Biodiversity and Ecosystem Services
National Research Programme

NRP 82 “Promoting biodiversity and sustainable ecosystem services for Switzerland”
Template Full proposal Research Plan

The research plan must fulfil the following criteria for a successful submission:

- *The research plan and preparatory-phase description must be submitted in English;*
- *The research plan must not exceed* ***20 pages****, excluding references;*
- *Use the font size, margins and line spacing given in the current document;*
- *The research plan must be uploaded in PDF format in the respective data container of your mySNF application. (deadline:* ***6 February 2025, 17:00 h CET****);*
- *Applicants must follow the structure given in this template, the “Additional information to the ToC and the indicators” and the instructions in the call document.*

Swiss National Science Foundation

1 Full proposal: Cover page

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Project title (max 120 characters)	VegCHange: A toolbox to investigate anthropogenic changes in the Swiss flora and vegetation
Short title	VegCHange

2 Broader context, state of scientific knowledge in the field and novelty of the project

2.1 Broader context

Our planet is facing increased anthropogenic extinction rates across taxonomic groups, which many researchers consider comparable to a mass extinction event in earth's history (World Resources Institute 2005; Cowie et al. 2022). There is a broad consensus that this rapid loss of biodiversity is severely diminishing nature's contribution to people, posing a fundamental threat to humanity's survival (Cardinale et al. 2012; Brondizio et al. 2019). This has inspired a broad range of actions and policies at international and national levels to safeguard biodiversity, such as the Convention on Biological Diversity (CBD), the Sustainable Development Goals (SDG's) of the UN, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) at a global scale. In Switzerland, ten overarching strategic goals have been established by the national Biodiversity Strategy (FOEN 2012) and complemented by two Action Plans (FOEN 2017a, 2024), which define specific measures to promote biodiversity, coordinate biodiversity policy across policy areas, and raise public awareness. Measures to conserve and restore biodiversity include creating protected areas (e.g. Hochmoorverordnung 1991, Auenverordnung 1992), agri-environmental schemes (e.g. Abs. 2 Direktzahlungsverordnung 2013), and mitigating the impact of invasive species (Freisetzungsverordnung 2008). However, despite notable progress in many areas, these measures have failed to reverse the trend of diminishing biodiversity (Gattlen & Klaus, 2023). The second action plan of the Swiss Biodiversity Strategy (SBS) for the period 2025 to 2030 specifically addresses existing deficits and aims to increase the effectiveness of conservation measures (FOEN 2024). Its strategic objectives include conservation measures to promote biodiversity at the level of species and communities and optimising the management of biodiversity data and information. This suggests that there are still important knowledge gaps in biodiversity conservation in Switzerland, which include: a) quantifying the relative importance of different drivers of biodiversity loss; b) quantifying long-term population trends of individual species; c) quantifying long-term trends in the diversity and composition of biological communities; and d) a lack of evidence-based working methods in applied conservation.

2.2 Knowledge on plant diversity loss and its causes

Despite extensive research during the past decades, our understanding of the nature of biodiversity loss and its driving forces is still limited, leading to inconclusive or even (apparently) contradictory results. For instance, while many species have declined or gone extinct at national or global scales, studies on time series of biodiversity data often find little to no decline in species richness at the local scale (Vellend et al. 2013; Dornelas et al. 2014). This phenomenon is known as the "biodiversity conservation paradox" (Cardinale et al. 2018, Jandt et al. 2022). In Switzerland, there are such contrasting results for plants: Whereas Kempel et al. (2020) found that 27% of rare plant populations have gone extinct at the 1-km^2 scale during the past decades, data from the national biodiversity monitoring program BDM suggest increasing species richness at this scale over the last 20 years (Abrahamczyk et al. 2022). At the plot scale, the BDM found an increase in richness since 2000 (FOEN 2017b; also Häberlin & Dengler in review), while the ongoing Square Foot Project (SNSF-197642) found a strong decrease in taxonomic and functional alpha diversity for grasslands in Switzerland over the past 120 years (Widmer, Dengler et al. in review). These apparently contradictory findings are due to differences in spatial and temporal scales (Chase et al. 2020). Although such scale-dependent contrasting trends can be understood from a theoretical perspective, communicating such findings to a broader public is challenging.

The picture becomes even more unclear when attributing biodiversity losses and changes to main drivers. Numerous studies test for single drivers (and often find effects) but ignore that different potential drivers always act in concert, leading to synergistic and antagonistic interactions. Moreover, different components of biodiversity might be differently affected, such as alpha vs. beta diversity or different taxonomic groups. Thus, our picture of the relative importance of drivers as land use, climate change, nitrogen pollution, biotic exchange, and direct exploitation is mostly based on the rough aggregation of expert opinions (Sala et al. 2000; Rounsevell et al. 2018). By contrast, there are very few data-driven analyses of the relative importance of drivers (Jaureguiberry et al. 2022). Further, many studies emphasize biodiversity losses and "negative", often abstract, drivers, ignoring that there are often also positive impacts, e.g. by conservation actions, which are often intuitively more accessible to a general public. Even drivers with typically negative connotations can have positive effects on native biodiversity, including neophytes or climate change. For, example, various studies reported increasing plant species richness in European mountain regions (e.g. Pauli et al. 2007). Regarding neophytes in Swiss grasslands, Dengler et al. (2024) found that when accounting for various other drivers, the influence of neophyte occurrence on native plant diversity diminished and turned neutral or positive for several species commonly perceived as negative.

Gap 1: We lack a quantified attribution of different components of biodiversity change/loss to drivers that would allow informed decisions which are the most effective measures to protect/improve different components of biodiversity.

2.3 The untapped potential of plant biodiversity data in Switzerland

Plants are a particularly important element of biodiversity as they are responsible for primary production and shaping habitats in nearly all terrestrial and freshwater ecosystems. As sessile organisms that are visible throughout most of the year, they can be more easily and completely sampled than animals, fungi, and microorganisms. In consequence, plants usually form the backbone of biodiversity monitoring systems (e.g. BDM and ALL-EMA; Koordinationsstelle BDM 2014, Meier et al. 2021) and have the largest amount of structured historic records (Dengler et al. 2011). Switzerland is among the countries with the most comprehensive data coverage of present and historical plant diversity. With BDM (Koordinationsstelle BDM 2014), WBS (Bergamini et al. 2016), and ALL-EMA (Meier et al. 2021), it has three statistically optimised nationwide monitoring programs focussed on plant diversity at the 10-m^2 and 1-km^2 scale. InfoFlora, the data centre for the Swiss flora, has compiled more than 14 million occurrence records of vascular plants and continually increases the size and utility of this resource, with citizen science and other activities. Compared to other countries, Switzerland has also a high density of historic vegetation-plot records (Schaminée et al. 2009), permanent plots, and resurvey studies (Knollová et al. 2024).

The vast potential of these records of plant and vegetation diversity in Switzerland over the past century has so far only partially been tapped (Bühler & Roth 2011; Kempel et al. 2020; Abrahamczyk et al. 2022, Scherrer et al. 2022; Kiebacher et al. 2023), due to issues such as a lack of data integration and workforce. Moreover, the data that has originated from "opportunistic" sampling, often by amateur botanists, contains a multitude of biases that challenges their proper analysis. However, there is now an increasing body of experience from neighbouring countries on how to overcome such impediments. In particular, the "sMon" project (https://www.idiv.de/de/smon.html) in Germany designed to get reliable answers out of such heterogeneous historic biodiversity data can serve as an inspiration. Despite facing a worse data situation than in Switzerland, using modern statistical techniques, this project has resulted in several groundbreaking studies that have significantly increased our understanding of diversity change in plants over the last century (Bruelheide et 2020; Eichenberg et al. 2020; Jandt et al. 2022). Evidently, the biogeographic and socio-economic situation in Switzerland, with large parts of the country being mountainous and thus being less subject to direct human pressures and the lowlands on the other hand being one of the most intensively used regions in Europe, is different from Germany so that methods can be transferred, while results likely will differ in various aspect.

Gap 2: While Switzerland has a large, if not globally unique, range of high-quality data on plant diversity, they have never been brought together and jointly analysed in a comprehensive manner.

2.4 Integrating flora and vegetation data with conservation action in Switzerland

Understanding temporal and spatial trends in plant species and habitats is at the core of conservation planning and management. However, Red Lists and lists of prioritized species or habitats (FOEN 2019), for instance, are largely based on inferred declines of species populations. However, unlike in the case of birds, for the taxonomic groups of vegetation, these assessments are so far typically based on semi-quantitative data and/or expert opinions, and require constant update. Moreover, currently conservation prioritization focuses strongly on rare species (FOEN 2019), ignoring that recent studies have shown that the moderately frequent species are those that show the strongest declines (Jansen et al. 2020 for Germany; Widmer, Dengler et al. in prep. for Switzerland). While such moderately common species are far from going extinct (in Switzerland, they are typically not even classified as NT = near threatened), their strong declines still raise conservation concerns, (a) because the frequent species are typically also the more dominant species and these drive the ecosystem services delivered (Engel et al. 2023) and (b) the more frequent plant species have more dependent taxa (such as monophagous insects or phytoparasitic fungi) and their decline thus could have cascading effects on other components of biodiversity.

Gap 3: Red list preparation currently suffers from the fact that standardised quantitative trend data (including uncertainties) for the species to assess is not available and also cannot be updated continuously in the future.

In Switzerland there is a core of conservation measures in place and the country and the cantons are spending substantial amounts of money to implement them. These include direct payments for farmers based on quality of grassland or the establishment of connecting habitat elements or “improvement of forest edged”. With a few exceptions (but see Meier et al. 2021 for quality payments for grasslands), these measures have been developed based on expert opinions and are not monitored quantitatively. Currently, Switzerland is on the way of implementing the “Ecological Infrastructure” (EI) as the future major conservation tool. The cantons are asked to plan the EI, but it is challenging to develop a sound planning that effectively improves biodiversity if the knowledge is limited which elements to support where and where to conserve existing biodiversity and where to restore impoverished biodiversity.

Gap 4: Many conservation instruments currently are not accompanied by a systematic evaluation of their effects on biodiversity.

