Vol. 16, No. 2, 2021

scnat
swiss academy of sciences

swiss academies reports

swiss-academies.ch

Biology Roadmap

for Research Infrastructures 2025–2028
by the Swiss Biology Community

IMPRINT

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RECOMMENDED FORM OF CITATION
Brunner D, Durinx C, Erb M, Fischer M, Hari Y, Jazwinska A, Leeb T, Reymond C, Scheidegger C, Stieger P, Studer B, Vergères G, Walter A (2021)
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Swiss Academies Reports 16 (2)

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constantincornel/stock.adobe.com

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Pp. 4, 10, 12, 18, 20, 42, 44, 46: Yvonne Hari

This report can be downloaded free of charges from scnat.ch/en/id/BGqdL

ISSN (print) 2297-1793
ISSN (online) 2297-1807

DOI: doi.org/10.5281/zenodo.4572622

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for Research Infrastructures 2025–2028
by the Swiss Biology Community

Content

1 Executive Summary

Biology is the study of life in all of its diverse manifestations. It involves investigations of the functioning, origin and evolution of organisms, as well as their interactions with other organisms and with their environment. Consequently, biological research is essential to understand, protect and improve the well-being of all life on our planet. In fact, many biological discoveries are motivated by societal and environmental issues. Biological research continuously contributes to efforts to tackle the global challenges we face today, including climate change, the excessive exploitation of natural resources and biodiversity loss. Moreover, it helps us to design better and more sustainable means to improve the health and well-being of humans and animals alike.

Possible solutions to complex global challenges require insights from multiple fields and interdisciplinary approaches. The boundaries between sub-fields are fading, as are the distinctions between fundamental, translational and applied research. Moreover, current research often combines sub-fields of biology, as well as physics, chemistry, geoscience and computer science. This development is manifested in many areas, including biomedicine, nutritional science, systems biology and ecology. While the transition from disciplinary towards interdisciplinary research is well under way in the Swiss biology community, it is often not fully represented on the institutional level.

The trend towards interdisciplinary approaches is adequately met by multi-nodal networks. Moreover, network infrastructures match the decentralised organisation of the Swiss biology community, which consists of numerous specialised research groups representing a wide range of public and private entities, each of which provides high-level expertise in a specific area. Consequently, we recommend that research infrastructures for biology take the form of networks, whereas, in contrast to other disciplines like physics, large single-site core facilities are less suitable. The importance of network infrastructures is mirrored on the international and European levels: many of the European Research Infrastructure Consortia (ERIC) are structured as networks connecting peers and institutions across numerous countries.

The need for four dedicated network infrastructures is described in this roadmap: **SwissBioCollection** is focused on building the technical infrastructure needed for the digitisation, curation and coordination of natural history collections and biobanks for scientific discovery. **SwissBioSites** involves the establishment of a network of experimental sites to study and monitor natural and anthropogenic drivers of change in ecosystems. **SwissBioData** is focused on facilitating the production, standardisation, integration, analysis and sharing of large biological datasets, in particular regarding -omics data. **SwissBioImaging** is dedicated to the analysis of complex biological imaging data, which poses specific challenges in terms of unprecedented volumes of data, data richness and the lack of efficient, accessible tools for image analysis.

Common to all four infrastructures described herein is the challenge of comprehensive data exploitation, which often constitutes a limiting bottleneck. This challenge extends far beyond mere data storage to all steps of data management. The configuration and setup of instrumentation should go hand-in-hand with the development of data analysis procedures that match both data acquisition schemes and data exploitation goals. Coordination between research groups is required to standardise workflows and streamline this development. Data management should achieve two major goals: interoperability of experimental datasets, as well as procedures that respect the specific requirements of the numerous sub-fields of biology. Therefore, in spite of the presence of somewhat related challenges in several fields of biology, four separate, dedicated network infrastructures are proposed to keep Switzerland at the forefront of international research in biology.

The proposed infrastructures were identified in the course of an 18-month process starting in July 2019. Biologists from all fields and regions across Switzerland were invited to participate in and contribute to the elaboration of the present roadmap. They were contacted through the SCNAT's Platform Biology of the Swiss Academy of Sciences, its specialised societies and the professional networks of all members of these societies.

2 Findings and Recommendations

General Findings

Finding 1: In the field of biology, specimen sampling and data generation are increasing exponentially, but integrated data exploitation poses a limiting bottleneck. To improve and exploit the generation and availability of biological data and materials, but also to investigate complex intradisciplinary and interdisciplinary questions, the research community would benefit immensely from coordinated experimental approaches, common adopted standards and shared large-scale infrastructures.

> **Recommendation 1:** To facilitate the democratisation of data exploitation, local nodes with infrastructure should be created and/or strengthened, and expertise concentrated at these nodes should be shared with the broader scientific community. These decentralised nodes should form highly interconnected networks, coordinated by central hubs that streamline data generation, interoperability and exploitation. Within these networks, hardware, tools and specialised skills should be intertwined to coordinate and balance resources for data acquisition and data analysis.

Finding 2: Competitive research is not possible without international networking and the ability to attract worldwide attention. Regarding international infrastructures, Switzerland's location in Europe means that European initiatives and programmes are considered the most important for Swiss biologists.

> **Recommendation 2:** Switzerland should remain committed to international collaboration in order to connect its collective academic expertise to international networks. It is crucial to establish strong national infrastructures that can serve as significant nodes in European networks, thus strengthening the ties between Swiss and foreign researchers.

National infrastructures

SwissBioCollection

Finding 3: Biologically relevant samples and specimens and the associated metadata, held in scientific collections and biobanks, have become essential in integrative research programmes for a vast set of scientific questions and as a source of scientific discovery. Such biological collections are essential for understanding our living planet and how organisms have evolved, as well as how they may react to anthropogenic changes. However, these collections are individually curated across multiple institutions, sometimes under different management standards. To facilitate future research, the huge volume of data held in these collections needs to be harmonised and digitised, and access needs to be fully centralised. At present, only 17% of the specimens in the Swiss natural history collections have been digitised. Coordination of the collections and biobanks would facilitate this process, placing Switzerland among the leaders in this field in Europe.

Recommendation 3a: We recommend the establishment of SwissBioCollection to promote the storage, management and curation of current and future natural history collections and biobanks in Switzerland. SwissBioCollection should be organised as a decentralised network and should incorporate the expertise of multiple institutions.

Recommendation 3b: Physical and virtual access to specimens and to biodiversity and geodiversity information should be unified by generating a Swiss Virtual Natural History Collection. The intention of the Swiss Virtual Natural History Collection is to provide new and efficient means of open and interlinked access. This field of action should build on the harmonisation and digitisation processes developed through existing initiatives, namely the Swiss Natural History Collection Network (SwissCollNet) and the Global Biodiversity Information Facility (GBIF). Moreover, a well-established reference system for taxonomic names, such as the Catalogue of Life, should be applied to link samples and make them accessible to the community at large.

Recommendation 3c: Physical and virtual access to samples stored in biobanks should be unified. This would require the development of harmonised common datasets for specific types of samples and the compilation of a comprehensive catalogue of all biobanked samples in Switzerland. A national coordination platform is already in place with the Swiss Biobanking Platform. However, the envisioned catalogue of samples and associated metadata would require additional decentralised infrastructure and personnel.

Recommendation 3d: Museum collections should be integrated with biobanks to help to harmonise processes and quality standards between collections and biobanks, enabling synergies with biomedical research.

SwissBioSites

Finding 4: Ecosystems provide essential services to society. To understand the value of these services and the ability of ecosystems to provide them, studies on the diversity and functioning of ecosystems, as well as drivers of change in natural and anthropogenic ecosystems, are becoming increasingly important. Pursuing this common goal, researchers in ecology, agriculture and forestry share many common concepts and ask similar questions. However, the communities would benefit from greater connectivity and tighter integration of existing infrastructures to increase the scope, scale and relevance of their research.

