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Biology Community Roadmap 2024

Update of Swiss Community Needs for Research Infrastructures 2029–2032

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Content

1 Executive summary

Switzerland's competitiveness in research and innovation hinges on state-of-the-art research infrastructures. However, the funding environment has become challenging. To maximise impact and efficiency, increased collaboration across institutions, borders, and disciplines is essential, ensuring that infrastructure development aligns with both researchers' needs and decision-makers' priorities. Four key areas of Swiss biological research infrastructure underscore several unmet needs and potential impacts:

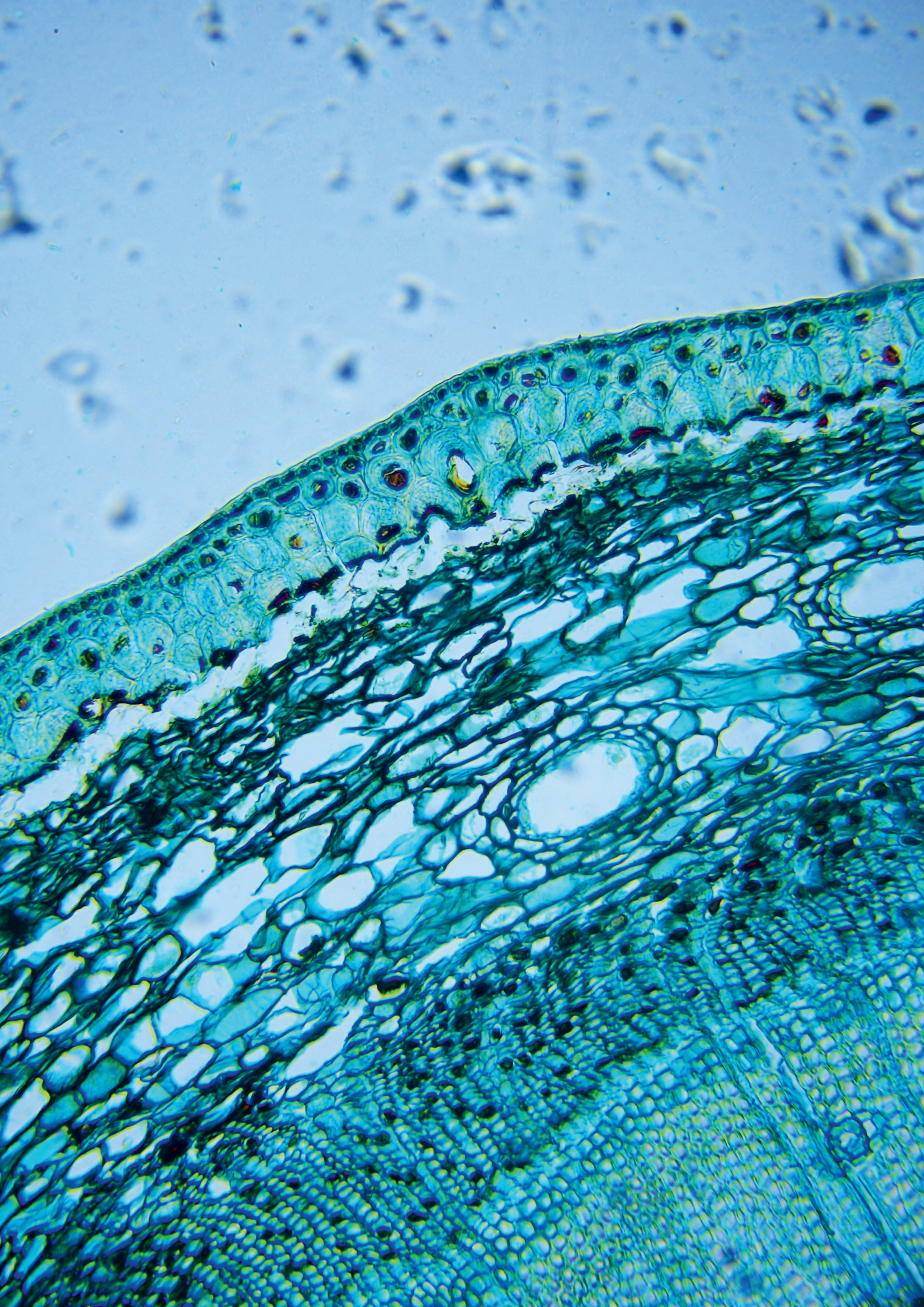
Biological imaging: To maintain competitiveness in bioimaging, there is an acute need for national-level investments in biological imaging, both in the acquisition and operation of cutting-edge equipment (e.g. electron microscopy) and in harmonised data management, analytical approaches, and data sharing. The research community increasingly faces massive challenges in leveraging the latest artificial intelligence (AI) technologies due to a lack of standardisation in bioimage data formats and metadata, as well as to a lack of common language between computer scientists and life scientists. Addressing these gaps is necessary to maintain the quality of research and teaching up to date with the progress in AI, drive innovation in precision medicine and biotechnologies, and ensure that bioimaging technologies continue to positively impact the Swiss economy.

Biological collections: There is an urgent demand for a national collections infrastructure to support biodiversity, agriculture, and health research. Rapid documentation and conservation of species and specimens in biobanks and natural history collections are critically needed due to accelerating extinction rates and environmental changes. Addressing these priorities by digitizing, integrating and standardizing data across collections would enhance global biodiversity and medical knowledge networks, would address societal challenges like climate change, biodiversity loss, and emerging health threats, and position Switzerland as a leader in environmental research.

Biological sites: Research on biodiversity, ecology, agriculture and forestry to address fundamental as well as global change-related and sustainability-related questions requires a coordinated nationwide infrastructure of permanent plots, spatially distributed field sites, long-term experiments as well as highly controlled facilities. The proposed research infrastructure SwissBioSites aims to integrate and increase such efforts and thus would benefit multiple research disciplines, enhance international collaborations, and support sustainable ecosystem management and agricultural transformation.

Biological core facilities and data resources: Our vision is a coherent, integrated and trustworthy federation of data platforms in line with the FAIR (Findable, Accessible, Interoperable and Reusable) principles. Interconnecting local data producing and data processing core facilities would facilitate seamless data sharing, processing, and analysis across local and international research communities. This would harmonise data acquisition and data analysis, establish new standards and foster collaboration between domain experts and data scientists. Better coordination among data producing core facilities would also enable the collaborative use of costly state-of-the-art equipment.

Addressing these unmet needs is essential for advancing scientific research, fostering innovation, and maintaining Switzerland's leadership in global biological research. Aligning infrastructure development with researchers' needs will maximise the impact and sustainability of these efforts.



2 Foreword

This document is an update to the Biology Community Roadmap published in 2021.[1] It presents the needs of the Swiss biology community in terms of future national and international research infrastructures. Together with similar community roadmaps in other disciplines, it is an important element of the four-year process leading to the development of the Swiss Roadmap for Research Infrastructures 2027 to be written by the State Secretariat for Education, Research and Innovation (SERI) in view of the ERI Dispatch 2029–2032 to the Federal Council. The role of these 'bottom-up' inputs is to serve as an important basis for the strategic planning of the higher education institutions in terms of new or major upgrades to national infrastructures, as well as to inform and support SERI during its decision-making process on Swiss participation in international research infrastructure networks and organisations.

SERI has formally mandated the Swiss Academy of Sciences (SCNAT) to update the seven community roadmaps previously published in the disciplines of biology, chemistry, geosciences, astronomy, particle physics, photon science, and neutron science. SCNAT engaged its network of member societies and commissions to reach out to the scientists willing to get involved. It encouraged diversity of the participating scientists and provided the needed support for the collaborative writing, the layout, the publication and printing of this document.

3 Introduction

State-of-the-art research infrastructures are essential for maintaining Switzerland's competitiveness in research and innovation. Just as an efficient public transport infrastructure facilitates the movement of goods and people, research infrastructures enable and drive the flow of knowledge and technological advancements. They encompass facilities, equipment, resources, and expertise that are essential for conducting high-quality scientific investigations. This is particularly true in biology, which has developed into an incredibly multifaceted discipline, involving a gamut of very diverse approaches and methods, across all scales of life. For example, the bioinformatics field has evolved from an ancillary role to experimental biology into a powerful subdiscipline that generates testable hypotheses for investigating complex biological systems.

At the same time, the funding environment is challenging. The COVID-19 pandemic has significantly strained federal budgets, leading to tighter funding conditions. Critical programs like the Swiss National Science Foundation (SNSF) R'Equip, which provided essential grants for high-quality, innovative research equipment, have been discontinued due to budget constraints. Recently, the ETH domain has announced cuts to high-priority projects slated for 2025–2028. Likewise, on swissuniversities side, the funding outlook for infrastructure for 2025–2028 under Art. 47 Higher Education Act (HEdA) remains highly uncertain.

Increasing impact and efficiency through collaboration across disciplines, institutions, borders, and stakeholders

To focus investments on the highest impact infrastructures, while minimizing dilution or duplication, coordination is key. Increasingly, institutions must federate their resources and collaborate. In particular, there is an increasing need to collaborate across the ETH domain, cantonal universities, Art. 15 RIPA research facilities of national importance, and other relevant organisations.

Maintaining a high level of cross-border cooperation and 'interoperability' is equally crucial, ensuring Switzerland remains integrated within European research networks despite the challenges of the current non-association of Switzerland with Horizon Europe.

Interdisciplinarity is key to how biological investigations are performed, blurring traditional divisions, such as biophysics and biological chemistry emerging as hybrid subdisciplines at the interface of biology, physics and chemistry. Similarly, borders between biology and geosciences become increasingly permeable when studying biodiversity, climate change and their impacts on Earth systems. Finally, and crucially, we need to improve collaboration between researchers and governing bodies. Indeed, research infrastructures must meet both the needs of researchers and the priorities and constraints of decision-makers.