2.5 Gaps in societal problem solving: the role of transdisciplinary research

Over the past few decades, conservation scientists and practitioners have arguably gained a wealth of experience and knowledge in biodiversity conservation. However, a lack of movement towards evidence-based working methods, as used in other disciplines, has been noted (Pullin & Knight 2001; Sackett et al. 1996; Hofer 2016). Efforts have therefore been made to adopt an evidence-based approach to conservation planning and management (Sutherland et al. 2004). Integrating scientific evidence into practice is however challenging. Scientists, practitioners, and policy-makers often have different perspectives, values and knowledge, and may "speak different languages" (Wyborn et al., 2023). As a result, they face difficulties in agreeing on the nature of the problem and how to solve it. Scientists and practitioners have also criticised the lack of exchange between science and practice, with the result that research findings are not taken into account when implementing conservation measures (Arlettaz et al. 2010; Braunisch et al. 2012; Prendergast et al. 1999; Toomey et al. 2017).

One strategy to address these challenges is a transdisciplinary approach to research. Transdisciplinary research is characterised by the participation of practitioners and policy makers throughout the research process (Bitoun et al., 2022; Elzinga, 2008; Enquist et al., 2017; Kates et al., 2001). Starting from a common problem formulation, such an approach leads to the integration of co-produced knowledge in the real world (Elzinga et al., 2008). According to Elzinga (2008), participation can 1) initiate a process of institutional change, 2) benefit the collection of data, 3) complement expertise with knowledge from other perspectives, 4) educate about science, and 5) be used to overcome mistrust in science. Indeed, in contrast to the expert-oriented (top-down) perspective of traditional science, developing research questions that arise from real-world management problems can foster high levels of trust and commitment between partners (Enquist et al., 2017). The Theory of Change (ToC) approach provides a useful and flexible tool to support transdisciplinary research. To improve conservation interventions, Rice et al. (2020) emphasize the importance of producing a shared vision of desired results, and actions, as well as the underlying mechanisms, among actors.

Gap 5: There is a disparity between knowledge and action in conservation, partly based on differences in values and perspectives between scientists, practitioners, policy makers and the society, which need to be overcome to fully embrace the implementation of evidence-based measures.

2.6 Our approach in VegCHange

To address the outlined research and implementation gaps, VegCHange will implement an approach as comprehensive as possible within the financial and temporal constraints of the project. First off all we will deal with all four major taxonomic groups of the vegetation (vascular plants and bryophytes in detail, but also lichens and charophytes) and prepare common analytical frameworks for these. Second, we will fully embrace the challenges as well as the opportunities coming from the scale-dependence of all aspects of biodiversity, biodiversity change and their drivers. We do this mainly by analysing in parallel local-scale alpha diversity data (from vegetation plots) and aggregated species occurrence data at larger grid cells (gamma diversity) as well as combining these with other grain sizes and beta diversity measures that link the grain sizes. To achieve the best-possible outcomes and impacts we will interact with societal stakeholders nationally (the scale of most of our analyses), but more intensively in a pilot canton (Grison) where we will have intense and regular interactions with the regional stakeholders to optimise co-creation and implementation. Acknowledging that the ideas born during the preparatory phase go far beyond the funding framework, we are striving for involving more researchers and additional funding to “harvest” as much of the fruits produced with our setting. Lastly, we have already initiated setting up tool research (and outreach) tools that will be of high value beyond the temporal framework and topical scope of the project, namely the national vegetation-plot database of Switzerland and the information platform “Plant diversity and vegetation of Switzerland”, and we are thus already considering permanent solutions for them after completion of VegCHange.

3 Objectives and main research questions

VegCHange is part of Molule 1: Drivers and Trends as we will investigate drivers and trends of plant diversity change and thus contribute to better methods for safeguarding plant biodiversity within Switzerland.

VegCHange aims at combining and augmenting the diverse and heterogeneous available data sources in Switzerland with their methodological challenges to derive an overarching, data-driven picture using modern statistical approaches of how the flora and vegetation in Switzerland has changed over the last century. To attribute drivers to biodiversity changes, the results will be broken down by spatial and temporal scale, region, habitat, and plant species group. A significantly improved knowledge of drivers and patterns will then be translated into tangible information for stakeholders to allocate resources for biodiversity conservation most effectively, and to identify and mitigate negative effects from other policy fields. With this comprehensive approach, VegCHange will be internationally unique and even go beyond the current achievements of its German counterpart sMon, which follows a similar approach but has not yet substantially addressed drivers of biodiversity change.

Our main **research questions** are:

- How are plant diversity losses and gains, as well as compositional changes distributed across space and time?
- Which species and habitats have been winners or losers over the past 100+ years?
- How can these spatial and temporal patterns of biodiversity change be used for a sound quantification of the relative importance of different drivers of biodiversity impoverishment?
- How can this knowledge be used to prioritise conservation?
- How can combinations of factors that have been identified as leading to regional preservation or even increases in biodiversity be used to design actions/policies for wider application?

4 Approaches and methods

4.1 Preparatory phase

During the preparatory phase, we approached a wide range of societal stakeholders and scientific experts (from Switzerland and abroad) to determine whether they are interested in participating in the initial stakeholder workshops during the preparatory phase and/or get involved in the full proposal and project. That way we successively formed the consortium for the full proposal (see below).

We organised two stakeholder workshops with a total of 29 participants in Zurich on 23 October and 11 December 2024. The Theory-of-Change expert Dr. Rea Pärli (WSL) moderated the first and bigger one, specifically devoted to co-creation between scientific and societal partners (Fig. 1). In the second workshop, we focussed on the situation of non-vascular taxa (bryophytes, lichens) and whether/how they could be included in the project. Among the major insights we took the following from the discussion:

- As the general setup of VegCHange (as approved by SNSF in the preproposal) is to conduct comprehensive research at national level, the main stakeholders are at national level (e.g. policy makers), but there it is hard to achieve measurable impact during short time.
- We thus should seek an exemplary case (topically or regionally) where we could elaborate more in-depth how specifications from practitioners could feed into the research design and the research output could feed back into conservation practice. One idea would be to involve a canton since nature conservation in Switzerland is the responsibility of the cantons.
- The prototype of the plant diversity-vegetation dashboard presented was perceived as a potentially powerful tool for stakeholders to get easy access to relevant information, if the dashboard is further developed to meet their needs.
- Analysis of drivers are useful, but results must be processed for practical applications e.g. as sythesis reports, fact sheets or policy briefs.

- Ideally, data analysis are aligned with the needs of ongoing planning and implementation processes in the pilot region or with the case studies

Fig. 1. Impressions from the first stakeholder workshop during the preparatory phase on 23 October 2024 in Zurich.

Before and after the two workshops we also succeed to implement the other tasks outlined in the preparatory phase proposal:

- We compiled and updated the overview of **existing species observation data** in Switzerland (vascular plants, bryophytes, lichens, charophytes) in the national data centres (InfoFlora, SwissBryophytes, SwissLichens) as well as various other suitable data sources.
- We took first steps towards a **national vegetation-plot database** by thoroughly screening the two biggest such datasets in Switzerland, assessing the work needed to clean, harmonize, and combine them and to transform them into a user-friendly and efficient tool.
- **Plant diversity and vegetation information platform (vegetation.ch):** a prototype (currently in German only) was released and subsequently refined and augmented based on user feedback. To date, it contains three interactive dashboards for the vegetation-plot database, the contemporary state of grasslands, and vegetation time series (currently based on a subset of resurvey studies conducted at ZHAW) (Fig. 2)
- **Vegetation recording tool in FlorApp:** in a meeting with the responsibles from InfoFlora, we discussed and prioritized the options for further improvement.

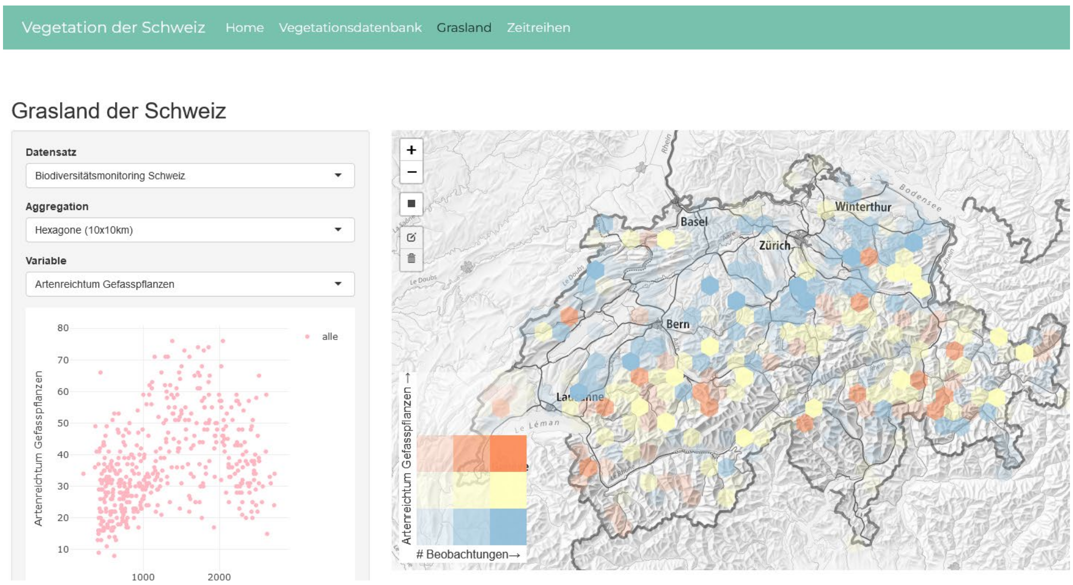

Fig. 2. Example of one of the interactive biodiversity dashboards already available in the prototype of "Plant diversity and vegetation information platform for Switzerland" (http://vegetation.ch). The chosen visualisation shows current species richness of vascular plants in 10-m^2 plots of representative grasslands.

Following the workshops, we continued the planning of the full proposal, including numerous exchanges of the applicants and stakeholders, finally shaping the idea of having a pilot canton as a way to bridge the gap from national-level general research outcomes to information that can be effectively taken up by practitioners, and thus to implementation and transformation. Accordingly, several key stakeholders from the canton of Grisons were consulted on their needs and interests, thus continuing the co-creation process started at the workshop with stakeholders at the regional level by identifying necessary tasks and milestones (see WP 5 in section 3.4). So far involved were M. De La Harpe (ANU, canton of Grisons, T. Wohlgemuth, I. Jansen (citizen science project FloRae), C. Rixen (SLF), S. Burg, S. Wipf (freelance ecologists), and D. Frey (canton and museum, TI).