Recommendation 4a: We recommend the establishment of SwissBioSites, a network integrating the expertise of multiple fields, including ecology, agriculture and forestry, to extend the scope and scale of ongoing research on ecosystems.

Recommendation 4b: SwissBioSites should encompass a combination of highly instrumented experimental sites established for long-term experimentation and spatially widely distributed permanent plots of land and monitoring sites, covering terrestrial and aquatic ecosystems. This network of dedicated sites would greatly advance research, as it would provide the analytical and statistical power required to address pressing fundamental and applied research questions in ecology, agriculture and forestry. The network should include a central hub to provide expertise and instrumentation for field experiments and analyses and to facilitate maximum synergies within the field of biology and between biology and geosciences.

SwissBioData

Finding 5: The current revolution in biological, nutritional and biomedical research is fuelled by large (-omics) datasets and advanced, integrated analyses of different data types. All areas of society and research are encountering an explosion of digitisation, which has led to the generation of huge amounts of data. These datasets can potentially be used to address fundamental, global research questions. Research infrastructures designed to enable the standardised generation of and access to high-quality datasets represent a major driver for innovation, accelerating both science and associated entrepreneurship. However, current infrastructures are not capable of supporting an integrated data generation and exploitation approach, especially in multi-omics. Indeed, many Swiss researchers do not have access to sufficient support for the analysis of their data, nor to infrastructure that facilitates the combination and analysis of large datasets or that allows federated analyses.

Recommendation 5a: We recommend the establishment of SwissBioData, a scalable and sustainable translational network, building on the expertise within the SIB Swiss Institute for Bioinformatics, as well as the existing -omics platforms and local bioinformatics core facilities.

Recommendation 5b: SwissBioData should enable the creation, sharing, combination, analysis and application of biological data from diverse basic and applied disciplines. This would enable the collection of longitudinal data. In particular, coordinated hardware standards and unified workflows are needed to connect 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 (Findable, Accessible, Interoperable and Reusable) repositories.

Recommendation 5c: The SwissBioData network should be aligned with the goals of SwissBioSites and SwissBioImaging, which would in turn profit considerably from such an overarching, integrative infrastructure in the form of a network that supports individual nodes for -omics data generation and experimentation and that includes a central hub to establish and coordinate workflows and integrate datasets.

SwissBioImaging

Finding 6: New imaging technologies and tools have revolutionised science and society in general, and especially the life sciences and medical research. They facilitate multi-dimensional live monitoring and the measurement of numerous aspects of dynamic biological processes at all relevant scales, ranging from whole communities of organisms down to the three-dimensional structures of proteins, DNA and RNA. These technologies and tools generate multiple types of highly complex biological datasets of unprecedented magnitude. Switzerland is at the forefront in terms of image acquisition technologies. However, the scientific community has only scratched the surface of the full potential of the collected image data, leaving substantial amounts of information unused. This is due to critical limitations on the analysis side, which is still in its infancy. Furthermore, a lack of standardisation prevents the exploitation of image datasets unfamiliar to individual research groups. All of this makes image analysis a highly demanding task that is currently only possible at a small number of laboratories. Consequently, most Swiss researchers are a large step away from comprehensive and internationally competitive image data analysis.

Recommendation 6a: We recommend the establishment of SwissBioImaging, an infrastructure including an institute specialised in the numerous aspects of image data processing and analysis. SwissBioImaging should be attractive to world-class experts, in particular experts on relevant artificial intelligence (AI) technologies.

Recommendation 6b: SwissBioImaging should develop and implement generally applicable high-end analysis solutions and coordinate and distribute efforts, resources and services of life scientists at the national and international level. This would give Swiss life sciences a massive competitive advantage in the worldwide context. Because digital images represent a universal language, this infrastructure has the potential to integrate the needs of other research communities, such as medicine, geography and agriculture, where increasingly complex imaging datasets are being generated and where live images support and optimise human and robotic activities in real time.

Recommendation 6c: Finally, SwissBioImaging should substantially improve current strategic and financial efforts of financing bodies and of Swiss universities and naturally foster innovation and industrial applications.

International infrastructures

Finding 7: Swiss biologists benefit from membership in international networks and organisations, in particular in institutions connecting Swiss biologists with their peers in Europe. Through international organisations, Swiss researchers gain access to key user facilities and platforms to share data and innovative approaches. In order to remain at the forefront of research, Swiss biologists need to be internationally connected in two ways. First, they need to participate in international exchange and collaboration in their specific sub-field. Second, they need access to international initiatives fostering interdisciplinary exchange.

Recommendation 7a: Switzerland should remain a member of the European Molecular Biology Laboratory (EMBL) and the European Molecular Biology Organisation (EMBO), which provide innovative research environments and platforms for molecular biologists, in particular young researchers.

Recommendation 7b: Complementing national initiatives on biological collections, Switzerland should become a full member of the Distributed Systems of Scientific Collections (DiSSCo) as soon as possible. Moreover, Switzerland should maintain its membership in the Global Biodiversity Information Facility (GBIF).

Recommendation 7c: Concerning biobanks, Switzerland presently holds an observer status at the Biobanking and Biomolecular Resource Research Infrastructure (BBMRI) and should become a full member in the near future.

Recommendation 7d: To contribute to pan-European climate monitoring, Switzerland should remain part of the Integrated Carbon Observation System (ICOS).

Recommendation 7e: Switzerland should join efforts to internationally coordinate the investigation of biodiversity and ecosystem functioning through LifeWatch ERIC. Similarly, Switzerland should engage in the coordination of plant phenotyping on the European level through participation in EMPHASIS, a new European Research Infrastructure Consortium that is currently being set up.

Recommendation 7f: Switzerland should remain a member of ELIXIR, the European network for integrating and sustaining bioinformatics resources across its member states. Switzerland should maintain its commitment to and participation in this valuable and unique network.

Recommendation 7g: Switzerland should maintain strong involvement in the Global Biodata Coalition, a forum for research funders to share and coordinate approaches for the efficient management and growth of biodata resources worldwide, where Switzerland is strongly involved through SIB and the State Secretariat for Education, Research and Innovation (SERI).

Recommendation 7i: Switzerland should aspire to full membership in Euro-BioImaging. The proposed national infrastructure SwissBioImaging would provide a distinct, spearheading and internationally visible body that would serve as the Swiss node of Euro-BioImaging and thus provide crucial international cooperation and exchange between Swiss researchers and the European community.

3 Introduction

The present roadmap for future large research infrastructures represents the view of the Swiss scientific community in the field of biology. It is a formal element of the process to elaborate the 'Swiss Roadmap for Research Infrastructures 2023' according to Swiss law (art. 41 Federal Act on the promotion of research and innovation; art. 55 of the corresponding ordinance). The roadmap describes the community needs in terms of national or international research infrastructures for the funding period 2025–2028. It shall serve as an additional basis for the decision-making on new or major upgrades of national infrastructures and/or major participations in international network infrastructures and user facilities.

The responsibility for the elaboration of the 'Swiss Roadmap for Research Infrastructures 2023' rests with the State Secretariat for Education, Research and Innovation (SERI). It has thus launched a process that includes (phase 1) the selection of infrastructures by the ETH Board and swissuniversities, (phase 2) the evaluation by the Swiss National Science Foundation, and (phase 3) the assessment of the feasibility again by the ETH Board and swissuniversities. The result will be submitted to the Federal Council for consideration and decision in the context of the Dispatch on Education, Research and Innovation 2025–2028. This whole process is complemented by a preparatory phase to establish the needs of the various scientific communities. The SERI has formally mandated the Swiss Academy of Sciences (SCNAT) with the elaboration of these discipline-specific community roadmaps to which the present one belongs.