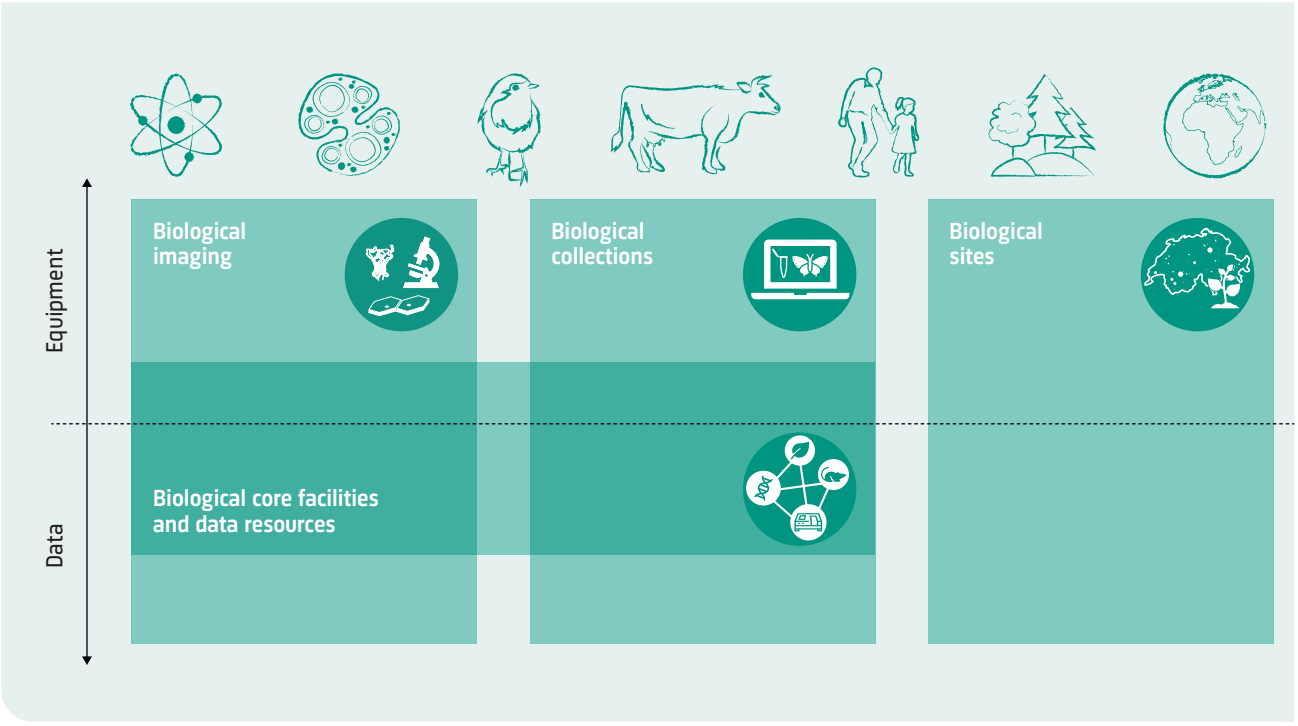
In this context, the present roadmap, the result of a bottom-up consultation of the broad Swiss biology community, constitutes an important part of the future infrastructure planning process. In the next phases (institutional priorities, Swiss Roadmap by SERI), the selection of research infrastructure proposals should thus not only consider institutional and national strategies (e.g. Swiss National Open Research Data Strategy) but also the needs of researchers identified through this bottom-up consultation process. In doing so, we can ensure that the development of research infrastructure is both responsive and sustainable, tethered to the realities on the ground.

An update to the 2021 Community Roadmap

In its 2021 Community Roadmap,[1] the Swiss biology community identified priority needs in four key areas (SwissBioCollections, SwissBioSites, SwissBioData and SwissBioImaging). Four years later, these needs remain not only relevant, but are even clearly augmented due to continued technological developments and a widening investment deficit on research infrastructures. Infrastructure for quantitative microscopy image analysis (SwissBioImaging) remains an essential component of biological investigations, spanning scales from cells to organisms, but the needs also extend to the acquisition and operation of specialised imaging technologies that have recently made technological leaps, such as in electron microscopy (EM) and nuclear magnetic resonance (NMR). National collections infrastructure (SwissBioCollections) is essential for biodiversity and health research in human and non-human species and samples. Rapid species and specimen documentation in biobanks and natural history collections is needed, especially with accelerating extinction rates and environmental changes. On a macro-scale, observations, experiments and related large data acquisition across controlled mesocosms, field plots and entire ecosystems (SwissBioSites) require an even greater strategic importance, given the effects of biodiversity loss, resource scarcity and climate change on food security, environmental health and the need to maintain safe space within planetary boundaries. Moreover, data acquisition, storage, retrievability, accessibility, security and reproducibility of -omics data, make the future of data management an

irrevocable aspect of any long-term vision for scientific competitivity and integrity. The need to federate data-producing and data-analysing core -omics facilities (SwissBioData) has only grown since 2021.

In the rest of this document, we provide an update of each of these four areas, then address the needs in terms of Swiss involvement in European Research Infrastructure initiatives, before concluding with reflections on the use of this community roadmap in the development of new research infrastructures of national importance.



The four key areas of Swiss biological research infrastructure underscore several unmet needs. It ranges from micro- to macroscopic scales and the depth spans both data and equipment infrastructures. Source: Christophe Dessimoz, Monique Borer

4 Findings and recommendations

4.1 General findings and recommendations

Finding: Each initiative described in the following sections presents specific opportunities and challenges, thus reflecting the diverse nature of the biology community. Nevertheless, the community agrees on the absolute need to meet these infrastructure and technology needs. This shall allow the Swiss biological research community to sustain and expand its level of excellence in science, research, training and technological advancement, both on a national and international level.

Recommendation: Grounding infrastructure in the actual needs of the research community is essential. A challenging budgetary landscape mirrored by rising material and infrastructure costs, makes it of paramount importance that common needs be prioritised and expedited. Never as now is there a need to share resources wisely, and to support national and international collaboration across research networks. This addresses community needs effectively, while maximizing impact of investment.

Recommendation: International collaboration remains essential. Large infrastructure investment is meaningful when it serves the interest of the largest possible reference community. Switzerland has deep-rooted ties to the global research landscape, with a special emphasis on European collaborative networks. Especially in view of current exclusion from most Horizon Europe funding, all opportunities for adhesion and membership to European large infrastructures should be promoted, as part of a wider strategy to regain full member status for Switzerland across all EU funding initiatives and schemes.

4.2 Specific findings and recommendations

Biological imaging

Finding: Open research outputs relying on the latest microscopy imaging technologies have the potential to drive innovation and translational projects and thus advance precision medicine, biotechnologies, and pharmaceutical developments, with a net positive impact on the Swiss economy. The multiple excellent isolated activities in the field of bioimaging across Switzerland must be federated. SwissBioImaging should be implemented as a national centre of excellence to coordinate technology development, research, and training efforts across Swiss academic institutions from image acquisition to AI-based analysis. In parallel, funding is urgently needed for the EM-Frontiers project and to continue investments into national infrastructure for NMR research-fields that have earned Switzerland Nobel Prizes and are now at risk of underfunding and increasing competition.

Recommendation: We recommend the establishment of SwissBioImaging, a national infrastructure that supports the development of cutting-edge imaging technologies, training, and data analysis resources across the different existing specialised technology hubs embedded in Swiss Universities. This would grant all life science researchers in Switzerland access to world-class experts in bioimaging.

Recommendation: SwissBioImaging should drive the transition towards Open Science in bioimaging. These efforts have the potential to turbocharge new research and technology development, with positive returns that extend to all research communities relying on digital image data, such as medicine, material science, geography, and agriculture.

Recommendation: It is of strategic importance to fund the EM-Frontiers project, to maintain Swiss NMR facilities, and to implement the integrative approach presented in SwissBioBridge. Major breakthroughs are to be expected in the preparation of biological specimens. Switzerland should stay abreast of technical progress in this field and be able to contribute to its development.

Biological collections

Finding: The vision for SwissBioCollections underscores the critical need for a national infrastructure to support comprehensive research on biodiversity, agriculture, and health. This infrastructure should integrate cutting-edge technologies and innovative management practices for natural history collections and biobanks. Such a national infrastructure is essential for integrating and standardizing data, enhancing digitization, implementing the Open Research Data strategy, and ensuring the longterm conservation and accessibility of both physical and digital specimens. By fostering interdisciplinary collaboration, adopting good Open Science practices, and aligning with international standards, SwissBioCollections will generate significant and high-quality data that will be instrumental in addressing global challenges such as species extinction, climate change,
and emerging diseases.

Recommendation: We recommend promoting biodiversity research through Open Science and long-term research collection storage to ensure preservation and reproducibility. Leveraging digital records and global standards will enhance transparency, global collaboration, and data reuse from Swiss institutions.

Recommendation: We recommend accelerating documentation and digitisation efforts such as initiated by the national SwissCollNet initiative (2021–2026). Achieving Switzerland's membership in DiSSCo-European Research Infrastructure Consortium (ERIC) would further strengthen its role in European natural history collection networks, fostering collaboration and access to EU projects.

Recommendation: We recommend enhancing data integration and interoperability to ensure that high-quality data from Swiss collections contribute to national and global biodiversity knowledge. This will be achieved through partnerships with international data aggregators, research infrastructures, analytical platforms, and information systems.

Biological sites

Finding: The SwissBioSites research infrastructure and its central hub for data analyses will allow addressing the drivers and consequences of changes in terrestrial and aquatic ecosystems, including effects of climate change or biodiversity loss. Based on such information, recommendations can be provided on ways to manage, restore or protect ecosystems in the most sustainable manner. Without such a coordinated, highly instrumented research infrastructure, the national efforts cannot be integrated, and decreasing finances cannot be used efficiently. The SwissBioSites research infrastructure and its central hub build on already existing research infrastructures allowing for unprecedented joint research efforts. Switzerland hosts a globally unique research opportunity with naturally existing climate gradients from the lowlands to the Alps where a coordinated data acquisition, analysis and share of long-term monitoring sites for biodiversity, ecology, agriculture and forestry will not only benefit the local researchers but attract international collaborations.