4.2 Our methodological concept

Kühl et al. (2020) outlined that effective biodiversity monitoring needs both the integration of a wide range of different data sources and the involvement of stakeholders far beyond the scientific realm – and we maintain that the same is true for analysing biodiversity trends and drivers. VegCHange thus aims at joining the full wealth of existing data on Swiss plant diversity from various different sources with the latest models of environmental drivers and state-of-the art statistical approaches to derive a comprehensive understanding of all the facets of plant biodiversity change and its underlying drivers. At the same time to achieve improvements in the state of plant diversity in Switzerland, we need to translate our findings into something that is tangible to be taken up by conservation practitioners as well as policy makers. In order to reach the project objectives (section 2) and inspired by the co-creation during the preparatory phase, we defined our methodological concept as follows:

Species occurrence data

Approach 1: The rich and ready-to-use species occurrence data of all four main taxonomic groups of the vegetation (vascular plants, bryophytes, lichens, charophytes) in Switzerland (see 3.3) offer an enormous and hitherto largely untapped potential to quantify plant diversity change with unknown temporal and spatial resolution. Probably the main reason why such analyses have not been conducted before is the fact that the majority of such observations come from opportunistic sampling, with numerous biases in space and time due to varying sampling intensity and sampling preferences, rendering results from simple trend analyses spurious (Burges et al. 2017; Bowler et al. 2022). So-called occupancy-detection models have been proved successful in modelling changes grid-cell distribution despite these ubiquitous biases, e.g. for invertebrates and non-vascular plants in the UK (Outhwaite et al. 2020) or dragonflies in Germany (Bowler et al. 2021). Eichenberg et al. (2021) applied this methodology to the 29 million records of more than 2,000 vascular plant species in Germany to derive the grid cell (25 km^2) occurrence probabilities of these species over nearly six decades with the FRESCALO algorithm (Hill et al. 2012). They modelled each individual species and then aggregated all species as well as certain species groups (e.g. neophytes vs. indigenous species) to model how their frequencies changed in time. They could resolve this temporally in two steps and spatially by 5 km. Given that the average amount of data for vascular plant data per area in Switzerland is almost five times higher (see 3.3), we anticipate that with the same approach we will be able to model floristic changes further back in time (possibly starting around 1900), and thus capturing the effects of the agricultural intensification during the 20th century. Moreover, it might be feasible to achieve higher temporal and spatial resolution. While one or several scientific publications based on these data will focus on overall changes of species richness per grid cell (gamma diversity) and groups of taxa (e.g. according to floristic status, rarity or habitat preferences), the full wealth of models for most of the vascular plant species will be made available in our plant diversity information platform. Once successfully implemented for vascular plants, we would expand this approach to bryophytes and potentially to lichens and charophytes. The results emerging from the VegCHange analyses will be included in the Red List revision process of vascular plants. Conversely, the quantitative analyses from the Red List projects also form a basis for the plausibility check of VegCHange results.

Species co-occurrence data (i.e. vegetation plots)

Compared to "occurrence-only" data, "co-occurrence" data based on vegetation plots provide added value, as they allow analysing a different grain size of typically 0.1-400 m^2 (vs. typically 25 km^2 in the previous case), meaning that they refer to alpha diversity. Moreover, vegetation-plot data allow for a wider array of analyses (see Dengler et al. 2011; Bruelheide et al. 2019) as they (a) contain true absences, (b) in most cases species abundance data (e.g. cover) and (c) often also *in situ* determined structural and environmental variables. This allows the direct calculation of biodiversity metrics as well as mean ecological indicator values (Landolt et al. 2010; Dengler et al. 2023; Midolo et al. 2023) or community-weighted means of functional traits (Kleyer et al. 2008, Kattge et al. 2020). This allows identifying large-scale patterns of vegetation change, such as thermophilisation (Kiebacher et al. 2023) or trait and composition changes due to fertilization (Boch et al. 2021).

Approach 2: Switzerland has three elaborate **national biodiversity monitoring schemes** (BDM, WBS, ALL-EMA). The oldest scheme (BDM) started in 2001 has a systematic grid of 1600 10-m² plots across Switzerland, thus representing the changes in the average landscape of Switzerland across all habitats (Koordinationsstelle BDM 2014). Apart from an initial study after the first resurvey (Bühler & Roth 2011), a specific study on thermophilisation (Kiebacher et al. 2023) and some reports in grey literature (e.g. FOEN 2017b), the potential of these data has hardly been tapped. We thus will submit the entire BDM vegetation plots with their records of vascular plants and bryophytes after five complete rounds of sampling to a comprehensive analysis of the 21st century changes in plant alpha diversity and vegetation composition of Switzerland.

Approach 3: Looking back in time before the onset of the national monitoring programs ist the strength of **resurvey studies**, largely relying on quasi-permanent plots, i.e. where the plot was not permanently marked but approximately resampled in approximately the same location (Kapfer et al. 2017; Diekmann et al. 2019). They have a great potential to derive non-biased estimates of changes in community attributes (Boch et al. 2019). In Switzerland numerous resurvey studies, based on permanent and quasi-permanent plots have been conducted for specific habitat types, regions and time-steps, mainly for lowland grasslands (e.g. Charmillot et al. 2021), alpine vegetation (e.g. Liberati et al. 2019), and forests (e.g. Staubli et al. 2021) (see also. https://wp.unil.ch/ppch/ and https://vegetation.ch/zeitreihen.html). However, no overarching synthesis like the meta-analysis by Diekmann et al. (2019) or the overarching synthesis by Jandt et al. (2022) has been attempted, despite this would give valuable additional insights (Verheyen et al. 2017). We thus aim to collate all available such studies and make them accessible for combined analysis, while at the same time filling some gaps in coverage. This is particularly true for bryophytes, which very rarely have been considered in resurveys (but see Diekmann et al. 2023; Kiebacher et al. 2023). Thus we will specifically look into a set of permanent plots for bryophytes set up in 1984-2006 as the National Inventory of Swiss Bryophytes (NISM; http://www.givd.info/ID/EU-CH-004), but never resurveyed since then.

Approach 4: In general, Switzerland is among the countries with the highest densities of vegetation-plot data in the world and also reaching back particularly far; just the data are not readily available for use so far (see 3.3). More than 15 years ago, Jandt et al. (2009) modelled the decadal trends of species composition in German semi-dry grasslands and beech forests using a medium-sized vegetation-plot database. They could demonstrate that vegetation-plot databases allow deriving realistic trends in species frequency at the local (alpha) scale as well as of community properties via ecological indicator values. They could do this analysis despite there being no pairs of historic and current plots, just by aggregating all plots in several time slices through which they led their trend curves. Despite vegetation-plot databases becoming much more numerous and larger meanwhile, to our knowledge, this approach was never followed since. This might be due to a simulation study Chytrý et al. (2014) finding that time series analyses of vegetation-plot databases (without temporal pairing of plots) could result in false positive outcomes (i.e. claiming change when there was none), which let conclude them that this is a “risky business”. However, this simulation referred only to a single aspect of change analysis, namely floristic distances in multivariate space, and is likely not or less true for aggregated metrics at plot level (such as diversity and mean indicator values). Moreover, temporal and spatial biases in vegetation-plot databases could be mitigated by cutting the entire data in spatial and temporal subsets and considering only trends that are consistent across these. A ongoing project at European level involving the main applicant (Midolo et al., to be submitted soon) is implementing exactly this approach for 675,000 plots from the European Vegetation Archive (EVA; Chytrý et al. 2016), combined with modern machine-learning techniques, namely random forest (Breiman 2001) and extreme gradient boosting (Cheng & Guestrin 2016). With this method, they could gain plot-size corrected species richness per each of four main habitat types (grassland, scrub, forest, wetland) per year and 2500-km² grid cells and thus derive realistic trends for each combination of habitat x decade x biogeographic region. Based on the fact that the density of available plots in Switzerland (4.4 plot km^{-2}; see 3.3) is more than 40 times higher than in the European study (0.1 plot km^{-2}), it is likely that we can model vegetation change in VegCHange with a significantly higher spatial and ecological resolution, i.e. broken down to individual habitat types. We preview that these products, and the concurrent implementation on the biodiversity platform, will greatly further the planning of ecological infrastructure.

Embracing the multidimensionality of plant diversity

Approach 5: To understand the complexity of diversity change it is crucial to consider the different scales and dimensions of change and to consider that different taxonomic groups might behave differently. Thus, in VegCHange we will comprehensively consider the two most widespread and at the same time best-documented taxa of vegetation, vascular plants and bryophytes, comprehensively, while foreseeing options to also include lichens and charophytes in some analyses. We will consider various different metrics of diversity and composition, including also functional diversity, the latter being particularly relevant for the provision of ecosystem services. VegCHange inherently looks into different spatial scales from less than 1 m2 (Riedel et al. 2023) via normal vegetation plots, 1 km2 (Z7 indicator from BDM), 25 km2 (probably grain size for floristic diversity analyses) to biogeographic regions and entire Switzerland. Understanding and using the underlying scaling laws will help achieve a more comprehensive understanding (Chase et al. 2018, 2020), for example, if fine-grain changes can be considered an early warning sign of delayed changes at coarser grain sizes. Likewise, we will not only focus on extinct or rare species, but also on frequency/dominance changes of moderately common species, which are usually not included in the Red Lists but are likely more influential for ecosystem service (e.g. Engel et al. 2022).

Co-creation and implementation to achieve outcomes and impact

Approach 6: In continuation of the activities in the preparatory phase, we will hold workshops with diverse stakeholders (FOEN, cantons, NGOs, environmental consultancies, botanists, data centres) to (a) identify which information on trends and drivers would be most valuable for them, (b) in which format it should be presented to be taken up in practice, (c) locate additional vegetation-plot datasets that could be mobilised, and (d) develop workflows and tools for the active involvement of the public in digitising existing vegetation plot data, recording new vegetation-plot data to fill data gaps and providing "ground-truth feedback" on our scientific findings (see 3.1), thereby employing tools developed by InfoFlora (e.g. field protocols for citizen involvement during the production of the new Red List 2024–2028). We will also call on the community to contribute vegetation data which is not already included within the common databases e.g. unpublished student projects, local restoration projects, environmental impact assessments or grey literature. We will make use of the networks of the project team, institutional websites, and social media to reach possible data providers.

