosystem research (eLTER) and international long-term ecological research (iLTER) can also be formed with the aim to minimize replications while providing platforms for joint research, information exchange and application for research funds (Mikkelsen et al., 2013) (Appendix 1).

Supersites have a long tradition in ecosystem observatory and management, with the main aim to provide statistically, geographically and climatically representative data that could be eventually applied as model-ready inputs for retrievals of both ecosystem status and dynamics (Karan et al., 2016). In summary, supersites commonly require (a) active, long-term data acquisition operations, supported by (b) appropriate funding and infrastructural capacity and (c) following well-established data acquisition, sharing and archiving protocols (see Fischer et al. (2011) and Karan et al. (2016) for recommendations on supersite selection and management).

These result in long-term investments in acquiring and archiving remote sensing data, combined with field measurements on fixed field stations (e.g. Flux Towers) and periodic measurements of biophysical attributes on representative locations (e.g. permanent sample plots). Examples of well-established forest supersites include Petawawa Research Forest (PRF, https://www.nrcan.gc.ca/science-and-data/research-centres-and-labs/forestry-research-centres/national-research-forests/13171) in Canada (White et al., 2019), Warra Tall Eucalypt supersite in Australia established within the terrestrial ecosystem research network (TERN) (https://supersites.tern.org.au/), as well as the LTER system (https://lternet.edu/ and https://www.lter-europe.net). Whereas the main features of the three site types are summarized in Figure 1, other well-known and comparable constructions and management arrangements are summarized in Appendix 1.

Successful and sustainable development of such constructions involve defining consistent guidelines, continuous funding as well as various data sharing policies that vary from supersite to supersite. While most supersites necessitate massive investments from national funding agencies coupled with a high administrative burden, smaller-scale data pools are less complex thanks to straightforward local management, less funding requirements and flexibility for augmented multi-sector and multidisciplinary research.

Data pools are also not restricted to certain measurements/instrumentations; thus they enable the provision of a greater variety of data. They commonly include open and catalogued metadata, without the need for the data to be necessarily open. The data pool is a mechanism to share data and information based on a contribution from partners, which differs with the US- and EU-based concepts of fully open global data.

Furthermore, data pools have a flexible structure to operate around specific thematic or disciple objectives, for example for validation of RS-EBVs (see Morsdorf et al., 2020 for recent example of Laegeren in Switzerland with thematic focus on joint use of radiative transfer models and LiDAR-derived forest structure for upscaling leaf-level RS-EBVs to canopy level). In the same manner, data pools may be thematically and/or geographically clustered based on