SCNAT has initiated the work to elaborate such discipline-specific community roadmaps in the fields of biology, geosciences, chemistry, and in sub-fields of physics in the last quarter of 2018. Its Board defined a process that provided for an overall strategic project lead and for community-specific sub-projects, all headed by acknowledged researchers. The whole process was modelled in analogy to the long-standing experience of SCNAT in the fields of astronomy and physics, where roadmaps for research infrastructures had been elaborated in earlier years by the various communities, which were assembled for that purpose around a so-called 'Round Table'. Accordingly, starting in 2019, such Round Tables were also established in biology, chemistry and geosciences. In the past two years, hundreds of researchers were invited to take part in this process and dozens of them actively participated in each of the various Round Tables. Whereas this effort was run under the overall responsibility and guidance of SCNAT, including the provision of considerable scientific, editorial and administrative manpower by its office, the final result must be considered a genuine bottom-up contribution by the various scientific communities.

The roadmap at hand expresses a vision for the future development of biological research in Switzerland and the infrastructure needs identified to realise this vision. Representatives of existing large research infrastructures, specialised societies, all Swiss universities and the ETH Domain, covering numerous sub-fields of biology, were invited to participate in the Round Table Biology. In a first phase, 12 sub-groups were formed to collect the views of many experts in specific areas of research. In a second phase, the thus identified needs were consolidated into four concrete proposals (see details in Appendix 1). These proposals were also coordinated with the other community roadmaps, especially the Geosciences Roadmap for Research Infrastructures (ecology) and the Chemistry Roadmap for Research Infrastructures (structural biology). Finally, almost 200 scientists were invited to review the present Biology Roadmap for Research Infrastructures.

4 Purpose and scope of this roadmap

The aim of this roadmap is to identify large infrastructures needed by the Swiss research community, as well as international initiatives that Switzerland should participate in to keep biological research in Switzerland at the forefront of the field. The focus lies on research in biological, ecological and non-clinical biomedical and nutritional research. It was decided at the outset of the elaboration of this document to exclude clinical biomedicine and thus the specific requirements entailed by studies involving human patients. However, there are strong links between the sub-fields covered herein and translational research, including clinical applications, as biomedicine is at the interface of biology, medicine, mathematics and a few other natural sciences. It forms a branch of the medical sciences in which experimental knowledge is applied to clinical practice in human health and diseases. At Swiss academic institutions, as in other countries, biomedicine is commonly integrated into the medical department. Links to biological departments are essential for biomedicine, but play a supplementary role at the institutional level. Importantly, through the existing academic connections, researchers in biomedicine have access to the biological infrastructure, and to guidance in mathematical programming and data analysis. In conclusion, biomedicine relies on evidence-based experimental research and will therefore benefit from the research infrastructures proposed herein through the synergies between different disciplines of health-oriented research.

The technologies and infrastructures of the future consist of networks and facilities that can be used by researchers from multiple fields, addressing a wide range of scientific questions and integrating results from multiple research areas. Because diverse biological systems have fundamental similarities, newly developed technologies will serve a wide range of disciplines within biology and beyond. Researchers are now using tools that enable high-throughput acquisition and the collection of information at all levels of the hierarchy of biological organisation and across all biologically relevant spatial and temporal scales. The development of powerful data capture and analysis tools; the standardisation of working protocols, data documentation and data storage; the efficient exchange of results; and general accessibility of data and specimens are all fundamental in enhancing the value of research output and accelerating further progress in research. New large-scale monitoring systems for ecological sites will make it possible to identify biological interactions and the influence of environmental factors on ecosystems. This new knowledge will help to reduce the impact of human activities on services provided by intact ecosystems and restore ecosystem function.

The roadmap provides detailed descriptions of four national infrastructures that will serve the entire community, encompassing the diverse organisational levels of biology, from single molecules to entire ecosystems. The infrastructures proposed herein will be open to all researchers at Swiss universities, federal institutes of technology and universities of applied sciences, as well as those in the private sector. A general overview of biological research activities in several sub-fields is given in Chapter 8 to highlight the context of the recommended new research infrastructures. However, a comprehensive summary of the research activities in the many fields of excellence in the Swiss life sciences would be beyond the scope of this roadmap.

5 Biology: the study of life

5.1 Biology and its organisational levels

Biology is defined as the study of life, ranging from unicellular organisms to humans. Biological research focuses on the morphology and structure of organisms, their vital processes, their origin, evolution and distribution, their behaviour, and their interactions among themselves and with their environment.

The organisational levels of biology stretch from single molecules and single units, such as DNA, proteins and metabolites, to cells, organisms, populations, communities and complete ecosystems. Studies can be classified according to the organisational levels considered. At the structural and biochemical level, the structure and function of single units (e.g. DNA, RNA, proteins and metabolites) and their context are studied. At the cellular level, the behaviour and the development of cells, tissues and organs as a function of their sub-units are investigated. At the organism level, the whole organism is studied in terms of origin, function, development and behaviour. At the multi-organism level, the composition, diversity and behaviour of groups of organisms is of importance. It includes the study of biological interactions, population biology, evolutionary biology, community ecology and ecosystem ecology. Evolutionary studies focus on the process through which different kinds of living organisms have developed, from the scale of genome and population processes to that of long-term dynamics, driving the transition to the current biota from earlier forms during the history of the Earth. Systematics deals with classifying living organisms, as well as establishing the evolutionary relationships among species. Ecology addresses the relationship of organisms with their biotic and abiotic environment. Conservation biology addresses the protection and renaturation of Earth's biodiversity. The common goals of these last two disciplines are to protect species from excessive rates of extinction and to prevent the erosion of biotic interactions, habitats and ecosystem functioning. From the molecular to ecosystem level, biologists seek to understand the mechanisms and processes that explain the origin, growth, reproduction, structure, morphology, physiology, anatomy, heredity, behaviour, distribution and diversity of life on Earth.

5.2 The history of biology

The origin of life and its diversification and functioning have fascinated humankind throughout history. The oldest records of biological studies (cave paintings, e.g. at Kesselloch (SH) dated at approx. 15,000–11,000 B.C.) point towards the observation of organisms and their classification. Records from the Greco-Roman age reveal a scientific interest in organisms and their parts. Medieval records point towards a focus on morphological investigations of organisms, first by observation and later by dissection. A new organisational level was reached in 1665, when Robert Hooke described cells for the first time. In the 19th century, cells were first suggested to be the fundamental units that all organisms are composed of, a proposition that remains central to cell theory to this day. Two more theories that emerged in the 19th century revolutionised biology: the theory of evolution, proposed by Charles Darwin, and Gregor Mendel's principles of inheritance, which provided the basis for modern genetics. In the 20th and early 21st century, vast progress was made in molecular and structural biology and genetic engineering, with the development of new concepts of cellular function. Moreover, substantial new insights were gained in animal and plant ecology, e.g. by the Swiss botanist Carl Schröter, who introduced the concept of synecology to describe the interactions between species occupying the same geographical area.

5.3 The significance of technology

Appropriate technologies and infrastructures are indispensable for ground-breaking discoveries in biology. Throughout recorded history, the development of new technologies propelled biological research and was often followed by milestones in discovery. The technologies essential for today's research in biology can be roughly divided into three groups: instruments and analytical devices, biotechnologies, and bioinformatics.