Approach 7: As initiated in the preparatory phase, we will co-develop effective means to deliver our results back to non-scientific stakeholders, practitioners, decision makers and the public. Currently, we envisage (a) an interactive website (biodiversity dashboard) to visualise the collected vegetation-plot data (Approaches 3 and 4) together with ad hoc analyses of states and trends (a prototype of this has already been developed by the ZHAW) and to be refined for the target region (see below), (b) workshops with stakeholders during later phases of the project to clarify how our results can be translated into more efficient policies and tools (e.g. Ecological Infrastructure, Red Lists, planning of conservation areas, agricultural policy) and (c) the production of "fact sheets" (similar to those of the BiodivERsA projects: https://www.biodiversa.eu/actionable-knowledge/policy-briefs/ or those of the Swiss Academy: https://scnat.ch/en/uuid/i/abf3e252-a389-5e05-9363-4ba2cfb80cca-Swiss_Academies_Factsheets) summarising the scientific results for laymen and policy makers.

Approach 8: Inspired by the sMon project in Germany, we will develop a "toolbox" for analysing messy, incomplete, and biased biodiversity time series that will be made available for other projects, e.g. involving regional datasets, other taxonomic groups or similar initiatives abroad. This could take the form of open workshops or direct cooperation between members of the VegCHange team and these partners. For example, sMon successfully analysed the biodiversity trends within a regional habitat survey (Bruelheide et al. 2020) and a regional mire dataset (Sperle & Bruelheide 2021). Approach 7 will go beyond the funding provided by SNSF, but we are optimistic that we can secure further funding for such outreach and synergies.

The canton of Grisons as a blueprint for national implementation

Approach 9: To reach our ambitious implementation goals, transfer to administration, practitioners, and society, and a positive long-term effect on biodiversity, we will focus transdisciplinary co-creation and implementation measures on the smaller spatial scale of the largest Swiss canton of Grisons rather than the whole of Switzerland. This will mainly concern aspects of the co-creation mechanisms, tool development, and implementation, and knowledge transfer to a suite of stakeholder groups and levels. The key findings, successful implementation steps and methods can subsequently be extended to the area of Switzerland within the scope of a planned "Transformation Accelerating Grant" (TAG).

The canton of Grisons is an ideal target area for implementation and knowledge transfer and exchange for several reasons. (a) With its altitudinal span from 250 m to 4000 m a.s.l., spread over three biogeographical regions, and numerous land use gradients and systems from wilderness to intensive agriculture, Grisons includes a great variety of climate and habitat types within a relatively small area. (b) With the process of setting up a cantonal biodiversity strategy (adopted in 2024), the cantonal authorities have a large regional knowledge base and assembled strategic planning, on which successful collaboration and co-creation with our project will build upon. (c) Grisons offers a high density of baseline data from historical sources as well as concurrent research projects and monitoring programs. (d) A collaboration with the currently running large citizen science project (>100 volunteer botanists) for a new Flora of Grisons (Flora Raetica, see www.florae.ch), offers ample possibility for data acquisition, collaboration as well as outreach and capacity building.

In parallel to our project, on behalf of the federal government, the cantons are developing plans for ecological infrastructure within the respective cantonal perimeters. The canton of Grisons has not yet started the detailed planning, and the responsible authorities (Amt für Natur und Umwelt ANU) would like to regularly exchange with and make use of VegCHange analyses during their project phase. The canton will be strongly involved in co-creation processes, and VegCHange results will continuously be integrated into the planning and implementation of the Ecological Infrastructure. This planning specifically focuses on the dynamic nature of species and habitats, acknowledging that in times of increased dynamism in the landscape, exclusively static planning of ecological infrastructure is futile. In our project, we aim to create a platform in which future data can be continuously integrated, providing an up-to-date picture of species trends and the drivers of these trends.

4.3 Data availability and mobilisation

Species occurrence data of the four major taxa building the vegetation (vascular plants, bryophytes, lichens, charophytes) are particularly well-curated in Switzerland compared to most other countries, each hosted by a specific national data centre: InfoFlora (vascular plants and charophytes: https://www.infoflora.ch/en/), SwissBryophyte (https://www.swissbryophytes.ch/) and SwissLichens (https://swisslichens.wsl.ch/en/). All three data centres offer websites that allow to explore distribution information of single species and several other aspects on interactive dashboards, combined with extensive background information. The data in the data centres are well curated, harmonised to common taxonomic backbones and georeferences with point coordinates and geographic uncertainty - thus allowing for statistical analyses without need for extensive further preparation.

Similarly to the data infrastructure, also the amount of digitally available species records in all four taxonomic groups is impressive in Switzerland (Table 1). As in other countries, the best represented taxonomic group in botany are the vascular plants, which surpassed 14 million observations in 2024, meaning an average of more than 3,000 observations per valid taxon, which includes rare neophytes recorded only once. To put this into context: Germany, for an almost nine-fold area, has "only" about 29 million records (Eichenberg et al. 2021). Impressively, georeferenced data in two of the taxonomic groups date back as early as the 16th century and to the late 18th century in the two others (Table 1). While in the early decades, the scarcity of data will probably exclude any quantitative analysis, for vascular plants probably starting in the late 19th century the amount of data recorded annually (Fig. x) might support trend analyses with modern approaches. Also the spatial coverage of the vascular plant data across Switzerland is impressive for vascular plants (Fig. 3 left) and not so much worse for the other taxonomic groups. Lastly, through the FlorApp smartphone application as user friendly and uniform tool across all four taxonomic groups, the Swiss amateur and professional botanists every year collect large amounts of new opportunistic high-quality data (e.g. more than 1 million vascular plant records in 2023). Through a motivating community platforms (e.g. InfoFlora, FloRae), citizen scientists more and more also help to collect more systematic data.

Table 1. Available species observation data in the Swiss data centres for vascular plants and charophytes (InfoFlora), lichens (SwissLichens) and bryophytes (SwissBryophytes) in January 2025.

Group	Valid taxa	Observations	Ratio observations / taxon	Years
Lichens	2,389	250,274	105	1790-2024
Charophytes	36	30,211	839	1794–2025
Bryophytes	1,153	401,225	348	1518-2024
Vascular plants	4,464	14,118,776	3,163	1555–2025

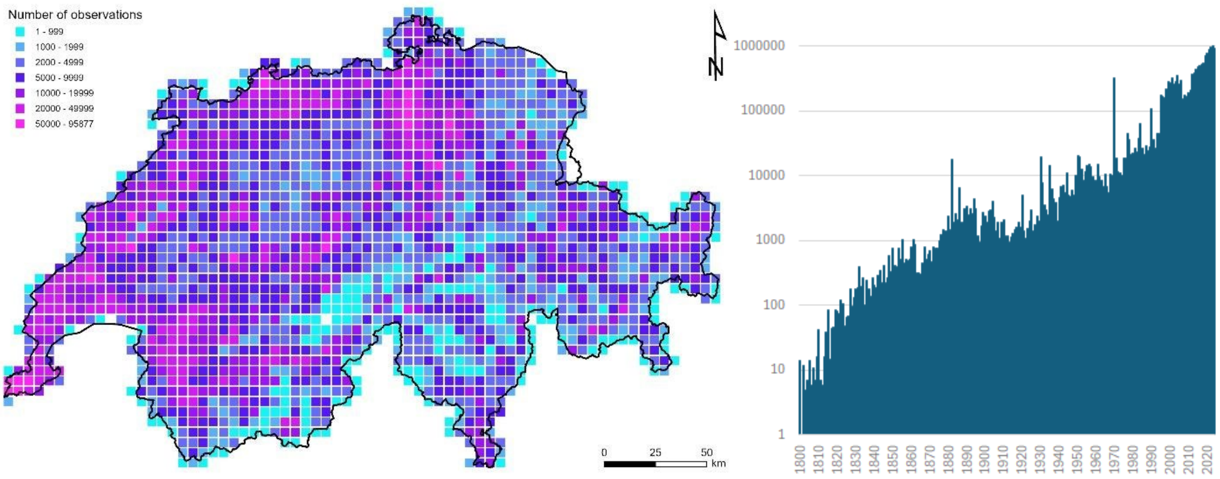

Fig. 3. Distribution of the vascular plant species records in the InfoFlora database over space (left) and time (right). The visualisations refer to the available observations from Switzerland in January 2025. Note that the colour scale in the left figure is roughly geometric and the y-axis in the right figure is logarithmic.

The idea of recording vegetation plots (relevés) was essentially invented and propagated by the Swiss botanist Josias Braun-Blanquet in the early 20th century. Therefore, it is not surprising that Switzerland has particularly many such plot records compared to other countries (Schaminée et al. 2009). However, Switzerland, unlike many other European countries, to date does not have a central plot database. In the European Vegetation Archive (EVA; Chytrý et al. 2016; https://euroveg.org/eva-database), Switzerland is only represented with two relatively small datasets together comprising about 20,000 plots. Moreover, these two datasets are not representative for the vegetation of Switzerland as a whole, as one contains only forest plots before 1995 and the other very recent records from the national priority habitats. However, largely unrecognised InfoFlora stores a large amount of vegetation-plot data in its database, resulting in 223,081 "plot" records. These data have been collected by InfoFlora mainly to feed the distribution maps of species with no existing export function. Accordingly, the plot data *per se* from InfoFlora have never been analysed before. During the preparatory phase we did some first steps in this direction, identifying "plots" that are no plots in fact (e.g. numerous single-species records, incomplete species lists or records of only trees or lichens in a plot). Still more than 160,000 according to the first checks appear to be usable. Combined with other promised and readily available datasets, this brings the Swiss national vegetation database already to about 185,000 plots (Table 2, Fig. 4), which in relation to the territory (4.5 plots per km^2) exceeds the density of georeferenced plots of any other country in EVA (Chytrý et al. 2016: highest value of 2.7 km^{-2} for the Netherlands). However, this initial screening also clarifies that a significant data harmonisation, cleaning and augmentation will be needed to make the database fully usable for science and stakeholders. Beyond the datasets listed in Table 2, we already identified several more that should be considered for integration if the owners agree.