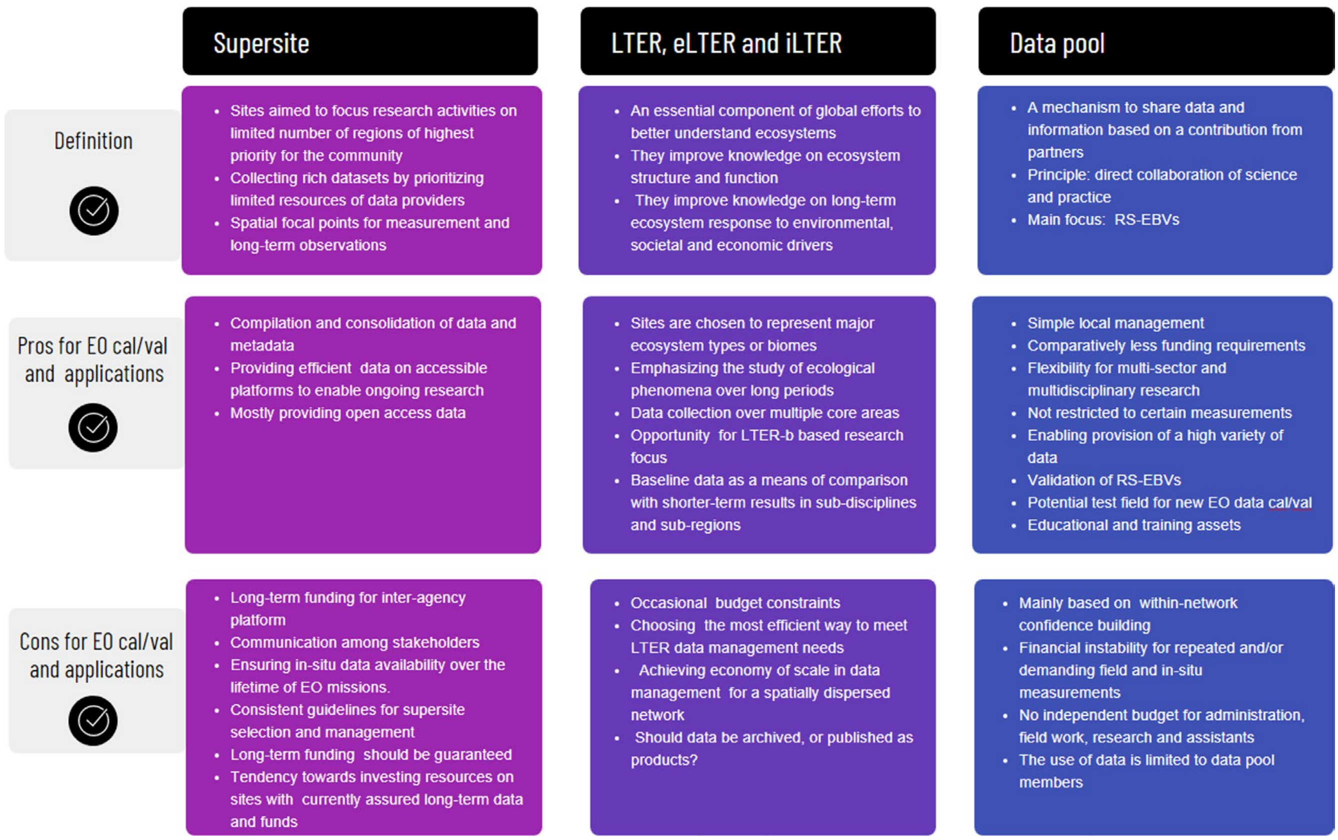

FIGURE 1 Info-box: main definition, pros and cons of supersites, LTER sites and data pools for earth observation applications. Abbreviations: cal/val, calibration/validation; eLTER, European long-term ecosystem research; iLTER, international long-term ecological research; LTER, long-term ecological research; RS-EBV, remote sensing-enabled essential biodiversity variable

spatial domains with specific ecosystem characteristics. In an ideal set-up, such data pools could be defined in a way to couple a small core of thematic/local stakeholders with a multidisciplinary network from research-and-development institutions, thereby forming an active initiative to foster the entire workflow of conceptualization, research and implementation. This is advantageous as it converts the data pool to a pool of ideas, in which each new idea primarily builds on previous results and analysis. Hence, this further supports the development of methods and leads to growing knowledge on the focal region and its ecological processes. Nevertheless, data pools require a significant initial effort to build confidence, ongoing coordination, as well as dissemination of results and provision of deliverables for subsequent research works. Their existence and characteristics (e.g. in comparison to the supersites) could also be promoted through relevant and operational Copernicus services (https://www.copernicus.eu/en/copernicus-services).

One may also note that the data pool principle is based on sharing intellectual properties, that is, data, methods and know-how instead of reallocating the data ownership or a sole data transfer. Therefore, data remain under the originator/owner's custody, but both data and science sharing become the norm as trust builds. This follows a different data sharing policy than it is typically implemented in supersites, in which data should be made publicly available since they are obtained using public funding (see Clarke et al., 2011).

2 | THE BENEFIT OF STRICTLY PROTECTED AREAS AS A FOCAL REGION

The current global extent of strictly protected areas (PAs) (International Union for Conservation of Nature (IUCN) categories Ia, Ib and II) follows a distribution listed in (https://www.protectedplanet.net/region), comprising non-intervention ecosystems that can be subject to joint research, particularly on RS-EBVs (Reddy et al., 2020). In view of the previously hypothesized 'global biodiversity observatory' (Jetz et al., 2016), data pool provides an example of integrating remote sensing spatial data, model-based approaches and in-situ trait and biodiversity measurements. Examples of such variables are species occurrence (from EBV category: species populations), biophysical plant traits (from EBV category: species traits), vegetation height and fragmentation metrics (from EBV category: ecosystem structure) and vegetation phenology (from EBV category: ecosystem function) (see Skidmore et al., 2015). Areas under strictly protected IUCN categories, as well as other globally endorsed PAs like *United Nations Educational, Scientific and Cultural Organization* (UNESCO) programs World Heritages, Biosphere Reserves and Man and the Biosphere would provide higher logistical and financial feasibility to survey most of these traits. Ecosystem research within the strictly protected zones is merited based on their pristine natural/near-natural condition, within which processes and interactions can be surveyed (Stolton et al., 2015). Furthermore, intensive research within PAs has been stated to be beneficial with protective effects for ecosystem conservation via benefiting local communities, increasing the awareness to safeguard biodiversity as well as the possibility for fundraising (Laurance, 2013).

Here, we introduce the remote sensing data pool initiative for the Bohemian Forest (Šumava mountains) ecosystem, which is a seamless case of a direct collaboration of science and practice for RS-EBVs on a transboundary PAs level, comprising entities from universities, space agency and PAs management. It is a landscape-level, participatory and reasonable alternative of typical supersites to develop validated practical products, EBVs and management plans based on remote sensing and forest ecosystem science.