Recommendation: We recommend supporting a coordinated nationwide infrastructure with spatially distributed field sites, permanent plots, long-term experiments, uniform equipment and facilities with their harmonised data acquisition and management. Such a national research infrastructure will benefit multiple research disciplines, enhance international collaborations, and support sustainable ecosystem management and agricultural transformation.

Recommendation: We recommend strengthening the national nodes of international research infrastructures. The integration of excellent and innovative science across Switzerland, including its unique experimental sites, is crucial to maintain the unique position Switzerland internationally also in the future, both for research and innovation as well as for educating the next generation of decision-makers.

Recommendation: We recommend that open access to sites and data becomes a cornerstone of how research on biological sites is conducted. Biology and ecology have a long tradition in providing data and code following FAIR principles, and Switzerland is at the forefront of Open Science and Open Research Data (ORD) practices.

Biological core facilities and data resources

Finding: Our vision is a coherent, integrated and trustworthy federation of data platforms in line with the FAIR principles. Interconnecting the currently fragmented local infrastructures would facilitate seamless data sharing, processing, and analysis across local and international research communities. Better coordination among data producing core facilities would also enable the joint development of methods and operation of costly state-of-the-art equipment. A federated landscape of data-producing and data-processing core facilities would increase quality, reduce costs, and boost the transformation of research data into valuable knowledge and innovation, and keep Switzerland at the forefront of data-intensive life sciences research.

Recommendation: We recommend establishing SwissBioData ecosystem (SBDe) as a decentralised infrastructure, supported by core facilities, to boost data-driven research in life sciences and to enhance Switzerland's capacity to convert FAIR research data into knowledge and innovation. SBDe involves 54 data-producing and data-processing units across 18 public research institutions, thereby reducing the current fragmentation and duplication of efforts by establishing unified standards for data acquisition, integration, and analysis.

Recommendation: We recommend sustaining essential data resources to accelerate research and enable trustworthy AI to remain competitive. Mining this high-quality data will maximise AI's potential as an accelerator of research and a value multiplier. This will benefit the broader research community and support data-heavy initiatives in life sciences, as well as AI-driven initiatives.

Recommendation: We recommend developing a collaborative state-of-the-art bioanalytical infrastructure across Swiss institutions to enhance access to cutting-edge technologies such as next-generation sequencing, mass spectrometry, and advanced molecular imaging platforms. By combining intellectual and infrastructure resources, collaboration will lower costs, ensure more efficient use of high throughput and specialised equipment, and foster scientific interactions among institutions and core facilities, ensuring that Swiss researchers remain at the forefront of global innovation in life sciences.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5 Needs of the biology community

5.1 Biological imaging

State of the art

Microscopy imaging requires ever more advanced skills both to operate instruments and to mine the information contained in the huge datasets they generate. Light microscopy technologies such as high-content and lightsheet imaging have kept on developing, exponentially increasing the quantity and quality of the images they produce. In parallel, cryo-electron microscopy (cryo-EM) has been revolutionizing structural biology since the 'resolution revolution' of 2014 that led to a more than five-fold improvement in resolution. It enabled several game-changing advances for a plethora of biological questions with high medical relevance, including cancer, neurodegenerative and infectious diseases. NMR applied to biological molecules has achieved a prominent role in structural biology to determine structure, dynamics, and interactions of biological macromolecules. Thus, NMR applied to biology (BioNMR) can be considered a form of non-microscopy based biological imaging approach. Further to individual modalities allowing to image larger volumes and at higher resolution, methods have also been developing to link modalities, with spatial transcriptomics and correlative light-electron microscopy as prime examples. In addition to individual modalities that allow imaging of larger volumes and higher resolution, methods have also been developed to link modalities, with spatial transcriptomics and correlative light-electron microscopy as prime examples. However, due to the high cost and advanced expertise needed to acquire, operate, and maintain these nascent technologies, access to them remains uneven across the Swiss research landscape and only a small fraction of their potential is currently routinely exploited.

Downstream of image acquisition, the amount of data and demands for advanced analysis have skyrocketed over the past three years as microscopy images have become richer than ever in terms of information content. While our technical ability to gather rich visual information on biological systems has increased significantly, so did the complexity of ensuring access to expertise in downstream data management and analysis. Although community efforts at the international level around minimal metadata standards and scalable file format have created a fertile ground for the development of FAIR analysis methods, quantitative bioimaging is still living through a reproducibility crisis due to a lack of resources.

The challenges outlined in the 2021 Thematic Roadmap have thus only aggravated and are now combined with urgent needs for securing additional capabilities to keep up with recent microscopy technology developments and ensure their access to all Swiss researchers. Notably, progress in AI over the past three years has moved forward in ways that could hardly be foreseen in 2021. Foundation models are revolutionising computer vision by providing general backbones with an advanced understanding of the visual world that can be tailored to an endless variety of problem-specific tasks, ranging from classification to generative modelling. Immense opportunities lie ahead in the adaptation of these cutting-edge AI technologies to harness information across the different scales of bioimaging. Seizing them however requires ensuring the availability of large amounts of standardised and curated data, and most importantly nurturing close interactions between computer scientists and life scientists to counteract a growing discrepancy between the number of researchers that are competent in high-end image acquisition and the number of researchers mastering advanced AI-driven data analysis techniques.

Major successes

Over the past few years, electron microscopy has seen massive investments in the USA, China, India, and Europe, leading to radical transformation of the possibilities of this technique. At the national level, a renewed focus on X-ray imaging and cryo-EM has been driven by the upgrade of the Swiss Light Source (SLS) 2021 to 2024 at the Paul Scherrer Institute (PSI) and the creation of the Dubochet Center for Imaging, an initiative of EPFL, the University of Lausanne, the University of Geneva, and the University of Bern. A major focus of SLS 2.0 is on fostering the development of novel imaging X-ray technologies for the life and biomedical sciences. Launched in 2021, the Dubochet Center for Imaging now consists of multiple sites in Lausanne, Geneva, and Bern. Knowledge transfer between the microscopy community and life science researchers in Switzerland has been successfully nurtured by the Life Sciences Switzerland (LS^2) microscopy intersection, which promotes the adoption of cutting-edge microscopy techniques as well as the implementation of standards in bioimaging.

Recognizing the enormous prospects of better-exploited bioimage data as well as the urgency of taking up advanced AI methods in bioimaging and structural biology, many European countries have implemented bioimaging and structural data analysis as part of their national scientific infrastructures (Germany, Sweden, Italy, France), most of which have become part of EuroBioImaging's im-

age data analysis service launched in 2022. In Switzerland, the Swiss BioImage Analysts' Society (SwissBIAS), founded in 2021 as a grassroots network of bioimage scientists across Switzerland, has been enabling an informal yet functioning sharing of knowledge and approaches across the national landscape. Most Swiss Universities have also responded to the ever-growing demand for custom bioimage analysis support by increasing the number of bioimage analysts embedded in microscopy platforms, as best exemplified by the EPFL Center for Imaging also founded in 2021. The University of Zurich and the Friedrich Miescher Institute for Biomedical Research chose to go beyond bespoke solutions and support the development of general-purpose, open-source resources to democratise the access to advanced algorithms accessible to all researchers. It led to the creation of the BioVisionCenter, launched in 2023, which attracted the attention of major international initiatives in the bioimaging space, including GlobalBioImaging and EuroBioImaging. Long term commitments and resources are however still dramatically lacking to network these many valuable local efforts into a nationally relevant infrastructure.

Future needs

Scientific need and urgency

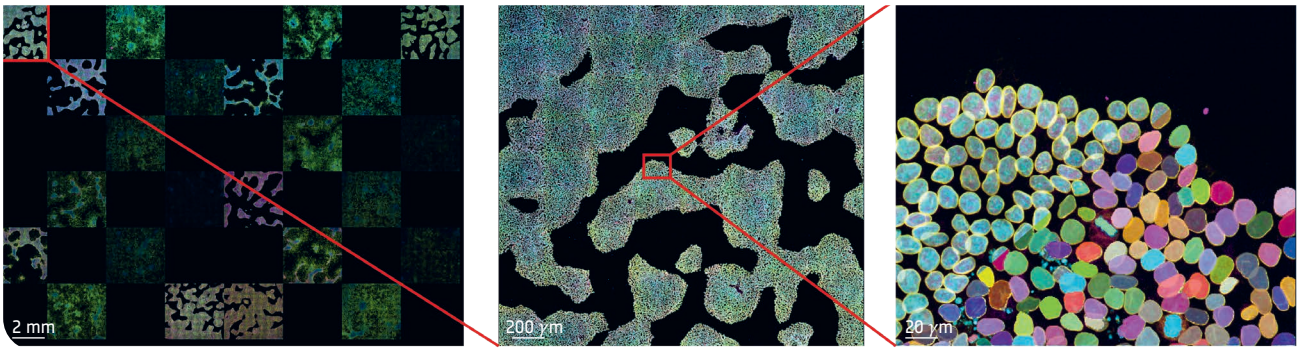
As highlighted in the 2021 roadmap, standardisation is needed more than ever across the whole bioimaging data life cycle, from acquisition to analysis. In addition, the need for resources to ensure adequate access to high-end light, electron and X-ray imaging infrastructure, has become acute. Without clear structures supporting researchers across Switzerland to build cross-institutional research projects, high-end light and electron microscopy remains out of reach for local universities, widening the gap in technological resources between research centres. In recognition of these unmet needs and of the role for non-microscopy-based imaging approaches in biology, four complementary initiatives are presented in this section, namely; SwissBioimaging, EM-Frontiers, SwissBioBridge and BioNMR.