Specifically, interesting are here resurvey studies with time series where Switzerland has also a particularly good coverage, many of which are now included in ReSurveyEurope (Knollová et al. 2024). Moreover, there are the data of the three Swiss vegetation monitoring schemes, BDM, WBS and ALL-EMA, based on a uniform plot methodology and statistically optimised spatial distribution of the plots. They provide an invaluable source of high-quality data for plant diversity changes in the 21st century. The time series data of the oldest of these schemes (BDM), including vascular plants and bryophytes and dating back to 2001 have only partly been analysed and will be available to the project (C. Bühler in litt.). Moreover, we have agreed with SwissBryophytes (H. Hofmann pers comm.) to resurvey a statistically selected subset of the 1237 100-m2 plots with complete bryophyte recordings sampled 1984-2006 across Switzerland (NISM; http://www.givd.info/ID/EU-CH-004).

Table 2. Large vegetation-plot datasets whose owners have already agreed to contribute to VegCHange.

Name of the dataset	Owner	Number of observations	Time range
InfoFlora (available data after plausibility check)	InfoFlora and contributors to InfoFlora	165’982	1884–2024
Swiss Forest Vegetation Database (EU-CH-005)	Dr. Thomas Wohlgemuth (WSL)	14,815	1904–1998
Vegetation Ecology Research Group of ZHAW (data from own projects and digitised from the literature)	ZHAW	ca. 3,000	ca. 1950–2024
Square Foot (historical and contemporary data)	ZHAW & Agroscope (will be open access after the end of the Square Foot project)	ca. 1,876	1884–2022
Total		**ca. 185,000**	**1884–2024**

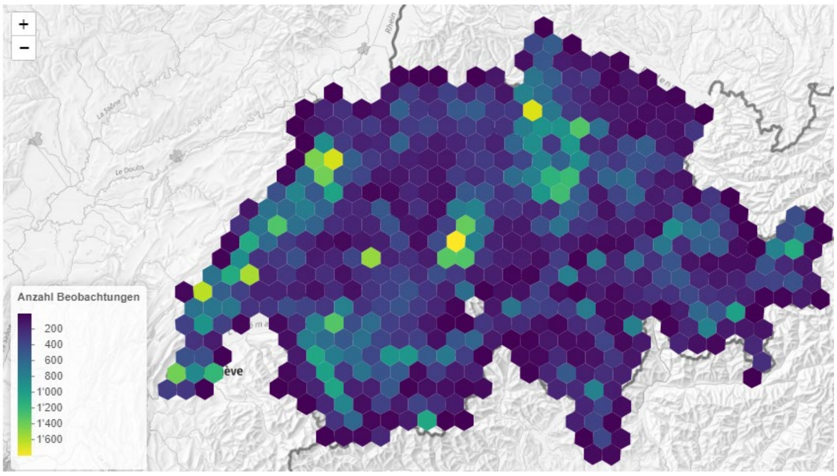

Fig. 4. Distribution of currently available vegetation plots (relevés) in the emerging Swiss national vegetation-plot database. The map shows the data aggregated to 10 km x 10 km hexagons. Only a single hexagon has no observations at all.

There is a wide range of high-quality GIS layers of environmental variables in Switzerland, which are constantly evolving and which we will use for attribution of biodiversity change to drivers, spatial and temporal modelling and for feeding scenarios of potential future developments. Among others, these include historical and current climate (Broennimann 2018), modelled fertilizer inputs (FSO 2024a, 2024b), nitrogen deposition (Meteotest 2023), habitats (Price et al. 2021), actual (FSO 2024c) and modelled landuse (Bütikofer et al. 2024) as well as landuse intensity (Weber et al., 2023).

4.4 Project consortium

The **project consortium** consists of two equal applicants: **Jürgen Dengler** (ZHAW, science partner) and **Stefan Eggenberg** (InfoFlora, societal partner). The two partners build an interdisciplinary team, combining their specific expertise to enable the multiple facets and challenges of the project to be addressed. **J. Dengler** is a professor of vegetation ecology and has extensive research experience in analysing vegetation change, quantifying biodiversity patterns across scales and relating them to drivers, optimising management methods for diversity conservation, developing tools for bioindication and ecoinformatics, particularly large vegetation-plot databases. He has extensive collaboration networks internationally and nationally and being employed at a university of applied sciences, which gets its research contracts mainly from the FOEN and cantons and graduates who normally seek positions in applied conservation, he is well aware of the needs of these stakeholders. **S. Eggenberg** has been the Director of InfoFlora for many years and in this role developed it into a nationally and internationally respected player in plant biodiversity documentation and conservation. He is very well connected with the conservation practitioners in Switzerland, while InfoFlora has become one of the most important players in developing key instruments of conservation in the country, such as red lists of species and habitats. Further, he is a member of the Biodiversity Forum of the Swiss Academy of Sciences and advises cantons and municipalities on the development of ecological infrastructure.

The consortium is complemented by the following **seven project partners**: **Marylaure de la Harpe** (Canton of GR) represents the conservation authorities in our pilot canton of Grisons and thus will continue to be a leader in co-creation of our research and translation of research results into information and tools usable by practitioners. **Thomas Wohlgemuth** (Flora Raetica and WSL) represents the citizen scientist project of GR, Flora Raetica, and has extensive knowledge in analysing changes in flora and vegetation. **Michael Kessler** (University of Zurich) will be the official supervisor of the PhD student and contributes extensive methodological knowledge in biodiversity analyses at any scales as well as from the citizen science projects (Flora des Kantons Zürich; Farnfreunde der Schweiz). **Florian Jansen** (University of Rostock, Germany) contributes the experiences from several methodologically advanced similar projects in Germany and Europe (sMon, MOTIVATE). **Ariel Bergamini** (WSL and Bryolich) is one of the leading Swiss experts in bryology and contributes the experience from the Swiss national biodiversity monitoring programs. **David Frey** (Cantonal Museum of Natural History in Lugano) has extensive experience in translating high-level research in the promotion of biodiversity on the ground from former SNF projects (BetterGardens, Nr. 154416, and Let's talk about Better Gardens, Nr. 191645), is a lichen expert, and represents a canton and a museum as important types of stakeholders. **Sabine Rumpf** (University of Basel) is an expert in the change of flora and vegetation, particularly in alpine areas. She will thus contribute to the high-level output from the project and serve in the PhD Committee.

We foresee having **three main employees** in the project: **(a) a Postdoc at ZHAW (50%)** who is responsible for the more complex and overarching studies and supports the project in project coordination and database management. **(b) a PhD student at ZHAW (100%)** who will focus on specific studies dealing with biodiversity change of bryophytes, including field sampling. **(c) a Coordinator for the pilot Grisons (35%)** employed by InfoFlora, who coordinates co-creation, implementation, specific knowledge acquisition and transfer, and citizen science activities in GR. Further, there will be small-scale assignments for data managers at InfoFlora and ZHAW, for a programmer of the biodiversity dashboard at ZHAW, and possibly civilian servants and/or student helpers for data digitisation and georeferencing.

At the national level, we will establish an **advisory board** comprising the seven project partners and additional stakeholders from different realms. Mostly, the advisory board will consist of those institutions and people already present at the two stakeholder workshops during the preparatory phase, but we anticipate complementing them with a few additional people at the start or during the course of the full project. The following experts have already agreed or shown interest to serve in the board (some are listed in multiple functions):

- **Societal stakeholders:** Federal Office for the Environment/FOEN: Jérôme Frei; cantons: Marylaure De la Harpe (Grisons), David Frey (Ticino) (we plan to involve ca. 2 more cantons); conservation NGO: Andrea Lips (Pro Natura), citizen science projects: Michael Kessler (Farnfreunde der Schweiz) & Thomas Wohlgemuth (FloRae); environmental consultancies: Kathrin Häberlin (B+S), Tobias Roth (Hintermann & Weber) & Philipp Schmid (quadra); conservation competence centre: Olivier Magnin (RegioFlora); botanical data centres: Heike Hofmann (or her successor; SwissBryophytes) & Silvia Stofer (SwissLichens); national biodiversity monitoring programs: Tobias Roth (BDM), Chantal Herzog (ALL-EMA), Ariel Bergamini (WBS); and biological collections: David Frey (Museum of Natural History Lugano).
- **Scientific experts Switzerland:** Michael Kessler (U Zurich), Sabine Rumpf (U Basel), Pascal Vittoz (U Lausanne), Ariel Bergamini, Klaus Ecker, Michael Nobis, Daniel Scherrer & Thomas Wohlgemuth (WSL), Christian Rixen (SLF), Serge Buholzer, Chantal Herzog & Manuel Schneider (Agroscope).

- **Scientific experts international:** Florian Jansen (U Rostock), Diana Bowler (UK Centre for Ecology & Hydrology), Franz Essl (U Vienna), Adam Clark (U Graz), Petr Keil & Gabriele Midolo (Czech U of Life Sciences), Iwona Dembicz (U Warsaw)

In the pilot canton Grisons, we will establish additionally a **regional advisory board** composed of stakeholders from various roles and interest groups. On one hand, this will comprise representatives from legal entities, such as canton/communities, collections/archives, parks, NGOs, on the other hand practitioners from environmental consultancies ("Ökobüros") and citizen interest groups (botanical society, FloRae citizen science project). The goal is for the scientists and coordinator of the project to interact and co-create analyses, data products and information digests, in order to directly target a transdisciplinary group of stakeholders with a variety of interests and needs, thereby facilitating decision making and conservation planning at the cantonal level.

4.5 Work packages

The project is organised in **six work packages** (WPs), whose relationships are shown in Fig. 5.