3 | CASE: THE BOHEMIAN FOREST ECOSYSTEM DATA POOL

3.1 | Geographical domain

The focal region of this data pool comprises a transboundary region of the approximately 24,240 ha Bavarian Forest National Park in Germany and 68,460 ha Šumava National Park in the Czech Republic. It consists of contiguous land use types within the Central European temperate and high altitude zones, including diverse natural and near-natural habitats ranging from temperate coniferous, deciduous and mixed stands to deadwood and recovered areas formerly affected by European bark beetle (*Ips typographus* L.), peat bogs, small clear-cut patches and other disturbances to habitat types (Figure 2).

The area is also identified as the Inner Bavarian Forest and comprises one of the largest contiguous forest ecosystems in Central Europe. In this case, the German-Czech border corresponds the Bohemian Forest ridgeline, which is also the watershed between the Danube and Elbe rivers and is considered as a part of European Green Belt (www.europeangreenbelt.org). The interactions between various site factors such as climate and soil are clearly reflected in this focal region, especially in the altitude-dependent zonation of the forests (Cailleret et al., 2014).

3.2 | Construction of the data pool

The idea to establish a data pool initiative to enable research and development based on RS-EBV-based data collection dates back to the concept suggested by Heurich (2006) for 'establishment of a test area of remote sensing sensors', a data pool in which multi-scale aerial photography, phenocam data, seasonal LiDAR and interferometric RADAR could be integrated with extensive field inventory and corresponding precise geodetic infrastructure (Heurich, 2006). This was later followed by personal communications within the core network of Bavarian Forest National Park (BFNP, https://www.nationalpark-bayerischer-wald.bayern.de), University of Würzburg (UW, https://www.uni-wuerzburg.de), the Faculty Geo-Information Science and Earth Observation at the University of Twente (ITC, https://www.itc.nl/) and the German Remote Sensing Data Center of the German Aerospace