SwissBioImaging can lead a national culture shift towards open and collaborative science by federating major investments in bioimaging in existing academic structures. Leveraging Swiss institutions' world-class expertise, it can create a distributed infrastructure that is technically excellent and exceeds current achievements. Besides ensuring adequate access to state-of-the-art microscopy technologies to all life science researchers across Switzerland, SwissBioImaging will also facilitate the integration of multiple imaging modalities into a holistic understanding of complex biological systems, allowing to map biomolecular and cellular interactions within tissues and entire organs. A national infrastructure supporting the whole image data life cycle, from acquisition to reproducible analysis, would have a transformative effect on bioimaging across the Swiss life sciences landscape and a positive impact on the quality of the relevant teaching across Swiss universities. SwissBioImaging can lead the development and maintenance of highly modular computational resources that would relieve individual research groups and institutions from the 'engineering' aspects of computational bioimaging (e.g. memory handling for large files, efficient computational resource assignments, workflow orchestration and user interface implementation), thereby allowing them to focus their efforts on actual bioimage analysis problems (e.g. novel method development, pipeline design). SwissBioImaging can also be resourced to take over the long-term maintenance of published image analysis methods of proven value, thereby ensuring they remain freely accessible to all in the long run. Existing funding streams typically do not provide support to achieve either of these goals, which are central to FAIRness and Open Science, as they do not result in classical research outputs (e.g. publications, patents).

The EM-Frontiers proposal (described in the 2023 SERI Roadmap) was put forward to implement a network for all Swiss EM platforms from life and materials sciences from five universities (University of Basel, University of Bern, University of Geneva, University of Lausanne, University of Zurich) and four ETH domain institutes (Empa, EPFL, ETHZ, PSI) into one collaborative network. Despite being prioritised for funding after evaluation at all levels, the start of EM-Frontiers has been postponed to at least 2026 considering the current financial constraints. In the absence of national coordination, equipment limitations in Switzerland both in quality and in quantity impose a dramatic bottleneck on the use of cutting-edge electron microscopy in research.

Marking efforts to emphasise the critical role of integrated imaging approaches in understanding complex biological systems across multiple temporal and spatial scales, the initiative named SwissBioBridge advocates for the establishment of a comprehensive multimodal, multiscale imaging infrastructure for functional, molecular and ultrastructural mapping of biomedical samples in Switzerland. This initiative will integrate cutting-edge technologies such as cryo-electron microscopy, ultra high-plex spatial -omics and high-throughput X-ray microscopy to drive discovery and innovation in biomedical research.

Finally, there is a need to strengthen and maintain infrastructure devoted to the application of NMR to the investigation of protein structure and dynamics (BioNMR). An important signal in this direction has been the establishment of the Swiss High-Field NMR Facility,[2] which serves the



Modern microscopy technologies generate TB-large image datasets capturing millions of individual cells. Recent breakthroughs in AI-based image analysis open the path to extracting this wealth of visual information at scale in a quantitative manner. Source: BioVisionCenter, UZH

needs of biomolecular and chemistry NMR communities. Target user communities are researchers at both biology and chemistry departments of Swiss universities, collaborating in basic and applied chemistry, biochemistry and biology. However, it is envisaged that the needs of these communities shall increase substantially over the coming years and BioNMR is proposed in recognition of this.

Across Switzerland, technology hubs with expertise in bioimaging should be strengthened to further expand on their leading role in developing and improving state-of-the-art microscopy techniques capable of large-scale functional, molecular and ultrastructural profiling across scales and resolutions. And just as pointed out in SwissBioImaging, there is a need to integrate in silico methods and to FAIRify and share NMR data.

Community

The SwissBioImaging infrastructure is poised to strengthen the interdisciplinary community of scientists engaged at the different stages of the discovery process involving bioimaging and will as such benefit a large community of researchers. The resources it will provide to simplify the access to advanced technologies in a standardised manner, both at the level of data acquisition and analysis, will significantly improve their scientific output and international competitiveness. The SwissBioImaging infrastructure will also drive the professionalisation and recognition of supporting roles that are key to ensuring the sustainable operation of bioimaging infrastructures such as core staff, data stewards, software developers, and technicians. These key profiles, although essential to ensure the long-term availability of in-depth technical expertise, remain currently challenging to retain in academia due to a lack of career outlook and professional development opportunities. Although bioimages come with substantial challenges that are unique on the data (size and diversity) and processing (resources and analysis strategies) fronts and should therefore not be mistaken as 'yet another kind of-omics', SwissBioImaging can naturally synergise with SwissBioData as the two infrastructures are highly complementary. Beyond national borders, SwissBioImaging will also offer a strong and internationally relevant connection point to EuroBioImaging, thereby granting Swiss institutions with enhanced exposure and scientific interactions with the larger European science community.

Vision for the future

Securing the means to ensure that bioimage data and their associated analysis are made openly accessible would not only turbocharge the development of AI-based methods, but also give a whole new value to curiosity-driven research in the light of its reuse beyond individually funded projects. Open research outputs relying on the latest microscopy imaging technologies also have the potential to drive innovation and translational projects and thus advance precision medicine, biotechnologies, and pharmaceutical developments, with a net positive impact on the Swiss economy.

To avoid duplication of efforts and maximise the value of resources put into bioimaging, the multiple excellent isolated activities across Switzerland must be federated. SwissBioImaging should be implemented as a national centre of excellence to coordinate technology development, research, and training efforts across Swiss academic institutions from image acquisition to AI-based analysis, while maintaining core resources to support the openness and sustainability of the generated data and research outputs. As a result, it will enable national researchers to stay at the forefront of innovation in imaging technologies and modalities across time and length scales, as well as drive the development and democratisation of AI approaches to quantitative bioimaging.

In parallel, funding is urgently needed for the EM-Frontiers project and to continue investments into national infrastructure for NMR research-fields that have earned Switzerland Nobel Prizes but which are now at risk of losing their global leadership due to underfunding and in-

creasing competition. Furthermore, SwissBioBridge and BioNMR advocate for the integration of complementary approaches to biological imaging across scales in biology.

Recommendation: We recommend the establishment of SwissBioImaging, a national infrastructure that supports the development of cutting-edge microscopy imaging technologies, training, and data analysis resources across the different existing specialised technology hubs embedded in Swiss Universities. In addition to facilitating coordination at the national level, SwissBioImaging should substantially improve current strategic and financial efforts of financing bodies and of Swiss universities in the bioimaging space. Importantly, SwissBioImaging should also coordinate access to the distributed technology hubs, thereby granting all life science researchers in Switzerland access to world-class experts in bioimaging.

Recommendation: SwissBioImaging should drive the transition towards Open Science in bioimaging by bringing the national community together to formulate guidelines enhancing the findability and accessibility of microscopy imaging data, as well as facilitating the interoperability and reuse of analysis systems. These efforts have the potential to turbocharge new research and technology development, with positive returns that extend to all research communities relying on digital image data, such as medicine, material science, geography, and agriculture.

Recommendation: Funding should be urgently secured for the EM-Frontiers project, to maintain Swiss NMR facilities, and to implement the integrative approach presented in SwissBioBridge. Major breakthroughs are to be expected in the preparation of biological specimens. Switzerland should stay abreast of technical progress in this field and be able to contribute to its development.

5.2 Biological collections

State of the art

SwissBioCollections highlights the urgent need for a national infrastructure to support in-depth research on biodiversity, agriculture, and health. This infrastructure is crucial for documenting the distribution of biological resources over space and time, thereby contributing to our understanding of environmental changes. The importance of biological collections for biodiversity monitoring and nature restoration has been reinforced by the adoption of the Kunming-Montreal Global Biodiversity Framework at the COP 15 (UN biodiversity conference) in 2022. This framework highlights the critical role of natural history institutions and their collections in understanding biodiversity, by providing baseline data on species and their occurrences over space and time, housing essential taxonomic expertise, undertaking training of future specialists and publishing or developing identification tools. While botanical and zoological archives, i.e. non-living specimens held in herbaria and museums, do not directly inform conservation efforts, the scientific data they provide is crucial for shaping informed conservation and policy decisions. In addition, botanical and zoological gardens, as repositories of living specimens, support the study and maintenance of biodiversity through managed conservation efforts. Biobanks are invaluable and complementary for supporting biomedical and biological research as well as public health initiatives, as they provide essential data and biological materials that inform disease prevention strategies, therapeutic developments, and understanding of health dynamics. Biobanking infrastructure for non-human samples – including storage systems for live and cryopreserved specimens of microbes and animal tissues – is essential to counter microbial diseases and preserve genetic diversity by enabling assisted reproduction in cases such as isolated animal populations suffering from inbreeding or inherited diseases.

Key initiatives include SwissCollNet, funded by the SERI and set up by the SCNAT for the period 2021–2026 to strengthen the management, preservation, and digitisation of natural history collections, as well as to develop a national platform for open access to digital specimen data. The SBP, funded by the SNSF, has made significant strides in enhancing biobank quality management and harmonizing practices across the country, including veterinary and microbiological collections. These efforts are crucial for supporting the full spectrum of organismal and biomedical research, as well as leveraging data from the Swiss population to advance biomedical research and personalised healthcare. Ensuring the interoperability of collections is increasingly vital in the context of OneHealth, which recognises the interrelations between human, animal, plant, fungal, and environmental health. Another example is the Microbiota Vault initiative, which developed standards and evaluated protocols for storing microbial community samples from around the globe, including Switzerland. In parallel, the availability of reference genomes has increased through international and national initiatives. In the field of biodiversity, the European Reference Genome Atlas (ERGA) aims to create high-quality reference genomes for European species to support conservation efforts and ecosystem management. In the realm

In a recent broadcast on SRF (SRF news, 6 April 2024), it was revealed that around 200 new species of Darwin wasps had been discovered in Switzerland through one of SwissCollNet's digitisation projects, highlighting the untapped potential for scientific discoveries in Swiss natural history collections. Source: SRF and Naturhistorisches Museum Basel

of human genetics, the Genome of Switzerland initiative – driven by the Swiss Personalized Health Network (SPHN), the Personalized Health and Related Technologies (PHRT) and alongside efforts like the Health 2030 initiative – focuses on building representative genomic data representing the Swiss population to advance biomedical research and personalised healthcare. By integrating and standardizing data, fostering interdisciplinary collaboration, and aligning with international standards, SwissBioCollections will contribute to position Switzerland as a leader in biodiversity and biomedical research, driving scientific innovation.