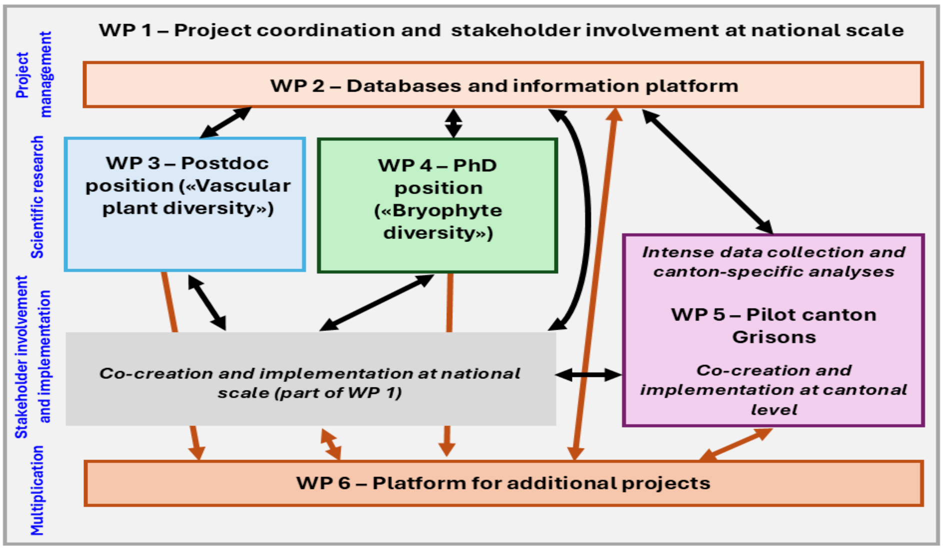

Fig. 5. Organisation of the project into six work packages and their relation among each other and to the different levels of the project (blue), in particular the scientific part and the societal (stakeholder involvement, outcome, impact) part. Everything is embedded in the grey matrix of the overall project coordination. Black double arrows indicate a flow of information and ideas in both directions. The brown single and double arrows indicate where the ideas for additional projects are originating and how their results would feed back.

WP 1: Project coordination and stakeholder involvement at national scale

WP 1 aims at the overall coordination of the different work packages to ensure that the outputs are produced in a timely manner and in a format that can be easily taken up by other work packages. At the same time it will continue the co-creation of VegCHange that was initiated during the Preparatory Phase and organise the transfer of achieved scientific knowledge to stakeholders so that they can take it up easily. The project will be coordinated by the two applicants, supported by the six project partners and the three main employees. A national advisory board consisting of societal and scientific stakeholders will be regularly informed about the project achievements and annual stakeholder events will be a primary place to explain the scientific results, gain ideas for the next analytical steps and for optimal ways to translate these findings into outcomes and impacts (T 1.1). As we foresee that our scientific results will be particularly relevant for the preparation of the next generation of Red Lists (T 1.2) and the development of the Ecological Infrastructure (T 1.3), we intend to be in contact with the relevant players involved in these conservation tools on a continuous basis to adjust our research approaches in WPs 2 and 3. This guarantees that the outputs are most useful for them while at the same time feeding pack our results into the planning processes already prior to scientific publication. Beyond contributing to these two concrete planning instruments, we plan to develop together with our national advisory board additional outputs and events focussed on non-scientific stakeholders (T 1.4). Among others these can be short "fact sheets"/"policy briefs", additional workshops, or additional elements in our dashboard (WP 2) that translate our research findings into information and guidelines that are tangible to a non-scientific audience, such as conservation administration, NGOs, ecological consultancies, and policy makers. We also intend to communicate key findings from WPs 3 and 4 to national media to achieve transformative impact. The midterm report (T 1.5) will be prepared by the two applicants and the other people involved in the coordination to demonstrate that the project is on track both scientifically and regarding the outcomes and impacts of the scientific results on problem solving. Since many desirable tasks and outcomes obviously cannot be achieved within the budget and time frame of the main project, we already now anticipate applying for a Transformation Accelerating Grant (TAG), whose details will be based on what we perceive then as the most important issues to implement after year 4 (T 1.6). Currently, we see two main issues we would like to address with a TAG: (a) Scaling up the achievements with the pilot canton Grisons to several other cantons based on the experiences of the project. We have already identified Ticino as one of the cantons that will then be considered but anticipate having at least one additional French and German-speaking canton in the TAG. (b) While both the national vegetation-plot database and the vegetation dashboard during the four years will be developed and maintained at ZHAW (see WP 2), to ensure permanent availability and further development beyond the end of the project, they should be hosted by InfoFlora in the medium- to long-term as InfoFlora is the institution in Switzerland that is devoted to such tasks. Therefore, a significant part of the TAG should be used for a fully functional integration of the vegetation-plot database in the InfoFlora data structure aligned with the Darwin core (Darwin Core Task Group 2009), and integrated with the international plot databases (EVA, sPlot).

WP 2: Databases and information platform

WP 2 deals with the more complex parts of data preparation and visualisation that cannot be handled directly in the respective research work packages (WPs 3 and 4). Our information platform "Plant diversity and vegetation of Switzerland" (https://vegetation.ch) with its interactive dashboards will be continuously updated and augmented to visualise both the raw data and the study results appealingly (T 2.1). The dashboards are programmed in shiny R (Chang et al. 2025). This allows stakeholders in an interactive manner to explore vegetation and flora and their change in space and time, and find relevant answers for their questions themselves. We plan to have the dashboards in four languages (German, French, Italian, English), with relevant background information and links to original publications embedded. It will be developed, based on feedback with the stakeholders, in a way that optimises user experience. Specific tools and spatial levels will be limited to the pilot canton of Grisons and tailored to meet specific needs and wishes of officials, practitioners and interested citizens (see WP 5). Further, the work package will integrate the rich historical and current vegetation plot data of Switzerland in a single vegetation-plot database that is directly usable within the project and beyond and contributes data also to the relevant international databases of vegetation plots (EVA, sPlot). While the three large vegetation-plot datasets already identified by and promised to VegCHange (Table 2) together comprise almost 190,000 plot observations, extensive work will be needed to transform them into a single uniform database with all the relevant fields filled and harmonized (T 2.2). This will often also involve communication with the original data providers or checks in the original sources. Moreover, data use agreements with data providers will have to be set up and implemented in a functional workflow, based on templates from similar collaborative databases (e.g. Skobel et al. 2024). The database will be set-up in TURBOVEG (Hennekens & Schaminée 2001) as this is the standard for the large international vegetation-plot databases EVA (Chytrý et al. 2016) and sPlot (Bruelheide et al. 2019). Once these aspects are achieved, we will, apart from using the data in the project, also contribute them to the European (EVA) and global vegetation-plot database (sPlot) at the earliest point possible, so that Switzerland is adequately modelled in international studies dealing with biodiversity, conservation, and global change. Vegetation data collected during the project as well as identified data from additional providers will be integrated. In regular intervals, we will feed back the vegetation data from the plot database to the InfoFlora database (so that they feed the distribution maps) and receive the plot data from InfoFlora collected with the FlorApp (field data acquisition tool of InfoFlora). Finally, both based on the requirements of the vegetation database and the wishes of the involved scientists as well as citizen scientists (see WP 6), we will during the initial phase of the project further optimise the vegetation recording tool in FlorApp (T 2.3).

WP 3: Postdoc position ("Vascular plant diversity")

Work package 3 refers to three fundamental and complex scientific studies mostly focussed on vascular plants and will be led by the project Postdoc. The first task is to comprehensively analyse the vascular plant occurrence data from InfoFlora, which only needs moderate curation before analyses can start (T 3.1). This task will yield a scientific paper and a large accompanying dataset that describes the frequency change of all vascular plant species of the country with a high temporal and spatial resolution, which when aggregated give a detailed picture of when and where biodiversity losses and gains for certain species group happened at the landscape scale (e.g. 25 km^2 grain size). The second task will for the first time provide an in-depth analysis of the wealth of vegetation-plot data in Switzerland to derive fine grain (ca. 1-400 m^2 grain size) trends in species diversity and composition. This task is building on intensive data preparation done as T 2.2. During the final third of the project, the Postdoc then will combine the results from tasks T 3.1, T 3.2, T 4.1, T 4.2 and possibly T 4.3 (i.e. both vascular plants and bryophytes) with spatially and temporally resolved information sources on patterns of presumed drivers of biodiversity loss/gain and composition change (climate, nitrogen deposition, land use, landscape structure, neophytes, conservation action) (T 3.3). Taken together, we anticipate that this will allow a quantitative attribution of which driver is responsible for which aspect of biodiversity change to which extent, resolved by regions and decades. Subsequently, per each major scientific publication, a popular science publication (e.g. in *N+L inside* or *News aus der Biodiversitätsforschung*) conveying the key messages will be published (T 3.4).

WP 4: PhD position ("Bryophyte diversity")

Work package 4 refers to three scientific studies mostly focussed on bryophytes and led by the project PhD student. In the first task, the PhD student will take all the 10 m^2 vegetation-plot data from the national biodiversity monitoring program BDM, both vascular plants and bryophytes, over the first five rounds of sampling (2001-2025) to conduct for the first time an analysis of 21st century changes in alpha diversity and composition of the Swiss vegetation across all regions and habitats (T 4.1). The second task will build on the methodological workflow developed by the Postdoc in task T 3.1 to apply it similarly to the complete species occurrence data of SwissBryophytes (T 4.2). Since bryophytes are not well represented in longer-term studies (starting before 2000), the third scientific study will involve some resampling of a subset of the NISM 100-m^2 plots systematically spread over Switzerland and sampled comprehensively in the years 1994-2006 (T 4.3). We will select a geographically representative subset, probably restricted to forests and grasslands to allow sound analyses, while limiting the time effort to what is possible during a PhD study. Field sampling will take place in the years 2026 to 2028, followed by microscopic determination in the subsequent winter terms. After each of the three major scientific publications, we will also prepare a popular science publication (see WP 3) (T 4.4). The entire work package will be accompanied by a PhD Committee (led by PD Dr. Michael Kessler), with regular meetings, finally leading to a PhD submission and defence at the project end (T 4.5).

WP 5: Co-creation and implementation in the pilot canton of Grisons

In work package 5, we will use the canton of Grisons as an exemplary target and test area for co-creation, implementation, and knowledge transfer and exchange. Key for the implementation of the projects in Grisons will be (1) a regional stakeholder group to consult with twice every year (one shorter online, one longer in-person meeting), involving participation from cantonal/communal agencies, parcs, NGOs, citizen science initiatives, and ecological consultancy companies (relevant persons identified and in part involved), and (2) a project position for a biodiversity specialist to coordinate the regional implementations and link them up with the larger-scale co-creation, research and development tasks and products. In a bottom-up co-creation approach, on one hand, stakeholders and scientists explore and co-design the type and content of analyses, tools, data products, and briefs on outcomes that are needed by and useful to stakeholders to answer their questions, update their knowledge base to improve work efficiency, planning and products (T 5.1). At the same time, regional stakeholder needs will influence the outcome of the Swiss-wide working steps, e.g. by complementing relevant analysis pathways, and feedback on hypotheses and outcomes in stakeholder meetings. In a top-down approach, on the other hand, Swiss-wide research outputs will be interpreted, processed and downscaled according to the co-developed blueprints to be of targeted use for stakeholders in Grisons (T 5.2). Moreover, additional pertinent research needs will be identified, shaped into potential research questions and distributed via the platform created in WP 6 (alongside with local expertise and support).