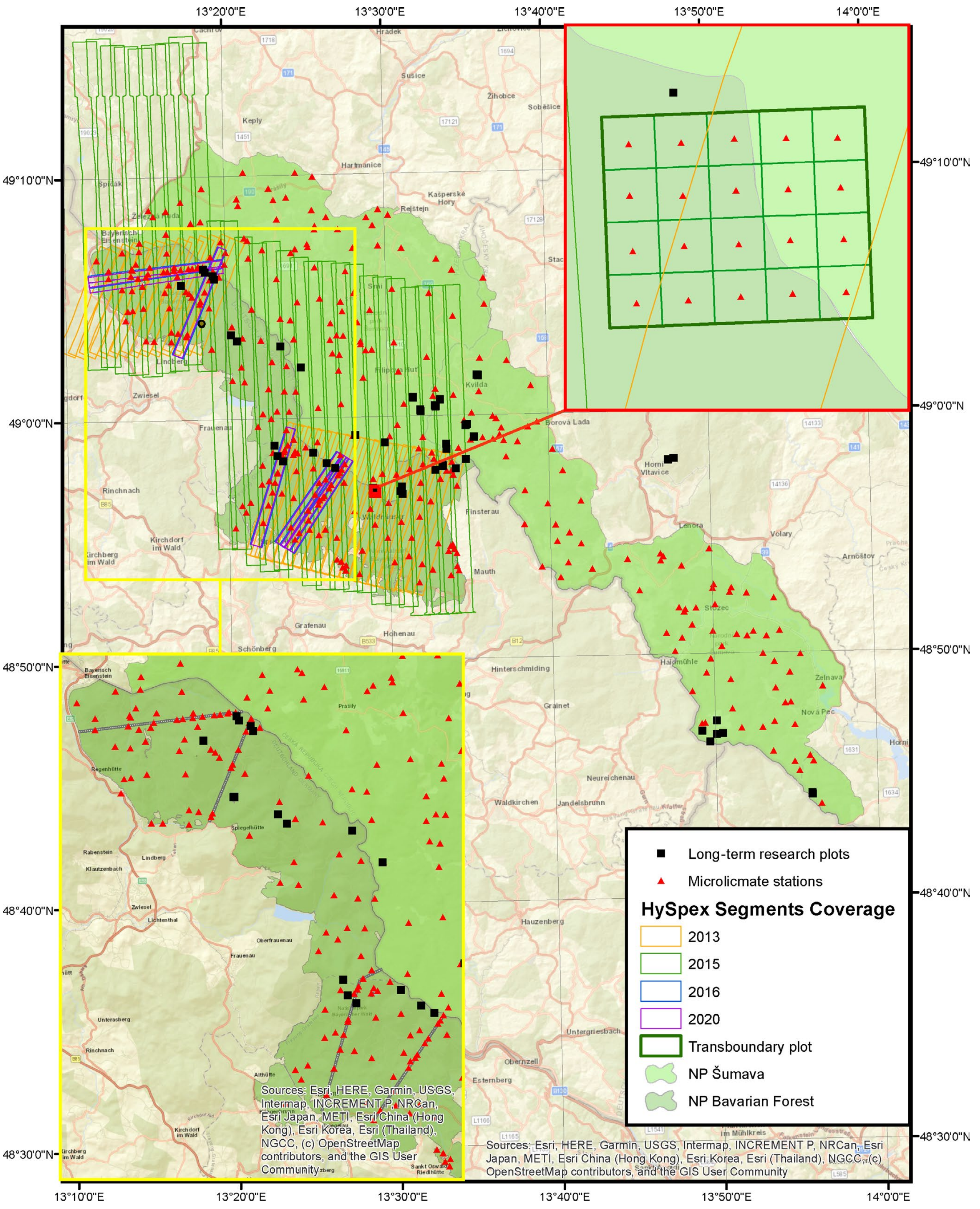

FIGURE 2 Sampling locations of the main data acquisition campaigns within the data pool region (Bavarian Forest and Šumava National Parks). HySpex data coverage has been shown as one of the examples of earth observation data within the data pool (please refer Appendix 3a for the full list)

Center (DFD-DLR, https://www.dlr.de/eoc), and led to an initial cooperation agreement. The data pool was officially established in 2015 by a final cooperation agreement among those as well as Šumava National Park (SNP, https://www.npsumava.cz), Munich University of Applied Sciences (MUAS, https://www.hm.edu), Technical University of Munich (TUM, https://www.tum.de/), The Czech Global Change Research Institute (CzechGlobe, https://www.czechglobe.cz), University of South Bohemia (USB, https://www.jcu.cz) and the Czech Academy of Sciences (IBOT, https://www.ibot.cas.cz) (Figure 3). The latest agreement released in April 2021 extended the network to three further institutions including Helmholtz-Zentrum für Umweltforschung (UFZ, Germany, https://www.ufz.de), Ludwigs-Maximilians-University Munich (LMU, Germany, https://www.lmu.de) and K.N. Toosi University of Technology (KNTU, Iran, https://en.kntu.ac.ir) (see the News Feed in German: https://www.nationalpark-bayerischer-wald.bayern.de/forschung/projekte/fernerkundungsdatenpool.htm).

The main activities of the data pool were the establishment of a RS-EBV laboratory by (a) acquisition and archiving of large field and remote sensing datasets, (b) considering the entire ecosystem as a test environment for the sensors on-board the upcoming DLR/ESA missions, (c) leveraging these multi-source data to study the dynamics of natural and near-natural ecosystems, (d) facilitating a closed collaborative environment for joint research on RS-EBVs and (e) providing the required facts and hints for the management of both PAs and beyond (Holzwarth et al., 2019).

Main effort was put on sampling designs and measurements of biophysical and biochemical vegetation traits. Key examples are leaf area index (LAI; e.g. Xie et al., 2021), Chlorophyll (e.g. Ali et al., 2020; Darvishzadeh et al., 2019), specific leaf area (SLA; e.g. Ali et al., 2016), nitrogen (e.g. Wang et al., 2017), leaf dry matter content (LDMC; e.g. Ali et al., 2016), carbon (e.g. Gara et al., 2019), species occurrence (e.g. Krzystek et al., 2020) and 3D vegetation structural attributes (e.g. Liu et al., 2018).

We briefly assessed the international influence and visibility of the data pool by an analysis of the resulted ISI journal publications. The word cloud created from titles of the total 69 journal contributions (Figure 4) suggests repeated occurrence of keywords such as forest, temperate, LiDAR, mapping, tree, leaf, habitat and data. The journal publications can be thematically clustered in topics summarized in Figure 4. In addition, Figure 5 shows the geographical distribution of 547 research works citing papers from the data pool, based on which the majority of citations have been from China, Germany and the United States.

The reader is referred to the Appendix 2a for a qualitative summary of journal publications. The Appendix 2b shows a chronological summary of publication Impact Factors per topic, which suggests an increase in the quantity and quality of research on topics 1, 4 and 5, as well as general dearth in extensive research on topics 8–10. The Appendix 2c summarizes the sum of total citations during January 2014–June 2021.