Major success

Several key milestones have been achieved through SwissCollNet and SBP, significantly enhancing the SwissBioCollections framework. SwissCollNet-funded projects were set to conclude in August 2024, and a two-year cost-neutral extension has been granted by SERI to process the data and outcomes of the 68 funded projects. These projects have successfully fostered collaboration among Swiss institutions, improved the quality and scientific usability of collections, and are feeding the currently implemented digital data access portal for Swiss natural history specimens (SwissNatColl) developed by SwissCollNet and hosted by the Global Biodiversity Information Facility (gbif.org). Notable related initiatives include eBioDiv, which links material citations and specimens based on Swiss specimen data submitted to the Global Biodiversity Information Facility (GBIF), the Plazi TreatmentBank, which converts journal articles into FAIR-compliant data for digital dissemination of taxonomic data, the Biodiversity PMC portal at the Swiss Institute of Bioinformatics (SIB) providing AI services to explore publications, and the Zenodo-European Organisation for Nuclear Research (CERN) Biodiversity Literature Repository, which links specimen data in publications. In addition, the establishment of the Naturhistorisches Museum in Zürich and the Naturéum in Lausanne, as well as a new collection building at the Geneva Museum have expanded the Swiss natural history infrastructure, providing state-of-the-art facilities for public education and scientific research. The recent Open Research Data in Veterinary Medicine (ORDVET) project, funded by swissuniversities, has helped raise awareness about the importance of open research data in veterinary medicine, highlighting the close relationship between data availability and the accessibility of research samples. The SBP has significantly contributed to harmonisation of biobanking practices and biobank interoperability across Switzerland, with the development of a Biobank Information Management System (BIMS), which ensures traceability and data security.

Description and development prospects

Recent technological advances have revolutionised our analytical capacity in a broad array of scientific fields. These advancements are coordinated via international standards like the International Image Interoperability Framework (IIIF), facilitating the sharing and use of image-based scientific data. Citizen science initiatives, such as iNaturalist, have also gained traction, engaging the public in biodiversity research and contributing to a broader understanding of global biodiversity. SBP has enhanced biobank quality, visibility and interoperability, integrating microbiology within the OneHealth framework, and contributing to non-human sectors such as veterinary medicine. The adoption of the Swiss National Open Research Data Strategy (CHORD) and initiatives like the Swiss Personalized Health Network (SPHN) have propelled forward a Swiss Federated Genomics Network Strategy, which includes creating a FAIR data repository. In 2023, Switzerland's full membership in the BBMRI was secured, improving its role in EU projects and establishing it as a leader in integrating health and biodiversity research.

Future needs

Scientific need and urgency

The accelerating rate of species extinction, biodiversity shifts, and environmental changes make rapid species documentation, description, and conservation actions of biological resources critically important. The increasing complexity of biomedical research and the emergence of new health challenges make efficient biobanking, data integration, and interoperability crucial. Linking biological samples with their associated data through standardised processes ensures a unified and accessible resource for enhancing the reliability of biodiversity and biomedical data and advancing research. High-quality, integrated data supports reproducibility and facilitates AI-driven research, connecting diverse data types like images, publications, deoxyribonucleid acid (DNA) sequences, and genomes. In addition, the invisible extinction of microorganisms underscores the urgent need to preserve microbial diversity, prompting initiatives like the Microbiota Vault to capture and safeguard this diversity, including that of the Swiss population. Among the most urgent priorities for SwissBioCollections are securing robust documentation and digitisation capacities, ensuring extensive and reliable data processing and storage, and providing long-term curation of digital collections. Ensuring the quality, sustainability, and digital access to biological specimens and their related published research is crucial. Notably, 75% of the 60 million specimens conserved in Swiss collections are awaiting digital processing. Digitizing these specimens is essential to reveal the scientific

In the context of SwissCollNet, the Entomological Collection of ETHZ generated 3D models of over 2400 type specimens – here, a type specimen of the black masked bee *Hylaeus nigritus*. These digital representations allow taxonomic studies by experts worldwide without sending the valuable specimens. Source: Christian Felsner, Entomologische Sammlung ETHZ

data they hold and to integrate them into the global pool of specimen-based biodiversity data.

Impact and community

SwissBioCollections plays a central role in providing digitised and physical specimens and related data to answer critical questions on biodiversity and health dynamics, strongly improving Swiss research quality and competitiveness. This infrastructure supports the management, growth, and enhancement of biological collections and biobanks, contributing significantly to national and global biodiversity and medical knowledge networks. It provides reliable data for addressing societal challenges such as biodiversity loss, climate change, and emerging health threats. Serving a broad community of stakeholders – from researchers and policy makers to biodiversity managers – SwissBioCollections strengthens biodiversity conservation, nature restoration, and supports practices in agriculture, personalised medicine, and academic-industrial collaborations. It facilitates genetic variation studies and ensures Switzerland's integration into international initiatives. Additionally, it leverages synergies with SwissBioData and other research infrastructures, utilizing Linked Open Data for comprehensive biodiversity characterisation. It also acts as a platform for training, public outreach, citizen engagement, and reinforcing its role in advancing scientific and community-driven goals.

Vision for the future

The vision for SwissBioCollections underscores the critical need for a national infrastructure to support comprehensive research on biodiversity, agriculture, and health. This infrastructure should integrate cutting-edge technologies and innovative management practices for natural history collections and biobanks. SwissBioCollections should build upon the existing successes of SBP, funded by SNSF since 2016, and SwissCollNet, funded by SERI during the 2021–2026 period. The updated research infrastructure could be hosted under an umbrella, possibly following a model similar to the Swiss Centre of Expertise in Social Sciences (FORS) social sciences hub, which could also accommodate further ERIC projects like BBMRI and DiSSCo. Such a national infrastructure is essential for integrating and standardizing data, enhancing digitisation, implementing the Open Research Data strategy, and ensuring the long-term conservation and accessibility of both physical and digital specimens. It will also facilitate the provision of high-quality and reliable biomedical and biodiversity data from within Switzerland. By fostering interdisciplinary collaboration, adopting good Open Science practices, and aligning with international standards, SwissBioCollections will generate significant and high-quality data that will be instrumental in addressing global challenges such as species extinction, climate change, and emerging diseases.

Recommendation: Promote biodiversity research through Open Science and long-term research collection storage: Building on SwissBiobanking Platform's advancements in open research data for biobanks, it is essential to extend this to natural history collections. Implementing national Open Science policies and requiring 'Sample Management Plans' for all biological research will ensure preservation and reproducibility. While biobanks have made progress in long-term storage and accessibility, natural history collections – including both biological and geological specimens – lag behind, despite efforts like SwissCollNet. Leveraging digital records and global standards will enhance transparency, global collaboration, and data reuse from Swiss institutions.

Recommendation: Accelerate documentation and digitising efforts: Facilitating species discovery, documentation, and conservation efforts requires supporting the databasing and digitisation of natural history collections, a process initiated nationally by the SwissCollNet initiative during 2021–2026. Integrating modern technologies, such as 3D imaging and CT-scans, strengthens digitisation efforts while creating comprehensive records of species that contribute to the global biodiversity knowledge network. Switzerland's membership in DiSSCo-ERIC should be achieved to further strengthen its role in European natural history collection networks, fostering collaboration and access to EU projects.

Recommendation: Enhance data integration and interoperability: Prioritizing the adoption of recognised biodiversity specimen and data standards, along with linking specimens to associated data – including observation data, -omics data, and material citations in publications – ensures that high-quality data from Swiss collections contribute to national and global biodiversity knowledge. This will be achieved through partnerships with international data aggregators, research infrastructures, analytical platforms, and information systems.

5.3 Biological sites

State of the art

In the Thematic Roadmap Biology 2021, relevant research infrastructures in Switzerland have been described for investigations of natural and managed ecosystems. All these research infrastructures still exist, providing excellent opportunities for scientists in Switzerland and beyond to address research questions in the fields of ecology, agriculture and forestry. For example, the Swiss FluxNet,[3] a network of eddy-covariance flux sites, has been continued, now providing >123 site-years of high-quality greenhouse gas fluxes for different land use types. While all sites are part of FLUXNET,[4] the global network of flux sites, one of the sites (Davos) is also part of the European Integrated Carbon Observation System (ICOS)[5] research infrastructure. The Swiss National Forest Inventory (NFI)[6] as well as the Swiss Long-term Forest Ecosystem Research (LWF)[7] networks have been maintained with all original sites, similarly to other biodiversity and ecology monitoring sites such as AlpFor, Calanda, Hölstein, Lavey, Rechalp, and Schynige Platte. Many of these sites and several Swiss networks are part of European and international networks, e.g. LWF is part of the UNECE International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)[8] and the Integrated European Long-Term Ecosystem, Critical Zone and Socio-Ecological System Research Infrastructure (eLTER).[9] Mountain Invasion Research Network (MIREN)[10] acts as an initiative of the Global Mountain Biodiversity Assessment (GMBA)[11] and is an officially endorsed project of the International Programme of Biodiversity Science (DIVERSITAS).[12] The airspace is also increasingly recognised as an essential habitat for a large proportion of the global biodiversity. International efforts in using networks of (weather and small-scale) radars for monitoring aerial biodiversity are now increasingly employed by researchers and stakeholders, such as within BioDiversa projects (HiRAD).[13] Moreover, various other universities and local research networks continued their activities, often embedded in national programmes led by FOEN, Agroscope, or research institutions such as Research Institute of Organic Agriculture (FiBL), ETHZ, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and Swiss Federal Institute of Aquatic Science and Technology (Eawag). Nevertheless, the shortcomings identified and described in the Thematic Roadmap 2021–2025, i.e. often short-term projects, distributed, small-scale plots, scattered among institutions, departments and individual researchers, have not yet been overcome. As a consequence of many long-term sites being run by individual principal investigators, the danger of losing excellent research infrastructures and their long time series of unique data is very high when these PIs retire in the coming years.