The co-designed approaches will be implemented by processing results, products and outcomes of our and other relevant projects to efficiently feed relevant information, products etc. to stakeholders through a co-designed knowledge platform (T 5.2). Specifically, this will involve reprocessing of data and complementing and refining the interactive dashboards of the plant diversity and vegetation information platform (T 2.1) for user-defined access to species- and habitat-specific information at customizable temporal and spatial scales (T 5.3). This will be particularly useful for spatial planning within the implementation of the cantonal biodiversity strategy and ecological infrastructure (field of actions 1 and 2 in the action plan of the Girsons' biodiversity strategy (Canton of Grisons 2023)), thus a close collaboration with partners from the cantonal administration is crucial. In addition to presenting pre-publication research to stakeholders for feedback, we will distribute one Grison-targeted policy brief per publication (WPs 3/4) and at least two Grisons-specific stakeholder briefs per year on relevant biodiversity information via the specific, co-designed knowledge platform. The general public will be reached via media releases on the science products.

An important aspect in our transdisciplinary implementation strategy in Grisons is the collaboration with the very active **citizen science project** Flora Raetica (FloRae). On one hand, the above products shall meet the non-professional botanists' need for information, therefore, representatives will be included in the co-creation process. On the other hand, our project will be offering taxonomic and methodological capacity building, particularly to foster the acquisition of plot- rather than only species-specific data in underrepresented habitat types and regions (T 5.4), in close collaboration with the activities of FloRae and WP 6. Moreover, there are many synergies between the stakeholder's, FloRae's and VegCHange's interest to make historical data and data currently not available on the InfoFlora database available. With the help of student staff, such grey data will be mobilized and digitized from publications, field books, herbaria and other resources (T 5.5).

WP 6: Platform for additional projects

Since the data we aim to mobilize and make accessible as well as the tools and analytical approaches we will develop during the project offer far more possibilities than we can realise with the limited time and money available for the SNSF project, with WP 6 we aim to expand the output and outcomes beyond WPs 2 to 5. We will invite scientists from across Swiss universities and research institutes (and potentially also abroad) who are willing to work on additional scientific or implementation projects using VegCHange's data, tools and analytical approaches (T 6.1). Some of these additional relevant analyses are obvious already (but not possible within the monetary framework), others will likely arise from demands/ideas of our stakeholders at national (see WP 1) and cantonal level (see WP 5). Among the obvious studies, but pending on additional resources, are:

- National analysis of the biodiversity trends for the two taxonomic groups of the vegetation with somewhat lower, but still reasonable data coverage, i.e. lichens and charophytes.
- Meta-analysis of the various individual resurvey studies already conducted in Switzerland (see https://wp.unil.ch/ppch/ and https://vegetation.ch/zeitreihen.html for subsets).
- Simulation study to project current trends into the future based on different scenarios of drivers.
- Comprehensive data-driven quantification of negative (and positive) impacts of neophytes on native plant diversity.
- Methodological comparison of trend analyses based on permanent or quasi-permanent plots or non-paired data pools from the vegetation-plot database.
- Data-driven optimal species assembly goals for restoration of degraded sites.

To achieve broader use of the data basis (M2.2), we will set up an online platform that brings together project ideas, potential supervisors and students of all levels (incl. Postdocs) to conduct them, and support them initially with expert knowledge on data, analyses, and funding opportunities. We anticipate that the globally exceptional data situation and a network of renowned potential supervisors will attract competent students and researchers to do relevant studies without the need of being paid by the SNSF project. There are different sources of students and researchers, and they vary from university to university. Just to name three easy options, the main applicant has at ZHAW: (a) Bachelor theses in the study program Applied Digital Life Sciences and (b) Swiss Government Excellence Scholarships for foreign postdocs, both for numerically demanding analyses, and (c) Master theses in ENR dealing with the transfer of our findings to practical conservation solutions. We anticipate that, similar to the German sMon community (https://www.idiv.de/research/projects/smon/), we will have annual workshops where we exchange on data and analytical methods to optimise the output from VegCHange. Lastly, after a positive mid-term evaluation, we aim to also seek complementary funding from additional sources based on the results achieved so far (T 6.2). Potential funders include state institutions (FOEN, #any other), cantons and private foundations. This funding can include various different aspects, such as additional research, additional outreach products and formats or already implementing similar solutions as in Grisons for other interested cantons.

5 Timeframe and milestones

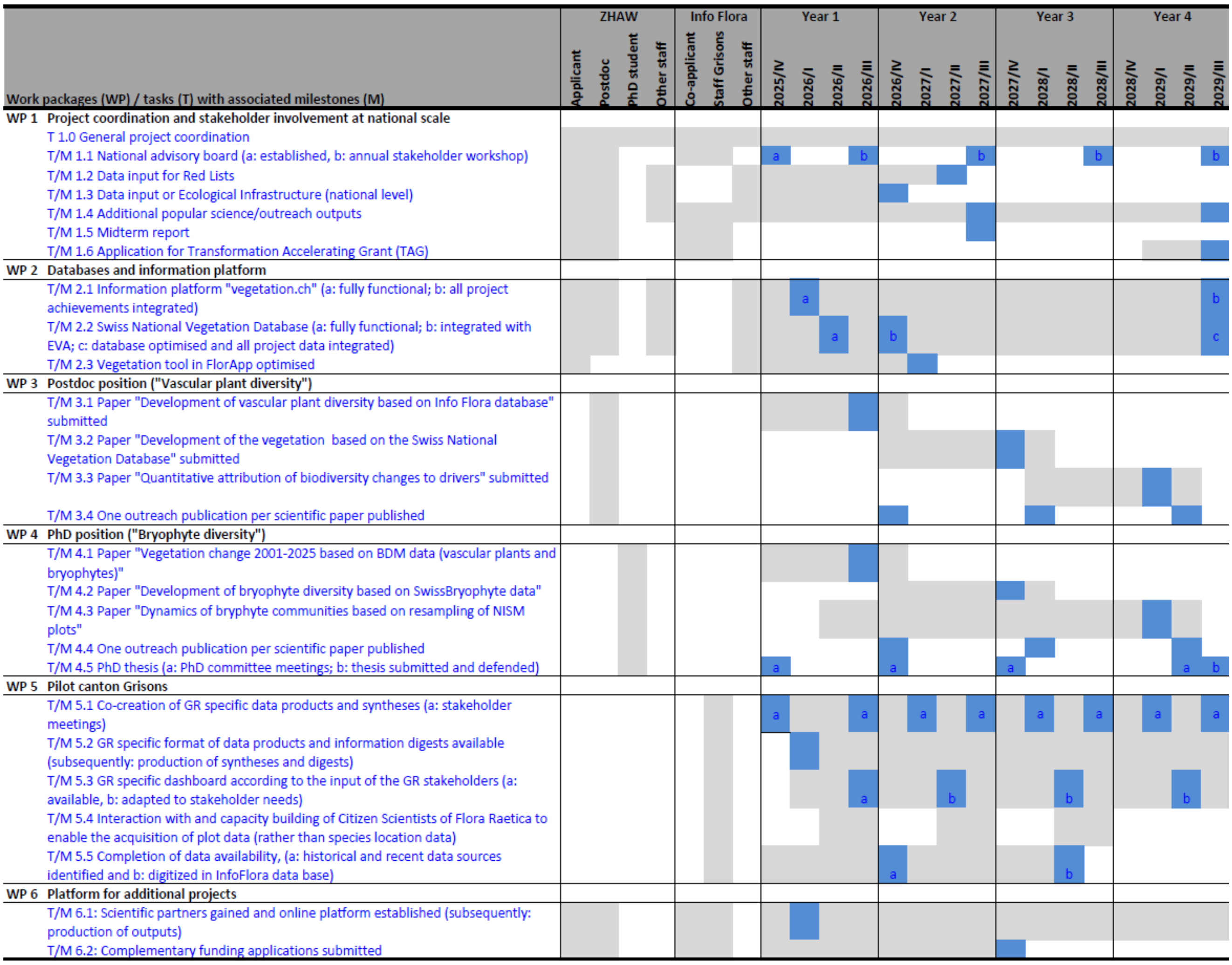

Fig. 6. Extended Gantt chart of the proposed project. The six work packages, the included tasks (grey) and resulting milestones (blue) as well as the responsibilities within the consortium are specified.

6 Practical significance, implementation and expected transformative impact

Switzerland implements a wide range of policies and activities with the ultimate goal of protecting biodiversity, e.g. nationally protected habitats, agri-enviromental schemes, combating so-called invasive neophytes, or developing conservation plans for threatened species. Despite the large amounts of money spent for biodiversity conservation, the state of biodiversity has continued to deteriorate (Lachat et al. 2010; Bornand et al. 2016). Our ToC narrative describes how VegCHange is going to lead to an improved biodiversity conservation in Switzerland. By combining and connecting the main outputs, namely the creation 1) of strong and equal stakeholder partnerships, 2) a national vegetation-plot database, 3) an interactive user interface (plant biodiversity information platform), and 4) analysis tools and scientific knowledge on vegetation change in CH (=sphere of control), we will contribute to 1) improved conservation status assessments (Red List) of aquatic and terrestrial vascular plants, 2) support the planning of ecological infrastructure in the cantons, and 3) improve the knowledge base on biodiversity change and its drivers in Switzerland (=sphere of impact). Ultimately, our goal is to foster a better understanding and acknowledgement of biodiversity changes over space and time for a variety of stakeholders, thus leading to improved biodiversity protection in the long term, both for plants and other taxa (=sphere of interest).