Instruments and analytical devices used in biological research often build on scientific discoveries made in other disciplines, namely physics and chemistry. Prominent examples of this group are imaging and spectroscopic devices. Since the discovery of the telescope and microscope, such devices have driven explosions in knowledge gain and opened up new avenues of investigation. The observation of cells, for example, was a revolutionary discovery made possible by the construction of light microscopes. Today, various sub-fields of biology benefit from state-of-the-art instruments used to investigate structures and processes, from the molecular level to complex landscapes, but also to test and measure environmental processes and their relationships with organisms. While some devices, like light microscopes, are accessible in many well-equipped laboratories, biologists continue to use and rely on dedicated, multi-user facilities, such as synchrotrons for X-ray crystallography of sub-cellular components.

The second group, biotechnologies, builds on insights into biological processes. Important milestones in this respect include the elucidation of DNA structure and its replication, the development of the polymerase chain reaction, Sanger sequencing and next-generation sequencing of DNA, and the discovery of the CRISPR/Cas9 complex and its role in DNA processing. These milestones laid the foundation for genetic engineering, which has become absolutely indispensable for modern biological research. Biotechnologies are used to study biological systems, development, evolution and ecology, and they have revolutionised medical diagnostics and treatment. This remarkable impact of biological research and its benefit for humankind is reflected by the numerous Nobel Prizes awarded to ground-breaking discoveries in biology. In fact, since 2000, 13 Nobel Prizes in Chemistry and 16 Noble Prizes in Physiology or Medicine have been awarded to biologists.

The third group, bioinformatics, combines insights into biological systems with computational methods. Initially driven by the exponential increase of sequencing and other -omics data, computational methods have since found their way into just about every field of biology. Bioinformatics facilitates data analysis on all structural levels, from studies on single molecules to investigations of entire ecosystems and the evolution of species. Bioinformatics has progressed from an auxiliary science, applied merely to develop tools for data analysis, to a critical area of research in its own right. Today, complex simulations modelling biological pathways or the functioning of entire cells combine information from numerous sources in unprecedented ways to gain novel insights. Text and data mining of millions of research publications play an increasing role in the discovery of biochemical pathways and help experts predict gene functions. Through the new Swiss copyright law, Switzerland has a research location advantage for text and data mining, which will undoubtedly lead to unprecedented discoveries.

5.4 Environmental and societal challenges ahead

Biological research is driven by the desire to find new solutions to pressing environmental and societal challenges. Most of the current global challenges are summarised by the 'One Health' concept, coined to describe the interconnectedness and interdependence of all living species and the environment. Accordingly, understanding and respecting this interdependence is key to solving the major societal and environmental challenges we face today: climate change, biodiversity loss, sustainable food production, and the health of humans and animals. One Health is advocated by international organisations like the UN, WHO and G20, and is manifested in international agendas like the Sustainable Development Goals, which target the health of humankind and a habitable planet Earth.

Today, major domains of biology are concerned with finding solutions to One Health challenges: fundamental research studies establish fundamental knowledge on the principles of life itself, thus revealing beneficial and detrimental factors to the proliferation of all living beings. Biomedical and nutritional science contribute to the improvement of health and reduction of health risks, including emerging diseases and antibiotic resistance. Research on biodiversity, ecosystems, agriculture, forestry and climate adaptation is concerned with the health of all living beings, and its aim is to provide the scientific foundation for maintaining a sustainable world with functional ecosystems. One of the most pressing challenges today is to reconcile various demands, namely the use of natural resources to produce food, feed and fibre, with the conservation of functional ecosystems. In pursuit of the balanced, sustainable use of resources, researchers in ecology and agriculture need to join forces today.

Research is an essential pillar on which solutions to these challenges must build. No single discipline will be able to comprehend and resolve today's global challenges. Instead, One Health highlights the need to overcome disciplinary borders and move towards interdisciplinary and transdisciplinary research. Today, researchers already integrate many sub-disciplines of biology, as well as physics, chemistry, computer science, engineering and mathematics. Systems approaches are widespread in the analysis of organisms, the interaction between organisms, and their interactions with their abiotic environment. Therefore, future findings in biology are expected to contribute directly to solutions to the large societal and environmental challenges ahead.

6 The current Swiss research landscape and the international context

6.1 Biological research in Switzerland

Switzerland is at the forefront of international research in biology. This status results from the contributions of numerous highly specialised research groups covering a broad range of topics on all organisational levels of biology, which in turn are supported by a continuous significant central investment in research infrastructures, and especially in state-of-the-art instruments. These research groups are generally well connected to their peers at Swiss and foreign institutions. Thus, the research agenda is shaped by the diverse initiatives and research interests within the biology community. The resulting diversity of approaches and topics covered, as well as the extensive expertise of researchers in Switzerland, are advantages of the decentralised organisation of the nation's biological research community.

The lines between the different fields of biology are increasingly difficult to draw and boundaries between fundamental and applied research are fading, especially in translational research. Consequently, interdisciplinary approaches and nationwide coordination are essential. The National Centres of Competence in Research (NCCR) are beneficial platforms for knowledge exchange and research coordination. Multiple NCCRs focus on life science and biomedicine, including the NCCRs Chemical Biology, SYNAPSY, Kidney.CH, TransCure, Molecular Systems Engineering, RNA & Disease, AntiResist and Microbiomes. In a similarly interdisciplinary approach, the aim of the Blue Brain Project at EPFL is to reconstruct the mouse brain digitally in great biological detail and to simulate neuronal processes.

The infrastructures required for biological research depend on the level of biological organisation at which a phenomenon is studied. Determining the structure of biomolecules generally involves highly specialised techniques, such as X-ray diffraction, NMR spectroscopy and cryo-electron microscopy. The highest spatial resolution of the investigated structures can be achieved using high brilliance radiation sources that are available at a limited number of dedicated sites in Switzerland, for instance the Swiss Light Source (SLS) at the Paul Scherrer Institute (PSI). A molecular resolution of biological structures is also achieved by the Swiss Free Electron Laser (SwissFEL) and the Swiss Spallation Neutron Source (SINQ), both at PSI.

At the next higher scale, most of the biochemical, cell biological and developmental biology studies in Switzerland are conducted in well-equipped wet laboratories or centres at research institutions. To meet the ever-increasing demand for imaging-based experimentation, most Swiss universities and research institutions have established advanced imaging facilities equipped with the latest electron and light microscopes, which can be used to perform high-end image acquisition. While these facilities give access to instruments required for data-intensive -omics and imaging research, the capacities and capabilities for comprehensive data analysis present a bottleneck to many research groups. This bottleneck is partially reduced by the SIB Swiss Institute of Bioinformatics, which provides comprehensive bioinformatics services and resources for life scientists and is highly regarded internationally. Furthermore, the Swiss National Supercomputing Centre (CSCS) develops and operates cutting-edge high-performance computing systems as an essential service for Swiss researchers. These computing systems are used by scientists for a diverse range of purposes, from high-resolution simulations to the analysis of complex data.

Research at the organism to multi-organism level depends on animal facilities, permanent plots and biological specimens, such as those stored in biobanks and held in natural history collections. Several existing frameworks are highly important for environmental, ecological and evolutionary studies, including the Global Biodiversity Information Facility (GBIF), InfoSpecies, SwissBOL, SwissFluxNet, the Swiss National Forest Inventory (NFI) and a number of sites for monitoring biodiversity and ecological processes.