3.3 | Outputs for data sharing, training and management

3.3.1 | Remote sensing data

The data pool serves primarily for remote sensing data provision and gives access to data from several, partly exclusive, data collection campaigns for members. A full list is presented in Appendices 3a,b that provides summaries on commonly and exclusively available data sources. Examples include airborne LiDAR data acquired by Riegl LMS-Q 680i waveform system for the entire BFNP (in 2012 and 2017), Šumava NP (in 2017) as well as across the so-called BIOKLIM transects within BFNP (in 2016) that were formerly established for measuring biodiversity traits (Bässler et al., 2009). In addition, colour-infrared and RGB (CIR-RGB) aerial photography campaigns

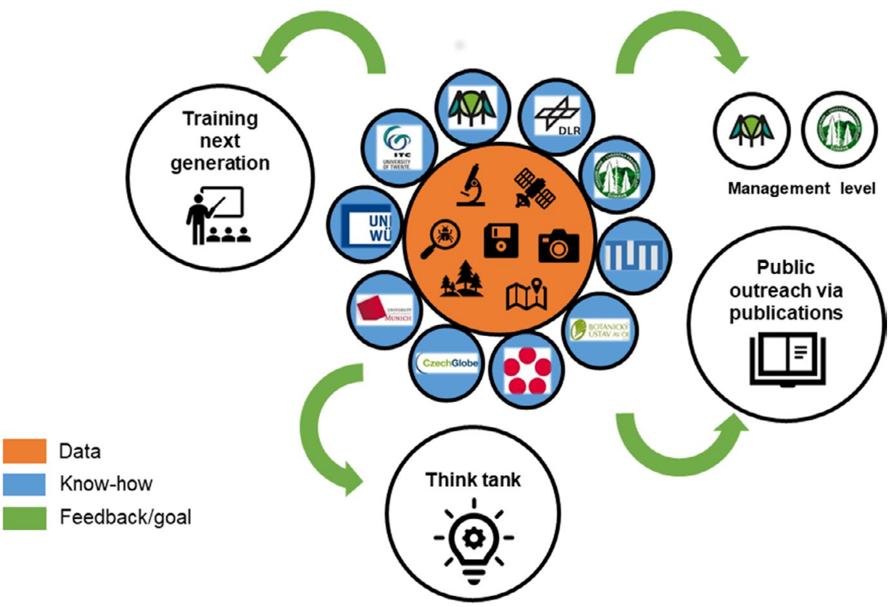

FIGURE 3 Schematic design of structure and relationships within the data pool

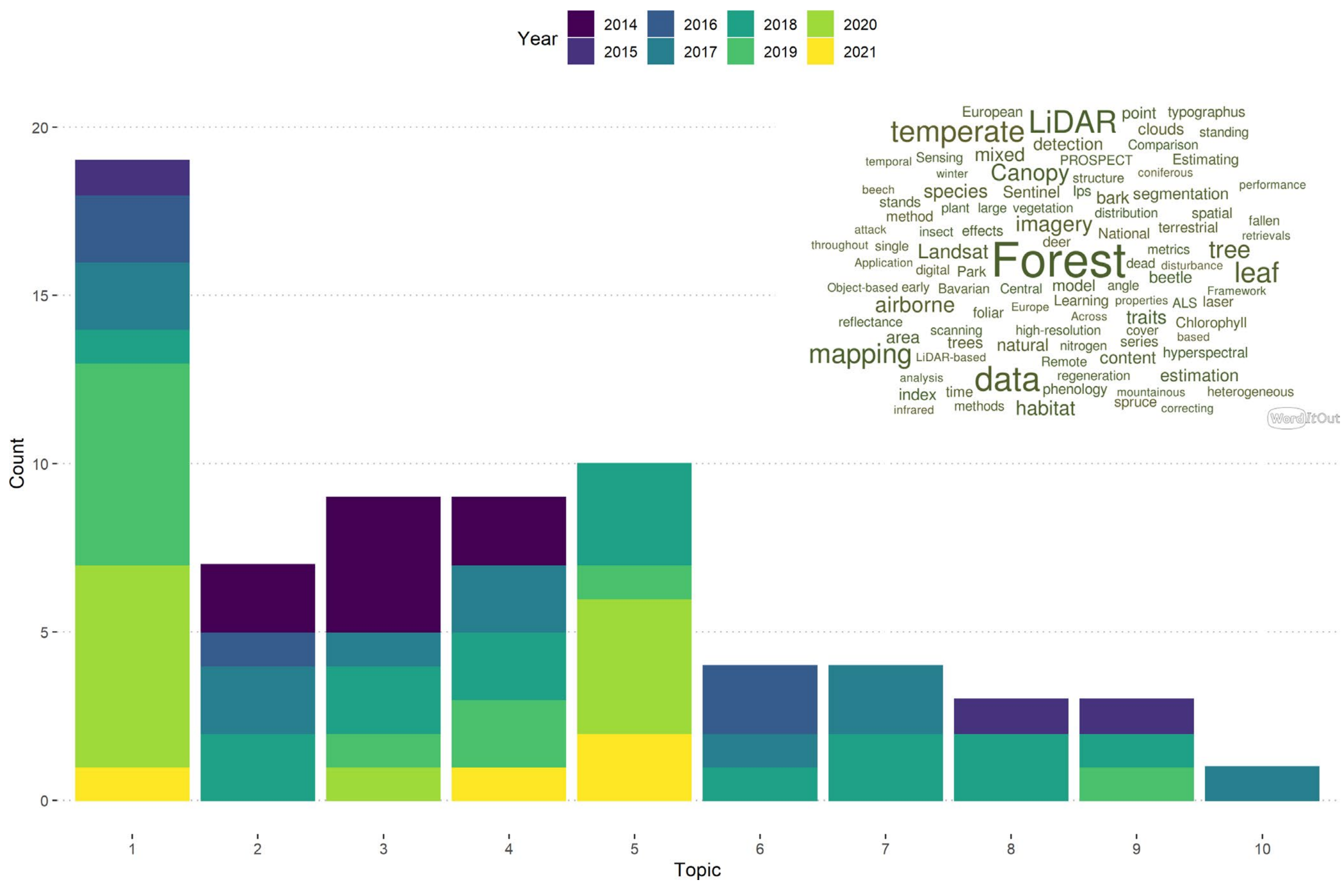