Recent developments

Since the Thematic Roadmap 2021–2025 was written, one major attempt to bring together existing RI distributed across Switzerland to support the transformation towards a sustainable agriculture, was the proposal of a joint research infrastructure, SwissBioSites for Sustainable Agriculture and Agroecology (SISAL) within the ETH domain. However, after a three-year process including several reviews, inclusion in the Swiss Roadmap for Research Infrastructure 2023 and the ERI Dispatch 2025–2028, SISAL was postponed for funding in March 2024 by the ETH Board due to financial reasons. Its future remains unclear. Additionally, the proposal for a Swiss Plant Phenotyping Platform (SP^3) was developed by and for the Swiss Plant Science Web (ca. 120 research groups) to build a worldwide unique infrastructure for seamless plant phenotyping from controlled to natural conditions. SP^3 was supported by all Swiss universities but rated low by the SNSF and thus not pursued. On the other hand, a long-term forest irrigation research platform in Pfynwald received substantial institutional and SNSF funding for 2023–2029 to disentangle effects from atmospheric and soil drought on a natural pine forest (VPDrought), however, again, on project-based funding.

Overall, the current development of the federal finances raises strong concerns for the future, i.e. for the integration of innovative research across Switzerland, for the further development of excellent research infrastructures in Switzerland and their contributions to international programmes. Moreover, there is a growing discrepancy between the expected excellence in research and teaching, growing student numbers, and financial resources. If funding is implemented as currently discussed, it will endanger the continuity and treasure of long-term research sites and their data and will jeopardise the pole position of the Swiss research hubs (see future needs below).

Future needs

Scientific need and urgency

The great potential of research infrastructures across Switzerland in the disciplines of biodiversity, ecology, agriculture and forestry to address fundamental as well as global change-related and sustainability-related questions, as described in the Thematic Roadmap 2021–2025, is still valid and are now even more urgent due to accelerated biodiversity loss, environmental degradation, and climate change. Thus, Switzerland´s unique position to act as an ideal model laboratory for the world to study both terrestrial as well as aquatic and aerial ecosystems

has gained relevance and should not be jeopardised now or in the future.

Community

A shared nationwide infrastructure of permanent plots, uniform equipment and facilities (e.g. for phenotyping, flux measurements, radar-based biodiversity assessments), long-term experiments, and data acquisition and management, i.e. SwissBioSites as described in the Thematic Roadmap 2021–2025 and proposed in SISAL and SP,[3] will benefit many research disciplines and stakeholders in Switzerland, complement research infrastructures in integrated geosciences, allow close collaborations with international research infrastructures and networks, and provide training opportunities to students and early-career researchers. With hundreds of users already engaged, the number is expected to grow as more research infrastructures become available and as open access to sites and data expands, in line with Switzerland's Open Science and ORD strategies. This growth will follow international best practices, including the FAIR and TRUST (Transparency, Responsibility, User Focus, Sustainability, Technology) principles. An excellent example can be found in the Swiss FluxNet whose data have been downloaded 26,800 times between November 2016 and February 2024.

Vision for the future

The SwissBioSites research infrastructure and its central hub for data analyses will allow addressing the drivers and consequences of changes in terrestrial and aquatic ecosystems, including effects of climate change or biodiversity loss. Based on such information, recommendations can be provided on ways to manage, restore or protect ecosystems in the most sustainable manner. Methodologically, the infrastructure involves analyses of the genome, transcriptome, metabolome, proteome and phenome of organisms, but also measures of the composition, diversity and performance of populations, communities and ecosystems, as well as environmental conditions (e.g. temperature, soil moisture and pollutants). Without such a coordinated, highly instrumented research infrastructure the national efforts cannot be integrated, and decreasing finances cannot be used efficiently.

Clearly, the SwissBioSites research infrastructure and its central hub build on already existing research infrastructures but allows unprecedented joint research and thus will expand their scientific impact beyond what single research infrastuctures might achieve. Switzerland hosts a globally unique research opportunity with naturally existing climate gradients from the lowlands to the Alps where a coordinated data acquisition, analysis and share of long-term monitoring sites for biodiversity, ecology, agriculture and forestry will not only benefit the local researchers but attract international collaborations.

Depending on the participating institutions and the funding allotted to the SwissBioSites research infrastructure, the research infrastructures provide evidence-based strategy development how to increase biodiversity, restore degraded ecosystems, increase aviation safety and public health, and mitigate climate change, and will contribute to the necessary transformation of agriculture towards increased sustainability.

Recommendation: We recommend supporting a coordinated nationwide infrastructure with spatially distributed field sites, permanent plots, long-term experiments, uniform equipment and facilities with their harmonised data acquisition and management. Such a national research infrastructure will benefit multiple research disciplines, enhance international collaborations, and support sustainable ecosystem management and agricultural transformation.

Recommendation: We recommend strengthening the national nodes of international research infrastructures. The integration of the excellent and innovative science across Switzerland is crucial to maintain the unique position Switzerland internationally also in the future, both for research and innovation as well as for educating the next generation of decision-makers. This also requires the development of national procedures how memberships in ERICs and international organisations is decided upon and financed.

Recommendation: We recommend leveraging the leading role of many Biology disciplines in open science and FAIR data. Biology and ecology have a long tradition in providing data and code following FAIR principles, depositing data and code in repositories following TRUST principles. These long-standing experiences can serve as role model for other disciplines, raise awareness through best practices, and contribute to efforts at the European level, namely of the European Open Science Cloud (EOSC) Association,[14] by supporting thematic nodes in Switzerland.

5.4 Biological core facilities and data resources

State of the art

The Thematic Roadmap 2021 presented the need for a scalable and sustainable network of data-generating and data-analysing core facilities to enable the creation, sharing, combination, analysis and application of biological data from diverse basic and applied disciplines in a concept entitled SwissBioData. In particular, coordinated data standards and unified workflows were identified as requirements to connect data from different -omics approaches across organisms and scales, to link them with data from literature and databases, and to leverage the potential of petabytes of research data from public databases and publicly funded grants – including EU and SNSF grants – that are deposited in FAIR repositories.

In 2022, the SwissBioData ecosystem (SBDe) proposal brought together 54 units across 18 Swiss institutions under the leadership of UNIBE and SIB. It obtained the highest possible score in the SNSF evaluation and was included to the SERI Roadmap 2023. In addition, SBDe was recognised as a key initiative to reduce fragmentation by the Task Force Health and Life Science Data which was mandated by the Swiss National ORD Strategic Council to analyze the Swiss ORD landscape. A funding decision through the 2025–2028 ERI Dispatch (Art. 47 HEdA and Art 15 RIPA) is pending.

Since the publication of the Thematic Roadmap 2021, the need for greater coordination across core facilities has intensified, not only for data processing but also for the development of experimental methods and the operation of analytical equipment. Advances in genomics, proteomics, transcriptomics, metabolomics – collectively referred to as '-omics' – have led to massive increases in data throughput, novel assay types, and greater complexity in analyses. The same is true for imaging facilities, which also have their specific challenges and opportunities, as outlined in the *Biological Imaging* chapter.

To optimise the use of expertise and analytical technologies across facilities, coordination of the local specialised knowledge and the collaborative use of infrastructure capacities is essential. This would enhance accessibility to cutting-edge technologies, streamline workflows, and support the rapidly growing research community.

Similarly, the rise of artificial intelligence, exemplified by the success of Large Language Models (LLM), has created new opportunities in data-intensive research. Locally deployable AI models, particularly open-source versions, offer potential for cost efficiency and compliance with data protection laws, but their effectiveness depends on access to structured, FAIR-compliant data. Linked Open Data (LOD) frameworks, such as Resource Description Framework (RDF) and Web Ontology Language (OWL), are critical for ensuring integration and interoperability of datasets across laboratories, which will be key to maximizing AI's potential in research.

The national/international context

Since 2021, the Swiss National ORD Strategic Council and substantial investments into the Alps supercomputer at the Swiss National Supercomputing Centre, the Swiss AI initiative, and Swiss Data Science Center represent significant efforts to foster coordination and infrastructure development for AI and data science in Switzerland. However, without similar coordination at the level of data-producing and data-processing core facilities, these initiatives will struggle to fully tap into the vast sources of relevant data and engage with the 'long tail' of researchers who produce and analyse these data. The lack of harmonisation in core facility standards, workflows, and data-sharing frameworks could limit the accessibility and usability of critical datasets. To realise the full potential of AI and data science for research acceleration, the integration of these core facilities into a unified national framework, aligned with FAIR principles, is essential. This coordination would ensure that large-scale data from diverse biological disciplines is efficiently generated, processed, and leveraged to drive breakthroughs in AI-powered analyses.

Internationally, several countries are moving rapidly to strengthen their data science and AI capabilities. In the UK, the BioFAIR initiative, funded by UKRI, is building a federated digital research infrastructure aimed at FAIR-ifying data, with an investment of £ 34 million over five years. The U.S. National Institutes of Health (NIH) recently released its Strategic Plan for Data Science 2023–2028, which outlines large investments to bolster data science, including federated infrastructures, AI innovation, and strategies to ensure that data from biomedical and clinical research is accessible, secure, and interoperable. In Europe, the EOSC continues to gain importance, with the European Commission viewing it as a critical component to securing the EU's competitiveness in the digital age. These international efforts highlight the urgency of developing national frameworks and infrastructures that are globally aligned and competitive. Without similar investments and coordination in Switzerland, the country risks falling behind in the global race to leverage AI and data science for scientific and technological advancements.