While the required instruments depend on the level of biological organisation being studied, all domains of biology have common needs: the skills and infrastructure to organise, share and store datasets and results; the expertise and capacity for data analysis; and procedures to enable the reuse of research data and thus take part in the open science endeavour. A series of developments and prospective initiatives have emerged in response to the challenge of digitalisation in various areas of biological research. For example, the Swiss Biobanking Platform (SBP) coordinates human and non-human biobanks, although it has limited funding compared with initiatives in other countries and cannot maintain biobanking infrastructure or replace underfunded local management of biobanks and their collections. The Swiss Network of Natural History Collections (SwissCollNet), an initiative started in 2019, will foster physical and digital access to natural history collections. BioMedIT, taking place within the framework of the Swiss Personalised Health Network (SPHN), is of high relevance to the biomedical sector and is expected to provide important solutions for the handling of clinical data. Some of the knowledge gained through this initiative could also be useful for future data management in biology. Moreover, artificial intelligence (AI) approaches such as deep learning are becoming widespread in biological investigations, and an Artificial Intelligence Center has recently been opened at ETH Zurich. The Swiss Data Science Center (SDSC), a joint venture between EPFL and ETH Zurich, has the mission to accelerate the use of data science and machine learning techniques within academic disciplines of the ETH Domain, the Swiss academic community at large and the industrial sector. In addition, SIB applies AI approaches in many of its activities.

6.2 International collaboration

Competitive research is not possible without international networking and the ability to attract worldwide attention. Throughout Europe, there is a trend to build networks between hubs equipped with infrastructure and expert staff. Within these networks, nodes are established to share data, common workflows are defined, and researchers have open access to data. In Europe, such international hubs usually have the legal form of European Research Infrastructure Consortia (ERIC), or as initiatives in their preparative phases to become an ERIC. Switzerland, being at the forefront of research in a vast range of disciplines, participates in many of these European initiatives at different levels. Some of the European initiatives achieve goals unattainable for individual states, such as the pan-European monitoring of greenhouse gases through the Integrated Carbon Observation System (ICOS), where Switzerland is a full member.

Swiss participation in these European initiatives is generally seen as highly beneficial for Swiss researchers. Good examples of how Swiss researchers benefit from international networking are the European Molecular Biology Laboratory (EMBL) and the European Molecular Biology Organisation (EMBO), which have been founded and financed with Swiss participation. Together, the two organisations provide an internationally highly visible and attractive hub of excellence in European molecular biology that reflects well on the research in all their member states. The EMBL provides a unique research environment that serves as a magnet for young, innovative scientists. While these young talents help to spread the newest technology and innovation to member states, they also often stimulate new technology developments themselves. Consequently, such technology is optimally and efficiently disseminated into all molecular biology laboratories of the member states. The EMBO fosters research in Europe in two main ways. First, it provides platforms for international information exchange (e.g. meetings) that attract the world research elite. Second, it offers fellowships that fund the most promising young researchers at an early stage and encourage their long-term involvement in the European research community. Organisations like EMBL and EMBO also spearhead, coordinate and contribute to important international research infrastructures (e.g. ELIXIR and Euro-BioImaging).

Concerning data management, Switzerland supported the establishment of a European network called ELIXIR. ELIXIR unites Europe's leading life science organisations in managing and safeguarding the increasing volume of data that is generated by publicly funded research. The network coordinates, integrates and sustains bioinformatics resources across its member states. Furthermore, it enables users in academia and industry to access services that are vital for their research. SIB is the Swiss node of ELIXIR and the largest national node in the network. Many SIB members play a very active role in ELIXIR and participate in the activities coordinated by the ELIXIR platforms and through the different ELIXIR Communities. For example, the ELIXIR Food & Nutrition Community, which is currently being established, will catalyse the transition of classical nutritional research to -omics-based nutrigenomics research. In this context, ELIXIR-Switzerland, i.e. SIB, will play a key role in supporting the development of the Swiss nutritional research community. Switzerland, through SIB and SERI, is also strongly involved in the establishment of the Global Biodata Coalition (GBC). The goal of GBC is to stabilise and ensure sustainable financial support for the global biodata infrastructure. In particular, its aim is to identify – for prioritised long-term support – a set of global core data resources that are crucial for sustaining the broader biodata infrastructure.

Some international research organisations provide their member states with access to state-of-the-art user facilities that are essential for certain sub-fields of biology. For structural determination, for instance, Swiss researchers have access to the European Synchrotron Radiation Facility (ESRF) in Grenoble, including the Swiss-Norwegian Beamlines (SNBL), and to beamlines at the Deutsche Elektronen Synchrotron (DESY) in Hamburg. These facilities complement the Swiss facilities at PSI. As detailed below, the Swiss research community demonstrates a keen interest in the participation in further organisations.

7 Vision for the future

Societal and environmental challenges have driven scientific inquiries in the past and will continue to do so in the future. The general public expects academic research to contribute to rapid solutions for societal and environmental issues, such as contamination, the biodiversity crisis, climate change, antimicrobial resistance and emerging diseases, as recently seen in the contexts of pesticide contamination in agriculture and the SARS-CoV-2 outbreak. In addition, stakeholders, including patients, consumers and farmers, want to be able to access research results to improve productivity and health.

The complexity of these challenges is likely to reinforce the trend towards interdisciplinary research within different fields of biology and in synergy with other disciplines, especially medicine, chemistry and geosciences. In biomedicine, the lines between basic research, translational research and diagnostic/clinical practices have become very difficult to draw, especially in disciplines like oncology, rare diseases and infectiology. Similarly, in systems biology the boundaries between genomes, proteomes and metabolomes have dissolved in efforts to understand organismal processes and identify important modulators of key biological processes. Moreover, the provision of ecosystem services and mitigation of global climate change effects can only be realised if the interaction of natural and managed ecosystems with environmental conditions can be addressed.

Across all organisational levels the most apparent challenge is the effective use of data through comprehensive analysis. To confront this challenge, increased national and international coordination is absolutely key. Such coordination would clearly make research more efficient and open up new research opportunities and fruitful collaborations for individual research groups. In particular, coordination with regard to the storage and open accessibility of biological samples and data, as well as standardised workflows for data acquisition, processing and comprehensive analysis, would be beneficial to researchers in all fields of biology.

New infrastructures for biological research should facilitate interdisciplinary approaches and capitalise on the broad expertise of the Swiss research community. This need is met more adequately by (inter)national multi-nodal networks rather than single-site core facilities. Owing to digital technologies, network infrastructures can facilitate access to biological samples, research data and expert knowledge. Accessible, interoperable data, as well as shared methods and knowledge on data analysis, have been identified as common needs and essential requirements to propel biological research in Switzerland. High-throughput technologies, cloud computing and big data analytics will continue to dramatically accelerate discovery.

Technical progress cannot be accomplished without accompanying policy changes fostering open data. Critical to the success of any data network are changes to governance and policies that impede data sharing and data contributions from the public, research and clinical communities. It is essential to build easy ways for researchers and citizens to contribute their data, whether directly or through a third party.

Moreover, artificial intelligence (AI) approaches such as deep learning have enormous potential in biological and biomedical research. Machine learning, and other types of AI, need clean, structured, unbiased, high-quality training data to function, as well as appropriate ontologies. Expert curation is essential for all these aims. Therefore, it goes without saying that the development and implementation of AI will best thrive when embedded in the relevant research environments, close to and fuelled by the scientific applications it serves.

The strength of AI lies in recognising patterns in data that humans would not detect. AI approaches have proven to be extremely adept in fields such as image analysis and protein structure prediction for two main reasons: first, there are strong correlations between individual data points (like pixels in an image or physical interactions between residues); and second, there are vast amounts of annotated training data for these applications (annotated images and experimental protein structures and homologous sequences). It is yet to be seen whether AI approaches such as deep learning will have a similarly transformative effect on other areas of biological research.