FIGURE 4 Quantitative summary of ISI journal publications by topic. The topic numbers include (1) leaf traits, (2) tree delineation and segmentation, (3) ecology of mammals, (4) forest disturbance, (5) species composition, (6) understorey, (7) phenology, (8) avian species ecology, (9) forest inventory and (10) DTMs/DSMs analysis. The word cloud on the top right side shows the summary of titles from 69 ISI journal papers published within the data pool (January 2014–June 2021), where the letter size corresponds to its rate of occurrence. It was created by www.worditout.com

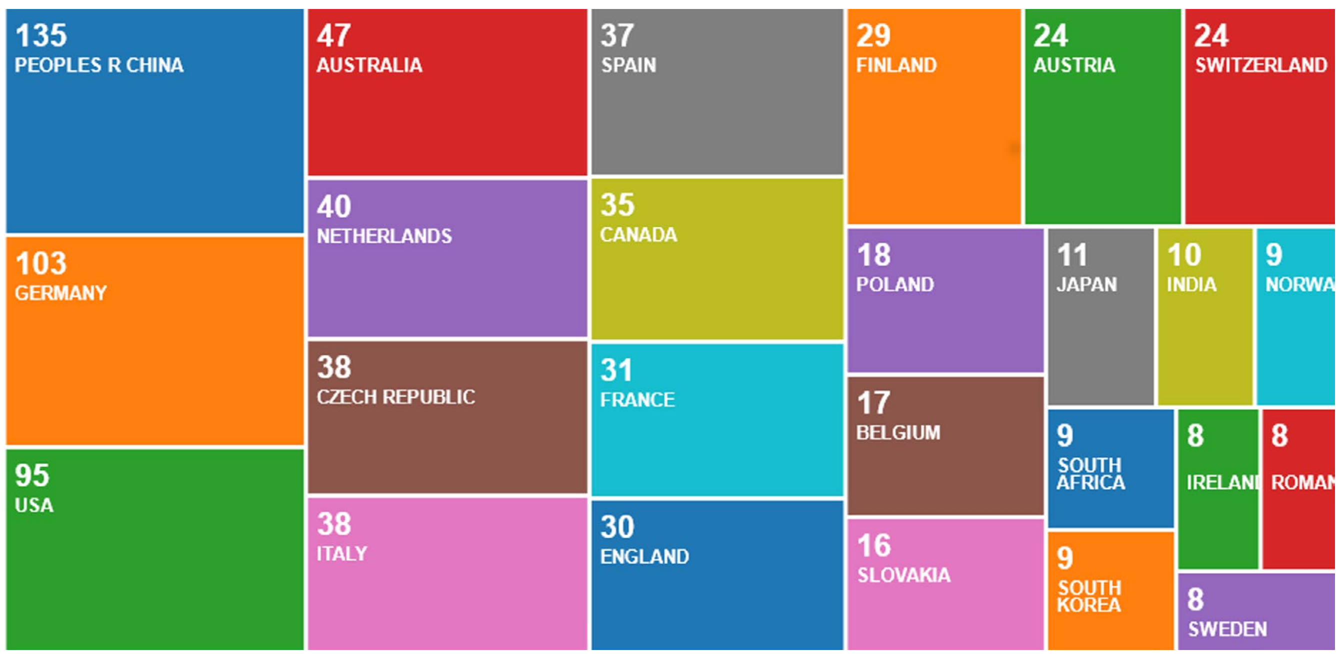

FIGURE 5 Geographical distribution of 547 citations (excluding self-citations) for the retrieved 59 publications from systematic search on the Web of Knowledge® (January 2014–June 2021)

were conducted during 1988–2020 yearly across the entire BFNP, and during 2006–2020 across Šumava NP. Furthermore, cross-border data by ultra-light UAV are acquired in 2018.