Biological data processing. Source: iStock/gorodenkoff

Future needs

Scientific need and urgency

Swiss institutions have long recognised the importance of bioanalytical technologies and have made significant investments in both data acquisition and analytical platforms. However, the current fragmentation of these infrastructures, which are often operated in local isolation and lacking critical mass, weakens Switzerland's capacity to compete at the international level. Establishing a scalable, federated network of core facilities for data acquisition and sharing at the national level, would address this issue. Furthermore, failure to fund SwissBioData ecosystem through the ERI Dispatch 2025–2028 period would represent a significant missed opportunity, and alternative funding sources will need to be urgently identified to safeguard Switzerland's competitiveness in the fast-evolving domain of data-intensive research.

Moreover, the need for an additional coordinated structure of specialised analytical expertise and state-of-the-art equipment across institutions remains critical. As equipment becomes more complex and expensive, and institutional and federal infrastructure budgets shrink, collaboratively using these resources is increasingly essential to ensure that cutting-edge technologies remain accessible and effectively utilised across the research community.

Finally, there is an urgent need to provide sustainable funding for key data resources, which underpin much of contemporary biological research. For instance, the Swiss Pathogen Surveillance Platform (SPSP) was established under National Research Programme 72 to collect and share whole genome sequences of bacterial and viral pathogens for research and public health, but it was not selected as a 2023 SERI Roadmap project and is struggling to find sustainable funding. PLAZI is another example: it has been crucial in biodiversity, digitizing the reference description ('treatment') for one million species from previously inaccessible publications, but has only survived through a fragile combination of European project grants, philanthropic donations, and voluntary work; its future is highly uncertain. SIB sustains a portfolio of universally used data resources but has not been able to keep up with the needs due to flat federal funding through Art. 15 of the Federal Act on the Promotion of Research and Innovation (RIPA) over the last decade. As a result, in the 2025-2028 period, several highly successful SIB resources, including

the flagship resource UniProt/Swiss-Prot, are receiving funding cuts despite unprecedented usage growth. The situation highlights the need for a clear funding strategy and accountability among federal offices and other stakeholders to maintain essential data resources.

Community

All universities and research institutions with a major involvement in life sciences have local core facilities. The SBDe consortium already integrates many relevant stakeholders, bringing 18 institutions and 54 units together. With the extended scope of this update, there is potential for even more core facilities to get involved. Beyond the core facilities themselves, the beneficiaries are researchers from the life sciences who generate and analyze -omics data. Integrating these institutions into national networks will also ensure that the user community will be large and inclusive. A general infrastructure addressing the need for coordination around equipment, analytical methods, and data would complement more specialised research initiatives, such as those outlined in the Biological Imaging and Biological Collections chapters. Addressing the needs outlined here would also complement existing national infrastructures such as SPHN, Swiss Data Science Center (SDSC+), Swiss AI Initiative (SwissAI), as well as National Centres of Competences in Research (NCCRs). Core facilities and data resources, and SBDe in particular, also collaborate with international counterparts including European Life Science Infrastructure for Biological Information (ELIXIR), European Molecular Biology Laboratory (EMBL), EOSC, and various EU projects. Finally, open/FAIR data resources are also valuable beyond the research realm – for the industry, government, and the general public.

Vision for the future

Our vision is a coherent, integrated and trustworthy federation of data platforms in line with the FAIR principles. Interconnecting the currently fragmented local infrastructures would facilitate seamless data sharing, processing, and analysis across local and international research communities. This would harmonise data acquisition and data analysis, establish new standards and foster collaboration between domain experts and data scientists. Better coordination among data producing core facilities would also enable the joint development of methods and operation of costly state-of-the-art equipment. Ultimately, providing researchers with a federated landscape of data-producing and data-processing core facilities would increase quality, reduce costs, and boost the transformation of research data into valuable knowledge and innovation, and keep Switzerland at the forefront of data-intensive life sciences research.

Recommendation: We recommend establishing SwissBioData ecosystem as a decentralised infrastructure, supported by core facilities, to boost data-driven research in life sciences and to enhance Switzerland's capacity to convert FAIR research data into knowledge and innovation. SBDe involves 54 data-producing and data-processing units across 18 public research institutions thereby reducing the current fragmentation and duplication of efforts by establishing unified standards for data acquisition, integration, and analysis.

Recommendation: We recommend sustaining essential data resources to accelerate research and enable trustworthy AI. To remain competitive, Switzerland needs to sustain its key data resources. Mining this clean, high-quality data will maximise AI's potential as an accelerator of research and a value multiplier. This will benefit the broader research community and support data-heavy initiatives in life sciences, as well as AI-driven initiatives like SwissAI.

Recommendation: We recommend developing a collaborative state-of-the-art molecular profiling infrastructure across Swiss institutions. This will enhance access to cutting-edge technologies such as next-generation sequencing, mass spectrometry, and advanced molecular imaging platforms. By combining intellectual and infrastructure resources, collaboration will lower costs, ensure more efficient use of high throughput and specialised equipment, and foster scientific interactions among institutions and core facilities, ensuring that Swiss researchers remain at the forefront of global innovation in life sciences.

6 Swiss participation in international research infrastructures

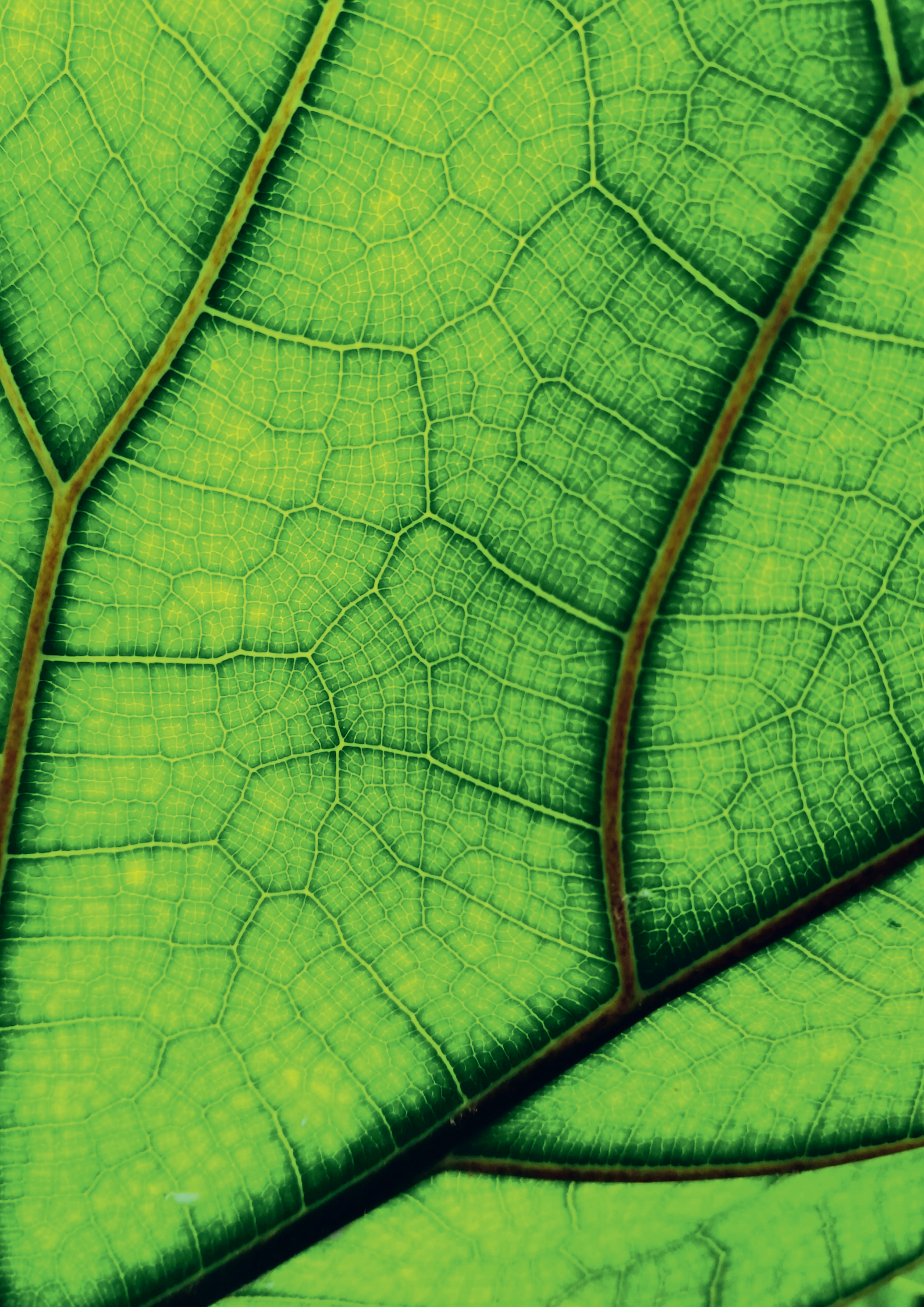
Switzerland is an active member of many international research organisations that conduct experiments and use world leading research infrastructures in their fields of expertise. In 2009, the European Union established a joint legal framework for a European ERIC to facilitate the creation and operation of research infrastructure networks at European level. For the Swiss biology community, involvement and membership in these networks is of vital significance and should be promoted whenever possible. Over the past few years, several European networks and research infrastructures have been developed relative to the life sciences and biology, which do not yet feature Switzerland as a full member (Table 1).