Due to limited resources, we focus on specific key stakeholders, synergize existing activities of project members and partners, and prioritize implementation activities in the canton of Grisons for our outputs and outcomes to have the greatest impact in terms of transformative change. As we will generate specific outputs on biodiversity change at species and community level with high spatial and temporal resolution, and also quantify the drivers behind them, practitioners in nature conservation are the most appropriate group - specifically, practitioners in applied biodiversity conservation in federal, cantonal, private (eco-offices) and non-governmental organisations from national to local level. Ideally, they will transform part of our outcomes directly into practice in a synergistic manner, e.g. by adapting and optimising current practices. In addition, by quantifying temporal population trends and their underlying drivers, our results will directly inform species conservation assessments for future Red List revisions… Other examples include the prioritisation of species and habitats (urgency and need for action) and the development of ecological infrastructure. The expected outputs of our project have clear practical applications and implications in these areas.

Fabian et al. (2018) showed that practitioners in nature conservation in Switzerland use a variety of information sources, but that experience-based information sources (e.g. own experience, exchange with colleagues or other experts, field trips) are more used than evidence-based information sources (e.g. leaflets, publications in national or international scientific journals). To foster transformative change, it is therefore particularly important for scientists to be involved in expert panels, field trips and to make time for transdisciplinary dialogue, such as personal contacts and direct exchange with nature conservation practitioners (Fabian et al. 2018). More often than scientific papers, practitioners use implementation articles in journals, leaflets, guidelines or textbooks as sources of information; therefore, a short, clear, sector-specific and multilingual presentation of information in overview publications or on specialised knowledge platforms are among the most effective tools for knowledge transfer and capacity building (Fabian et al., 2018). Based on these facts, we will design outreach outputs in a co-creative workflow with stakeholders, both within the project group and within our partners in the target canton of Grisons, in order to formulate - in a common language - *key message*s that summarise the main findings of the scientific results. The key messages will be formulated as short, clear, sector-specific (e.g. cantons, NGOs) and multilingual presentations and published as overview articles in existing Swiss multilingual outreach journals (e.g. N+L Inside, etc.). The relevant linguistic and technical expertise is available among the project partners. The key messages can also be published as handouts on relevant websites (e.g. InfoFlora), to support the experience-based information sources, such as discussions with colleagues and field trips, that are part of our daily work. The key messages will be published as outreach publications alongside the scientific publications, at a rate of one (multilingual) outreach publication for every scientific publication (1:1 ratio), along with additional outreach products targeted to stakeholders, practitioners, policy makers and the public.

Furthermore, we expect that the project's digital output (tools such as the interactive, user-customizable plant diversity information platform, or improved plot data collection module on FlorApp) to enhance the experience-based information sources. We expect ramifications far beyond the project, as these tools will allow users to visualise their own and other users' data and as well as historical data on biodiversity patterns and underlying drivers at the user-specific scale of interest. In particular, because of the high spatial resolution, users can learn about biodiversity status, change and their underlying drivers at customizable spatial and temporal scales (e.g., within a Canton, in an area of interest and a given time frame) - depending on data availability. This is relevant for conservation activities, since understanding the scales of human management interventions and their alignment (or lack thereof) with the scales at which ecological patterns and processes occur is key to effective conservation (e.g. Cumming et al. 2013).

The enhanced knowledge base of key stakeholders through the above implementation, and the access to spatially explicit relevant data for practitioners and stakeholders, will therefore directly contribute to several key measures of the action plan 2025-2030 of the Swiss Biodiversity Strategy (FOEN 2024): Identifying and weighing drivers of forest composition and biodiversity change (M1), identifying and pointing to restoration measures based on our results on habitat and vegetation composition and change over time (M4), management implications for federal land areas (M6). Moreover, it will be crucial to exchange with representatives of various working groups, e.g. on biodiversity and climate change (M7), species conservation (M8; already established e.g. through this collaboration), nature-based solutions (M11), and data- and information management (M14). Representatives of these latter working groups will be invited to stakeholder meetings and be directly informed about relevant output and outcomes.

7 Theory of Change and indicators

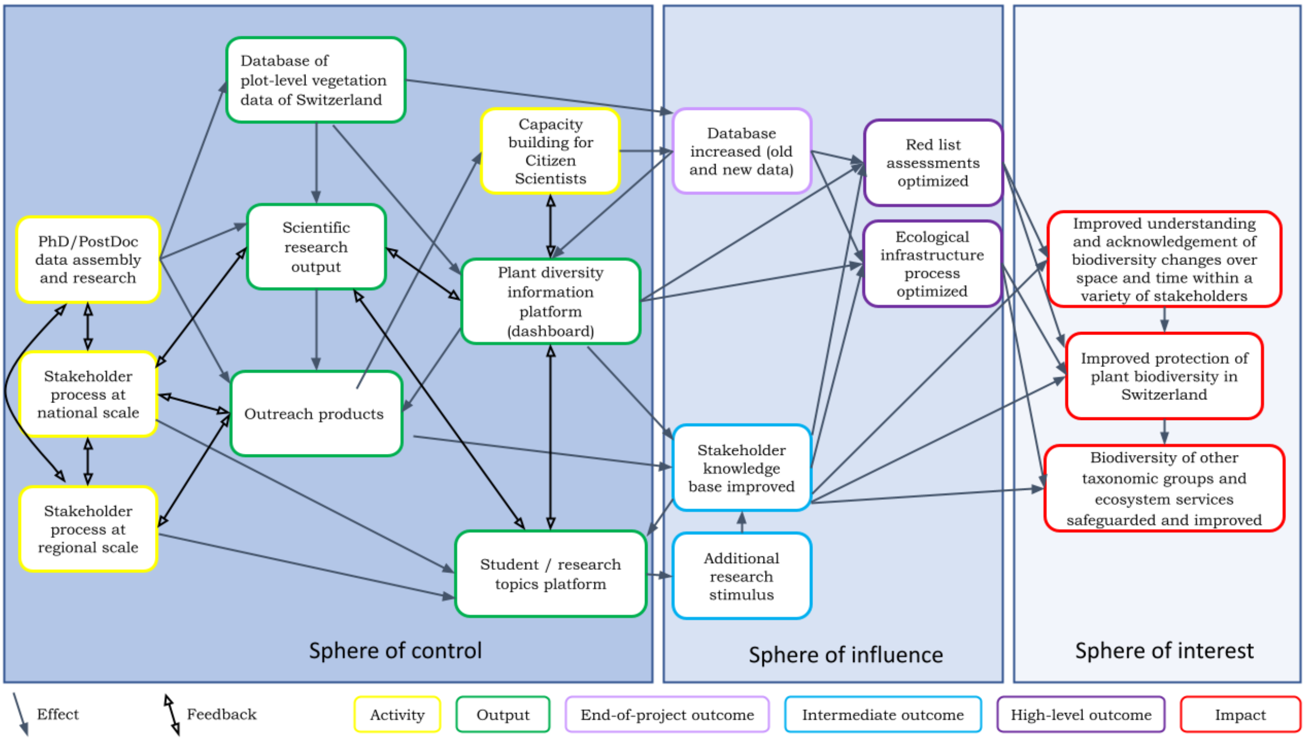

Fig. 7. Visualisation of the main pathways of the Theory of Change (ToC) assumed by VegCHange.

Table 3. Table of the different indicators relevant to the project and the program. The indicators are classified in three categories, according to their place in the theory of change: A. output, B. outcomes, and C. impacts.

Element of the ToC	Method	Baseline (end of preparatory phase)	Data/results (mid-term report)	Data/results (final report)
A. Output (sphere of control)				
1. Co-creation through equal partnership of researchers with societal actors and stakeholders through the whole research process, starting from the beginning (T 1.1, 5.1)	Target disk	Stakeholder feedback during preparatory phase documented (see 3.1)	Required, generated towards the mid-term	Required, generated towards the end of the research phase
2. National vegetation-plot database (T 2.2)	Statistics of use at national and international level, feedback to WP 6 (database of additional research questions and opportunities), statistics/literature overview of citing ressources	Not existing	Feedback generated at the second national stakeholder workshop, statistics generated for report	Feedback generated at the last national stakeholder workshop, statistics generated for report
3. Plant diversity information platform (T 2.1), incl. refined version for the target canton of Grisons (T 5.2)	User statistics and feedback (collected at workshops and via the webpage)	Current version discussed during initial stakeholder workshop	Feedback generated at the second national and regional stakeholder workshops, statistics and website feedback collected for report	Feedback generated at the last national and regional stakeholder workshops, statistics and website feedback collected for report

Element of the ToC	Method	Baseline (end of preparatory phase)	Data/results (mid-term report)	Data/results (final report)
4. Diverse, spatially and temporarily resolved results on changes of different components of plant diversity achieved and published (T 3.1-3, 4.1-3)	Feedback from stakeholder workshops where we discuss results, user numbers, citations	NA	Feedback generated at the second national and regional stakeholder workshops, statistics and website feedback collected for repor	Feedback generated at the last national stakeholder workshop, citation statistics generated for report
5. Translation of the scientific results for non-scientific stakeholders at the national and cantonal level (T 1.4, 3.4, 4.4, 5.2)	List of events and products	NA	statistics generated for report	statistics generated for report
B. Outcomes (sphere of influence)				
1.Stakeholders' engagement: linking scientific processes of knowledge production on biodiversity with societal processes of learning and changing practices that influence biodiversity	Stakeholders' engagement table	See section 3.1	Generated for the mid-term report	Generated for and included in the final report
2. Red List assessments optimised through outputs from VegCHange (T 1.2)	Feedback from the Red List authors	NA		Generated and summarized for the final report
3. Development of Ecological Infrastructure ("ÖI") supported through outputs from VegCHange (T 1.3)	Feedback of and interactions with "ÖI" developers	NA	Summarized and listed in mid-term report	Summarized and listed in final report
4. Uptake of VegCHange results and recommendations by practitioners, policy makers and the general public	Documentation of feedback from stakeholders, reports in media, citations etc.	NA	Summarized and listed in mid-term report	Summarized and listed in mid-term report
C. Impact beyond the project (sphere of interest)				
1. Transformation: providing solutions and accompanying the transformation phases together with stakeholders from relevant sectors.	Evaluation "H"	NA	Generated towards the mid-term	Generated towards the end of the research phase
2. Plant biodiversity in Switzerland safeguarded and improved	National biodiversity monitoring programs	Clearly not achieved by now	Can be quantified (but effect after such short time unlikely)	Can be quantified (but effect after such short time unlikely)
3. Biodiversity of other taxonomic groups and ecosystem services in Switzerland safeguarded and improved	NA (beyond the scope of VegCHange)	NA	NA	NA

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