Information on leaf/canopy traits for remote sensing-assisted leaf-to-canopy upscaling involves access to airborne imaging spectroscopy data, for which campaigns from DLR's HySpex sensor systems along the visible, near-infrared and shortwave infrared domains were conducted across biodiversity transects (2016, 2017 and 2020), larger within-BFNP areas (2013) and the entire area (2015). The data acquired in 2017 were collected by NERC Airborne Research Facility (NERC ARF; http://arsf.nerc.ac.uk) with Specim AISA Fenix and Owl (thermal domain) systems during a European Facility for Airborne Research (EUFAR, https://www.eufar.net)-sponsored PhD summer school 'RS4ForestEBV-airborne remote sensing for monitoring essential biodiversity variables in forest ecosystems' (Darvishzadeh et al., 2017). Further airborne imaging spectroscopy data acquisition is foreseen in 2021 with NASA's Airborne visible/infrared imaging spectrometer-next generation (AVIRIS-NG) instrument.

Additional data were recently acquired by the DLR Earth Sensing Imaging Spectrometer. DESIS (on-board the International Space Station from June 2018 on) in 2019 and 2020, and the site was additionally targeted by ESA's PRecursore IperSpettrale della Missione Applicativa (PRISMA) mission from summer 2020. The current database also includes multitemporal SPOT-5 satellite data (from 2015) as well as Advanced Land Observing Satellite (ALOS) (20 data acquisitions during 2006–2017), TerraSAR-X (more than 100 data acquisitions during 2007–2016) Synthetic Aperture Radar data.

3.3.2 | In-situ data

Furthermore, the field data include plot-based structural, compositional and functional forest attributes for RS-EBV studies, including leaf- and canopy-level traits. The highest effort has been on sampling the leaf- and canopy-level traits of SLA, chlorophyll, leaf-level stream density and nitrogen content, carbon content, LDMC, stomata conductance, equivalent water thickness as well as tree height, diameter, LAI and canopy closure. In addition, more spectrally relevant data comprise aerial photo-based land cover and habitat type maps, hemispherical photographs, terrestrial laser scanner point clouds and PhenoCam data installed on fixed locations (see the full list in Appendix 3).

3.3.3 | Implications for training and management

The data pool was primarily designed for developing and validating useful products for managers from available and upcoming remote sensing sensors. A bonus has been that the field data campaigns stimulated interdisciplinary research and research directions in particular in the domain of RS-EBVs within two long-established ecologically contiguous, strictly protected national parks.

The research output directly impacted the monitoring and management of the PAs, justifying the investments of the NP administrations. For example, development of methods for single tree detection from airborne LiDAR data in combination with digital aerial photography enabled the administrations to carry out a more precise forest monitoring, while reducing costs up to 10% compared with traditional forest inventories (Latifi et al., 2015). Additionally, LiDAR-derived information has formed an essential contribution in many ecological research projects, supporting information on forest structure and helping to answer questions that could not be answered with conventional forest inventory data. Nature conservation management also benefited from the work by producing fine-scale habitat models, which have helped identifying critical habitats of rare species. These supported targeted management measures to promote their survival (Kortmann, Hurst, et al., 2018; Kortmann, Mueller, et al., 2018; Zielewska-Büttner et al., 2018). Applying products from the data pool enabled addressing fundamental ecological questions such as the meaning of habitat amount versus fragmentation for conserving rare dead wood-dependent species or the development of multi-taxa diversity along a forest succession gradient (Hilmers et al., 2018; Seibold et al., 2017).