However, for some ERICs, Switzerland moved ahead, supporting the national research communities. For example, in May 2023, Switzerland changed its status from observer in ICOS Research Infrastructure (since 2013) to member; other examples exist in GeoSciences and the Humanities. This was a large step towards recognizing the relevance of Swiss research infrastructures being embedded in international research infrastructures, also emphasised in the White Paper on Research Infrastructures published by the SNSF in September 2023. Moreover, the European Infrastructure for Plant Phenotyping (EMPHASIS)[15] is on its way to being established as an ERIC with highly relevant contributions of the Swiss node consisting of crop variety testing (Agroscope) and crop phenotyping (ETHZ). The European research infrastructure eLTER is currently being established as an ERIC, with contributions of many national institutions (i.e. WSL, ETHZ, University of Basel).

In summary: International collaboration remains essential and should be promoted for the Swiss biology community to remain connected and competitive at both the national and international level.

Table 1: Current and proposed future Swiss participation in International Research Infrastructure Networks and International Research Organisations. Source: SERI[16]

Infrastructure/Programme	Abbreviation	Current status of Switzerland	Recommended status	
Current Swiss participation in International Research Infrastructure Networks				Swiss Node
Biobanking and Biomolecular Resource Research Infrastructure	BBMRI	Full member	Full member	SwissBiobanking Platform
European Life Science Infrastructure for Biological Information	ELIXIR	Full member	Full member	SIB
Integrated Carbon Observation System (ERIC)	ICOS	Full member	Full member	Consortium: ETHZ (Lead), Empa, WSL, UNIBE, UNIBAS, MeteoSwiss
Distributed System of Scientific Collection (transition to ERIC)	DiSSCo	Currently not a member	Full member	n/a
Euro-BioImaging (ERIC)	Euro-BioImaging	Currently not a member	Full member	n/a
Instruct-ERIC	Instruct-ERIC	Currently not a member	Full member	n/a
Integrated European Long-Term Ecosystem, Critical Zone and Socio-Ecological System Research Infrastructure	eLTER	Supportive	Full member	WSL
European Infrastructure for Plant Phenotyping	EMPHASIS	Supportive	Full member	ETHZ and Agroscope
Current Swiss participation in International Research Organisations				Swiss counterpart
European Molecular Biology Laboratory	EMBL	Full member	Full member	n/a
European Synchrotron Radiation Facility	ESRF	Full member	Full member	Swiss Light Source
European X-Ray Free-Electron Laser	European XFEL	Full member	Full Member	Swiss X-ray Free Electron Laser



7 Conclusions

The purpose of this document is to outline the updated needs of the Swiss community in terms of research infrastructures of national importance in biology, as previously illustrated in the thematic roadmap published in 2021.[1] This document is, therefore, the expression of a diverse community of colleagues spread throughout Switzerland. It intends to inform future decision-making processes concerning significant national investments and association with existing international infrastructure and/or organisations.

The benefits of establishing the proposed research infrastructures are hard to overstate: The national and international integration of the Swiss biology research community in a fiercely competitive European and global research landscape is dependent on timely and cost-effective existence and access to technology and research platforms and cutting-edge equipment in Switzerland, combined with full access to European platforms and networks. A failure to do so might provincialise Swiss research communities, thereby reducing the attractiveness of Swiss institutions for higher level research and teaching in biology. The exclusion of Switzerland from most Horizon Europe funding schemes has already caused significant damage to the Swiss biology community.

Finally, it is our expectation that this document shall serve as an important instrument in the selection of viable research infrastructure proposals by the ETH Board and swissuniversities (for example via the Swiss Roadmap of SERI), and the scientific assessment by the SNSF and appropriate funding. This shall ensure the founding of national investments in real bottom-up, shared and documented community needs, both nationally and internationally, especially at times of limited resources and rising costs of excellence in research, coupled to fast-paced technological advancements. Furthermore, it shall demonstrate the large bottom-up efforts the biology research community has taken to integrate and coordinate needs for Research Infrastructures in Switzerland.

8 Links

1 https://zenodo.org/records/4572622

2 https://www.swissnmr.ch

3 https://www.swissfluxnet.ethz.ch

4 https://fluxnet.org

5 https://www.icos-cp.eu

6 https://www.lfi.ch/en

7 https://www.wsl.ch/en/forest/forest-development-and-monitoring/long-term-forest-ecosystem-research/

8 http://icp-forests.net

9 https://www.elter-ri.eu

10 https://www.mountaininvasions.org

11 https://www.gmba.UNIBE.ch

12 https://uia.org/s/or/en/1100046157

13 https://hirad.science

14 https://eosc.eu

15 https://emphasis.plant-phenotyping.eu

16 https://www.sbfi.admin.ch/sbfi/en/home/research-and-innovation/research-and-innovation-in-switzerland/uebersicht-forschungsinfrastrukturen.html

9 Acronyms

Agroscope	Swiss Confederation's Center of Excellence for Agricultural Research
AI	Artificial Intelligence
AlpFor	Alpine Forschungs- und Ausbildungsstation Furka
BBMRI	Biobanking and Biomolecular Resource Research Infrastructure
BIMS	Biobank Information Management System
BioFAIR	A BioCommons Infrastructure for UK Life Science Researchers
CERN	Conseil Européen pour la Recherche Nucléaire, European Council for Nuclear Research
CHORD	Swiss National Open Research Data Strategy
COP 15	UN Biodiversity Conference
DiSSCo	Distributed System of Scientific Collections
DIVERSITAS	International Programme of Biodiversity Science
DNA	DeoxyriboNucleic Acid
Eawag	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz, Swiss Federal Institute of Aquatic Science and Technology
eBioDiv	Literature Services for Biodiversity
ELIXIR	European Life Science Infrastructure for Biological Information
eLTER	Integrated European Long-Term Ecosystem, Critical Zone and Socio-Ecological System Research Infrastructure
EM	Electron Microscopy
EMBL	European Molecular Biology Laboratory
Empa	Eidgenössische Materialprüfungsanstalt, Swiss Federal Laboratories for Materials Science and Technology
EMPHASIS	European Infrastructure for Plant Phenotyping
EOSC	European Open Science Cloud
EPFL	École Polytechnique Fédérale de Lausanne
ERGA	European Reference Genome Atlas
ERI	Education, Research and Innovation
ERIC	European Research Infrastructure Consortium
ESRF	European Synchrotron Radiation Facility
ETHZ	Eidgenössiche Technologische Hochschule Zürich, Swiss Federal Institute of Technology Zurich
EU	European Union
European XFEL	European X-Ray Free-Electron Laser
FAIR	Principles for Scientific Data Management and Stewardship: Findability, Accessibility, Interoperability, Reuse of digital assets
FiBL	Research Institute of Organic Agriculture
FOEN	Federal Office of the Environment
FORS	Swiss Centre of Expertise in Social Sciences
GBIF	Global Biodiversity Information Facility
GMBA	Global Mountain Biodiversity Assessment
HEdA	Higher Education Act
HiRAD	Harmonizing and Integrating Radar-based approaches for monitoring Aerial bioDiversity
ICOS	Integrated Carbon Observation System
IIIF	International Image Interoperability Framework
iNaturalist	Community for Naturalists
LLM	Large Language Models
LOD	Linked Open Data
LS²	Life Sciences Switzerland
LWF	Langfristige Waldökosystem-Forschung, Swiss Long-term Forest Ecosystem Research
MIREN	Mountain Invasion Research Network
NCCR	National Centres of Competence in Research
NFI	Swiss National Forest Inventory
NIH	National Institutes of Health (USA)
NMR	Nuclear Magnetic Resonance
-omics	In Biology, the word -omics refers to the sum of constituents within a cell
ORD	Open Research Data
ORDVET	Open Research Data in Veterinary Medicine
OWL	Web Ontology Language
PgB	Projektgebundene Beiträge, Federal project related contributions, granted by the Swiss Higher Education Council
PHRT	Personalized Health and Related Technologies
PLAZI	Association supporting and promoting the development of persistent and openly accessible digital taxonomic literature
PSI	Paul Scherrer Institute
RDF	Resource Description Framework
RIPA	Federal Act on the Promotion of Research and Innovation
SBDe	SwissBioData ecosystem
SBP	SwissBiobanking Platform
SCNAT	Swiss Academy of Sciences
SDSC+	Swiss Data Science Center
SERI	State Secretariat for Education, Research and Innovation
SIB	Swiss Institute of Bioinformatics

SISAL	Research Infrastructure for Sustainable Agriculture and Agroecology
SNSF	Swiss National Science Foundation
SP3	Swiss Plant Phenotyping Platform
SPHN	Swiss Personalized Health Network
SPSP	Swiss Pathogen Surveillance Platform
SRF	Schweizer Radio und Fernsehen
SwissAI	Swiss Artificial Intelligence Initiative
SwissBIAS	Swiss BioImage Analysts' Society
SwissCollNet	Swiss Natural History Collections Network
Swiss FluxNet	Network of eddy-covariance flux sites
SwissNatColl	Swiss Natural History Collections
TB	Terabyte
TRUST	Principles for digital repositories: Transparency, Responsibility, User focus, Sustainability and Technology
UKRI	United Kingdom Research Initiative
UNIBAS	University of Basel
UNIBE	University of Berne
UNIFR	University of Fribourg
UNIGE	University of Geneva
UNIL	University of Lausanne
USI	Università della Svizzera Italiana
USP	Universitätsspital Zürich, University hospital Zurich
UZH	University of Zurich
UNECE	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)
VPDrought	Project on Vapor Pressure Deficit by WSL
WSL	Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Swiss Federal Institute for Forest, Snow and Landscape Research

SCNAT – network of knowledge for the benefit of society

The **Swiss Academy of Sciences (SCNAT)** and its network of 35,000 experts works at regional, national and international level for the future of science and society. It strengthens the awareness for the sciences as a central pillar of cultural and economic development. The breadth of its support makes it a representative partner for politics. The SCNAT links the sciences, provides expertise, promotes the dialogue between science and society, identifies and evaluates scientific developments and lays the foundation for the next generation of natural scientists. It is part of the association of the Swiss Academies of Arts and Sciences..