8 Development of national infrastructures and Swiss participation in international organisations (2025–2028)

Swiss researchers continuously push the frontier of knowledge in all fields of biology, using and relying on high-quality equipment and infrastructure. Consequently, access to state-of-the-art infrastructure on the national and international level are key to maintaining the high level of excellence in Swiss biological research. The purpose of the present roadmap is to propose infrastructures that will serve broad groups of researchers from various fields of biology and related sciences. During the 18-month consultation process leading to the present roadmap, four complementary national infrastructures for research in biology were identified: SwissBioCollection is focused on building the technical infrastructure needed for the management, curation and digitisation of natural history collections and biobanks holding specimens that form the basis for high-quality research in many fields of biology. SwissBioSites involves the establishment of a network of experimental sites to study and monitor natural and anthropogenic drivers of change in ecosystems. SwissBioData is focused on facilitating the sharing, combination, analysis and standardisation of data from various sources and fields of biology, in particular -omics data. SwissBioImaging is dedicated to bioimaging, which poses specific challenges in terms of unprecedented volumes of data, data richness and the lack of efficient, accessible tools for image analysis.

Common to all four infrastructures is the challenge of comprehensive data exploitation, which often constitutes a limiting bottleneck. Coordination between research groups is required regarding standardised workflows to produce interoperable experimental datasets, consistent data processing, and efficient, sufficiently specialised tools for data analysis. Ideally, the configuration and setup of instrumentation should go hand-in-hand with the development of data analysis procedures that match both data acquisition schemes and data exploitation goals. Coordinated data management should lead to interoperable research datasets while still respecting the specific requirements of the numerous specialised sub-fields of biology. Therefore, in spite of the presence of somewhat related challenges in several fields of biology, four separate, dedicated network infrastructures are proposed to keep Switzerland at the forefront of international research in biology.

Moreover, membership and participation in several international research organisations and initiatives is recommended. A non-exhaustive list summarising these initiatives is given in Appendix 2.

8.1 SwissBioCollection: biobanks and natural history collections

8.1.1 Repositories of past, present and future scientific knowledge

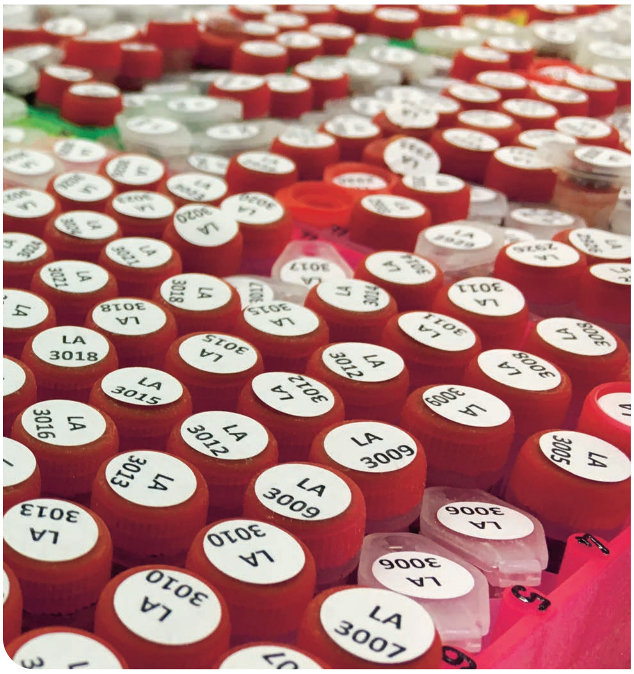
Specimens of entire or fragmented organisms, organs, cells, single units and molecules are regularly used for scientific investigations in the biological and medical fields, whereas in geosciences studies are performed on specimens of rocks, minerals, fossils, soils and sediments. These specimens, generally curated in natural history collections, contain the accurate and persistent information required to understand and manage natural systems. Specimens also offer a window into the past, making it possible to trace changes and patterns in ecology and evolution back in time, thus providing base-line data for robust science-based decisions in the future. Additionally, samples such as organs, tissues, cell cultures, blood, DNA, RNA, proteins, seeds and embryos are frequently stored in biobanks of research institutions and hospitals. Processing and storing these samples often requires precisely defined and standardised conditions to ensure that the samples can be productively utilised for specific research experiments.

Collected organisms may represent taxa that are new to science or additional samples of known species, which provide information on natural variability. They also encapsulate several layers of metadata and carry a large potential for associated studies on pathogens, macromolecules and metabolic compounds. Consequently, they are gaining importance in various areas of research, including biology, biotechnology, environmental and agricultural studies, and medical and veterinary sciences. They are crucial for answering fundamental scientific questions about ecological, evolutionary and geological processes. Data derived from Swiss and European natural history collections underpin countless discoveries and innovations, including scholarly publications and official reports that support legislative and regulatory processes on land use, societal infrastructure, health, food security, biodiversity loss, sustainability and environmental change. Natural history collections are also at the heart of databases, maps and descriptions of scientific objects and observations, and they are a resource for education and knowledge dissemination to the general public.

Biological material stored in biobanks and the corresponding data are considered the essential raw material for the advancement of many fields, such as evolutionary research, genetics, biochemistry, microbiology and precision medicine. Biobanks facilitate the reception, registration, processing, storage and shipping of potentially sensitive and valuable specimens to researchers for use in diverse scientific experiments. Biobanking practice has greatly evolved over the last years, from the individual collection of biological material towards professional infrastructures addressing technical, ethical, legal and quality issues, as well as access and benefit-sharing policies. However, more complex samples, such as soil and microbiota samples, are also coming into the focus, requiring very different types of infrastructure, knowledge and quality elements.

Despite its small size, Switzerland holds over 60 million specimens in its natural history collections, assembled over the last two centuries, and more than 10 million non-human specimens in biobanks. Swiss natural history collections and biobanks are therefore a pivotal infrastructure for meeting the most important challenge the global community will face over the next decades: mapping a sustainable and healthy future and supporting the natural systems upon which we depend.

In contrast to the situation in many non-federal countries, Swiss natural history collections and biobanks are not concentrated in a national institution but are decentralised and located across the cantons. Natural history collections are stored, curated and managed in museums, botanical gardens, zoos, universities and institutions of the ETH Domain. Similarly, biobanks are curated at multiple institutions, mainly at the research group level in universities and other public and private research institutions.



Dog blood samples intended for genetic research (photo Vetsuisse Biobank, University of Bern)

Collection of snail (ex coll. Shuttleworth) shells at the Natural History Museum in Bern (photo Estée Bochud)

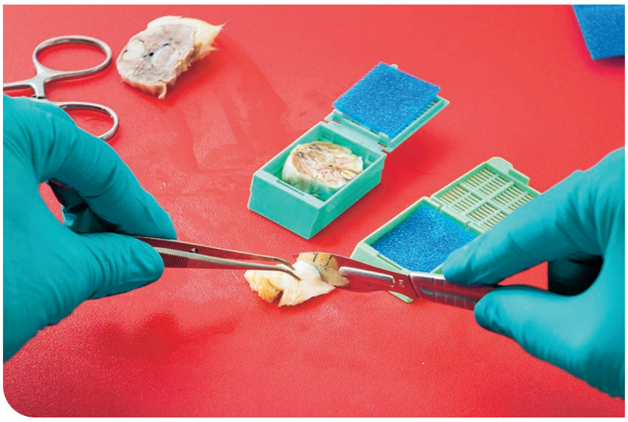
Despite the pivotal function of biological and geological specimens for current and future research, Switzerland is far behind in making these specimens available to the international scientific community and will need to invest substantial funds in this area in the coming years in order to keep up with international scientific developments. Currently, only a small percentage (17%) of specimens in natural history collections held in Switzerland are digitally available, and some collections require re-determination according to modern taxonomic concepts. Acknowledging the scientific potential of natural history collections, the Swiss Academy of Sciences – together with a group of experts – has identified measures to valorise natural history collections and to make them accessible for research. Furthermore, the Academies of Arts and Sciences have proposed the establishment of a national research infrastructure, the Swiss Natural History Collection Network (SwissCollNet), for the planning period 2021–2024. Likewise, SwissCollNet, in close collaboration with the Swiss institutions hosting collections, is currently elaborating a National Natural History Collections Strategy for 2021–2031, resulting from extensive roundtable discussions in the framework of the current Biology Roadmap.