These developments were also transferred to areas outside of the two national parks such as the German exploratories for large-scale and long-term functional biodiversity research (http://www.biodiversity-exploratories.de/) and resulted in high-ranking research output in both communities of remote sensing (Bae et al., 2019) and ecology (Bae et al., 2021; Heidrich et al., 2020). The data pool also serves as an important platform for the research on natural disturbance, which contributes to developing methods for the remote sensing-based detection of insect outbreaks (Latifi et al., 2018; Oeser et al., 2021; Tanase et al., 2018). These products are additionally used for the NP management and the analysis of the spatio-temporal dynamics of bark beetle populations (Seidl et al., 2016) and forest development (Senf et al., 2019), with impacts on management stretching beyond the data pool (Senf & Seidl, 2021; Stereńczak et al., 2020). Ecological and remote sensing concepts have been developed among groups within the data pool which have been translated into papers and policy documents beyond the data pool itself. Examples are (a) biodiversity policy Used in Convention on Biodiversity Subsidiary Body on Scientific, Technical and Technological Advice (SBSSTA, https://www.cbd.int/sbstta13/about.shtml) Policy Development 2017, (b) Biodiversity Policy Development 2018 developed letter from convention of biological diversity (CBD, https://www.cbd.int) secretariat to committee on earth observation satellites (CEOS, https://ceos.org) to maximize utilization of space-borne assets by the parties to the conventions, (c) ESA-based Copernicus Hyperspectral Imaging Mission for the Environment (CHIME, https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/chime-copernicus) satellite Mission Advisory Group (2017—present) and (d) presentation and provision of evidence to Netherlands House of Representatives (https://www.houseofrepresentatives.nl) hearing and debate on monitoring illegal poaching.

The data pool additionally serves as a platform to stimulate new research questions going beyond those that were considered at the time of its establishment, and to provide management with sought after indicators, information and advice. It has succeeded in supporting multiple joint field campaigns for management purposes or targeted for specific new research objectives. A recent review (Holzwarth et al., 2020) demonstrated that most studies on remote sensing of forest ecosystems in Germany are taking place in the BFNP. In addition, an annual workshop of the data pool (since 2015) for presentation and discussion of the accomplishments and ongoing research provides a discussion forum among junior and senior scientists of member institutions, in which new field and remote sensing data campaigns are discussed and decided in terms of their extent, location, sample size and required logistics.

4 | CONCLUSIONS AND OUTLOOKS

The open data/open science policy is underlined by the EU initiative of the European Open Science Cloud (https://eosc-portal.eu) which is implementing the FAIR (Findable, Accessible, Interoperable, Reusable) principles. So far, there has been no common platform on which all data are physically stored and made available, thus only the metadata of all available datasets is published on a data pool internal share point. This also ensures that the data owner is always informed about the use of the data. However, this is under consideration to be changed in the future, as a result of increase in participation of new institutions in the data pool.

All in all, this idea is associated with the advantages that (a) research topics are enabled to be broadly defined, (b) an in-depth collaboration with space agency (in this case DLR) is guaranteed, (c) the scientific results can be directly integrated into protected area management, (d) research for covering multiple aspects related to ecosystem monitoring with earth observation is repeated and broadly networked, (e) experimental errors are corrected to a large degree via repeated and internally connected research topics on geographically overlapping areas. Last but not least, the areas covered in the data pool are currently regarded as fixed forest ecosystem test fields for feasibility studies on new satellite missions (e.g. DESIS, CHIME and EnMAP). In the future, it may be possible to contact other field site networks to coordinate and link with local data pool initiatives, but this should be well-thought to maintain respecting the unique data-sharing arrangements of the data pool.

Finally, we suggest a range of future actions for reinforcing this (and other structurally similar data pools) including increased use for calibration of satellite data from upcoming DLR and public–private partnership campaigns, and use of cloud-based data infrastructures that increase training opportunities. The data pool is currently seeking a cloud-based solution similar to DIAS (Data and Information Access Services; e.g. CODE-DE developed by DLR, https://code-de.org) to store/access and process the data.

We also propose a collaboration between similar sites to standardize data capturing to increase the possibilities for training and testing applications to map biodiversity from space. We are planning to develop the data pool as a part/cornerstone of the suggested 'global biodiversity observatory' (Jetz et al., 2016) with an in-deep integration of in-situ trait and biodiversity measurements with remote sensing data. Therefore, an integration into national and international initiatives such as GEO BON will be pursued.

Finally, publishing a 'best practice tutorial for RS-EBV data pool establishment', has direct implications for establishing and maintaining similar constructions in other geographical parts of the globe.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHORS' CONTRIBUTIONS

H.L., S.H., A.S. and M.H. designed the research and wrote the first draft of paper; J.C., M.H., J.B. and S.H. provided the raw material on the data pool statistics; H.L., S.H. and J.B. conducted the systematic literature search, data processing and preparation of quantitative results. H.L., S.H, A.S., M.H., R.D., J.M., L.H. and U.H commented on the draft and all authors finalized it. H.L. was the corresponding author.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/2041-210X.13695.

DATA AVAILABILITY STATEMENT

The required data and R code to produce boxplots of data pool publications (2014–2021) are available at Github and can be retrieved via https://zenodo.org/badge/latestdoi/390224424 under https://doi.org/10.5281/zenodo.5146374.

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R code and tables for Appendices 2a and 2b. Retrieved from https://zenodo.org/badge/latestdoi/390224424. https://doi.org/10.5281/zenodo.5146374

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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