Digitisation room set up in the frame of an international initiative aiming to digitise all type specimens stored in worldwide herbaria (photo Conservatory and Botanic Gardens of Geneva)

In the European Union, the importance of digital unification of natural science assets was recognised through the creation of the Distributed System of Scientific Collections (DiSSCo) in 2018. This initiative is part of the European Strategy Forum on Research Infrastructures (ESFRI) roadmap and is currently being established between partner nations and participating institutions. Swiss scientists have been involved in designing data policies and, together with Zenodo, exploring ways to store the vast number of digital copies of specimens for DiSSCo repositories. Switzerland has not yet joined DiSSCo, although single experts are actively participating in its development through other professional channels, such as membership in the Consortium of European Taxonomic Facilities (CETAF), with the aim that Switzerland will join DiSSCo in the near future. BiCIKL, a new EU-funded research infrastructure based on ELIXIR, DiSSCo, Biodiversity Literature Repository and Catalogue of Life, will help to link -omics, specimen and literature-based data, and it will provide tools to enhance access across these domains.

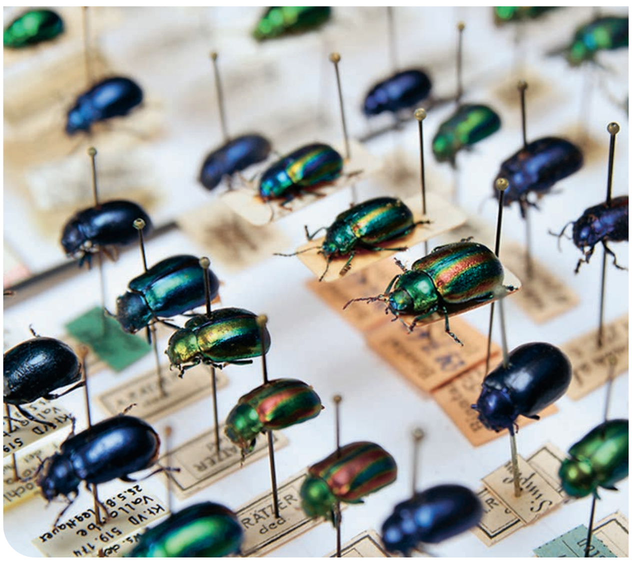
Biobanking activities in Switzerland support a broad spectrum of research disciplines, ranging from purely medical research in hospitals to clearly biologically motivated initiatives. As an example of the latter, the Swiss Barcode of Life (SwissBOL) is an initiative to inventory genetic data on Swiss biodiversity, built on a network of specialists and institutions and supported by the Federal Office for the Environment (FOEN). Some Swiss biobanks are situated at the interface of biology and medicine. For instance, microbial culture collections are of growing importance in the context of microbiome and biodiversity research, as reflected in international efforts like the global Microbiota Vault initiative, which includes plans for biobanking in Switzerland. Human and non-human biobanking in Switzerland is coordinated by the Swiss Biobanking Platform (SBP), an initiative of the Swiss National Science Foundation (SNSF), which responds to the increasing needs of biomedical researchers in terms of quality, access, transparency and interconnectedness of biobanks and associated data. SBP centralises information on human and non-human biobanks, each established to address specific scientific questions, and ensures broad access to these biobanks for research purposes. It is building a register of biobanks in Switzerland, which currently comprises predominantly medically oriented human biobanks. SBP provides technical know-how and support for biobanking and IT management, provides counselling on legal and ethical aspects, and helps to ensure high quality and interoperability in biobanking. However, many existing biobanks, especially those outside the purely medical field, still operate with heterogeneous processes and are not registered, or even recognised by the scientific community in some cases, making it difficult for researchers to access their samples.

At the international level, a European initiative called the Biobanking and Biomolecular Resources Research Infrastructure (BBMRI-ERIC) is in place to bring together all main players in the biobanking field, with the aim of developing a pan-European distributed research infrastructure in order to facilitate access to high-quality (biological) resources and facilities for biomolecular and biomedical research purposes. Switzerland holds an observer status at BBMRI and is represented by SBP as the Swiss national node. SBP ensures the harmonisation of biobanking practices with international and EU standards and provides the Swiss research community with information on biobanking networks abroad and international biobanking-related activities.



Trimming of formalin-fixed animal tissues for long-term preservation using paraffin-embedding (photo Conrad von Schubert)

The importance of natural history collections and biobanks is expected to increase dramatically in the future. Novel methods will make natural history collections even more available and valuable for cutting-edge scientific research (e.g. DNA analyses of historical specimens). High-quality digitising technologies are becoming available for small specimens (insects), and mass digitising technologies are available to digitise entire collections with millions of specimens. Given the decentralised organisation of natural history collections, there is an urgent need to build a Swiss Virtual Natural History Collection that connects decentralised collections, provides open access to all digitally available information across the Swiss collections, and links Swiss natural history collections in a European and international context. In addition, countries at the forefront of biological research must have high-quality biobanks with well documented specimens that require storage conditions other than those available in natural history collections. An intense exchange of knowledge in different fields of biobanking will ultimately benefit the entire Swiss research landscape. Major effort will be required to internationally harmonise biobanking standards and to facilitate new accessions with modern research foci and the exchange of samples and data. The breadth of biobanking requires a carefully coordinated funding policy to adequately support Swiss scientists from different disciplines, ranging from fundamental science to, for instance, clinical medicine. While clinical biobanks are currently evolving quickly, comparable support and infrastructures for non-human biobanking are currently lacking. In publishing future research results, scientists should follow best practice, including publishing data following FAIR (Findable, Accessible, Interoperable and Reusable) standards and indicating taxonomic names and accession or specimen codes linked with persistent identifiers. Switzerland should make use of the expertise in scholarly publishing provided through the BiCIKL consortium and, based on this expertise, play an important part in this development.



Collection of leaf beetles held at the Naturmuseum Solothurn (photo Nicole Hänni, Naturmuseum Solothurn)

8.1.2 Proposed developments

Today, it is considered vital to provide and ensure access to all specimens and associated metadata in natural history collections and biobanks and to follow standardised conservation and archiving policies. Furthermore, genetic and other metadata associated with physical specimens should be valorised. The curation of physical specimens as a potential source of genetic data is of particular importance for research on evolution and the temporal development of biodiversity. Despite the efforts of the Swiss node of the Global Biodiversity Information Facility (GBIF) to synthesise all data and metadata from natural history collections, we are still facing a situation in which the existing samples are generally managed individually by the host institutions, in a systematic or project-oriented manner.

With the SwissBioCollection initiative, Switzerland will build an infrastructure that will serve the needs of SwissCollNet, InfoSpecies and GBIF, but also SBP and important non-human biobanks that are required for biological, biotechnological, environmental, agricultural and veterinary research. It will be constructed as a decentralised Swiss infrastructure. Facilities holding collections will be required to follow common technical standards and the system will evolve into one integrated and highly interconnected national infrastructure. Through this process, the collections will become more efficient in terms of sample management and storage, as well as access to published data about samples, which in turn will facilitate rapid responses to requests for access to samples for scientific research. These standards for natural history collections will be in accordance with the recommendations of DiSSCo, the global Biodiversity Data Standards Group (TWDG) and GBIF. Similarly, the standardisation of medically oriented and non-human biodiversity biobanks will follow the recommendations of BBMRI and the Global Genome Biodiversity Network (GGBN), respectively. Interactions with BBMRI will be handled via the national node SBP, to ensure coordination with clinical biobanking and to avoid redundancies. Furthermore, the preservation of genetic samples should be in agreement with the strategy of initiatives like GGBN and SwissBOL, which aim to ensure the continuity of the genetic referencing of species in Switzerland as part of national biodiversity monitoring programmes. The Earth Biogenome Project and its European node, the European Reference Genome Atlas (ERGA), plan to generate reference genome sequences of all eukaryotic species on the planet. SwissBioCollection will form an essential prerequisite to reach these visionary goals.

In summary, SwissBioCollection will:
- Promote the storage, management and curation of historical, recent and future samples and specimens within natural history collections and biobanks in Switzerland. To achieve this goal, sustainable funding will be required for physical infrastructures, such as storage facilities and automated devices for specimen or sample intake, processing, retrieval and distribution.
- Enable and unify physical and digital access to specimens and to biodiversity and geodiversity information. To this end, specimen information will need to be digitised, mobilised and published, following the standards used by the GBIF.
- Provide new, linked and open access to data associated with collections in a Swiss Virtual Natural History Collection of biological and geodiversity specimens, as part of a decentralised research infrastructure for Swiss natural history collections and non-human biobanks, as well as access to unpublished data and data liberated from scientific publications.
- Follow open science policy to publish research results in a format that includes specific annotations to include and link the data with the specimens in the collections or biobanks (FAIR data).
- Promote the scientific and educational use of Swiss natural history collections and biobanks nationally and internationally, and encourage the training needed for the array of taxonomic, systematic and technical jobs related to natural history collections and biobanks.

Imaging station to digitise entomological collections at ETH Zurich (photo Pierre Kellenberger, ETH Bibliothek)

Collection of animal tissue slides for morphologic microscopic analyses (photo Conrad von Schubert)

Collection of vertebrate skeletons at the Natural History Museum in Fribourg (photo michaelmaillard.com)

– Integrate Swiss natural history collections and biobanks into international efforts to mobilise biodiversity and geodiversity data in a coordinated way, with the aim to benefit Swiss research and international collaborations. To reach this goal, it is important that Switzerland develops strong national nodes within the European initiatives DiSSCo, BBMRI and GGBN.

Effectively, the creation of a nationally recognised, distributed infrastructure for natural history collections and biobanks will promote the unification of all Swiss natural science assets under common policies and practices that aim to make the data openly available to scientists in accordance with the FAIR open data policies. The transformation of the currently fragmented and heterogeneous landscape of the crucial natural history collections and biobanks in Switzerland into a coordinated research infrastructure will facilitate scientific excellence by providing interconnected empirical evidence on the natural world. This in turn will open up the Swiss natural history collections and biobanks, and their associated data, to scientists both nationally and internationally, facilitating Swiss participation in sister-initiatives in Europe that have already recognised the importance of these biological archives for science.

Knowledge stored in and gained from natural history collections and biobanks will benefit the public sector and private industry in many ways. Ecosystem management, agriculture, sustainable development, biodiversity conservation, disease control and environmental monitoring, but also medical applications, civil engineering and many other fields profit from these biological archives. For example, research based on biobanks is done in close collaboration with Swiss breeding organisations. In general, samples and data are exchanged between industry and academic researchers. Georeferenced biodiversity and geodiversity data play a pivotal role in applied research and in administration at the federal, cantonal and municipal levels. It informs politics and public administration, i.e. the Federal Office for Agriculture (FOAG), the Federal Office for the Environment (FOEN) and the Federal Food Safety and Veterinary Office (FSVO). Research enabled by high-quality biobanking supports almost all global Sustainable Development Goals (SDGs 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 17).

In addition, Swiss institutions hosting natural history collections are strongly involved in education within the ETH Domain and at universities and universities of applied sciences. Swiss museums, botanical gardens and zoos host exhibitions, offering a supporting framework for the broader society and for courses in organismic biology at universities. Biobanking of samples from privately owned domestic animals enables and encourages a strong element of citizen science. The involvement of motivated breeders and owners and the utilisation of experience-based knowledge is an integral part of this kind of research.

8.2 SwissBioSites

8.2.1 Long-term and large-scale investigations of natural and managed ecosystems

Dedicated sites for research and sampling serve as starting points for biological research endeavours, especially in the fields of ecology, agriculture and forestry. The global scope of modern research in these fields and of many of the toughest challenges we face today necessitates knowledge of patterns and processes at large spatial and temporal scales. Nonetheless, most research activities are still undertaken at small spatial scales and in short-term projects, which are scattered among institutions, departments and individual researchers. In recent decades there were some efforts to undertake large-scale and long-term research in these fields, and it was realised that such research requires adequate infrastructures.

Currently, there are essentially two types of infrastructure relevant to these fields. On the one hand, there are infrastructures that were established as systems of permanent plots, used in comparative studies of differences between ecosystems, e.g. between managed and unmanaged forests, between differently managed agricultural fields, between different types of grasslands, or between nature reserves and unprotected land. On the other hand, there are infrastructures that were established as larger-scale and longer-term experiments, e.g. agricultural trials of different crop varieties or management methods, research afforestation, and experiments addressing effects of environmental or biotic manipulation on biodiversity and ecosystem processes. The commonality between all of these infrastructures is that the biological parameters of organisms, populations and communities are measured. Depending on the research question, this involves analysis of the ecophysiology and phenotype of organisms, the interactions between organisms, or various aspects of biodiversity and ecosystem function. The overlapping interest consists of: (a) addressing the drivers and consequences of changes in terrestrial and aquatic ecosystems, including effects of climate change; and (b) providing recommendations on ways to manage, renature or protect ecosystems in the most sustainable manner. Methodologically, these infrastructures involve analyses of the genome, transcriptome, metabolome, proteome and phenome of organisms, together with measures of the composition, diversity and performance of populations, communities and ecosystems, and measures of multiple environmental covariates (e.g. temperature, soil moisture and pollutants). The nature of these analyses leads to strong synergies through in-depth cooperation with the field of geosciences and with the infrastructure SwissBioCollection. Specific equipment used in analytical chemistry and gas exchange analysis, phenotyping devices such as cameras and unmanned aerial vehicles, and environmental sensors are all used on site and are provided and managed by the individual institutions operating the experiments. The current manifold activities and infrastructures, with their specific research questions and designs, need to be continued. Beyond that,

Unmanned aerial vehicle carrying colour and thermography cameras to assess height and temperature of wheat breeding plots (photo Norbert Kirchgessner, ETH Zurich)

A flowering meadow in Engadin, Switzerland (photo Gabriela Brändle, Agroscope)

however, they need to be extended and complemented to enable the comprehensive synergies and interdisciplinary networking needed to address many advanced questions. This requires access to experimental sites and permanent plots and to state-of-the-art methods and central support staff experienced in the multiple facets of experimentation, from experimental design, to comparative observation, to data analysis and interpretation. It also requires 'nudging' (motivating, incentivising) to encourage collaborations between researchers from different communities, such as ecology, forestry, and livestock and plant breeding. Close coordination of such efforts with work undertaken in the infrastructures SwissBioData and SwissBioImaging is required as well. Nonetheless, the specific challenges of data collection and monitoring in the field demand an independent SwissBioSites infrastructure serving the needs of multiple large research communities.

For research in biodiversity and ecology, the Swiss FluxNet is among the most important infrastructures in Switzerland. The Swiss FluxNet comprises seven long-term ecosystem sites coordinated by ETH Zurich, where the exchange of CO_2 and H_2O (partly also N_2O and CH_4) between vegetation (grassland, crops, forests) and the atmosphere is analysed via eddy-covariance flux measurements. Physiological parameters of the vegetation are also measured at some sites (e.g. phenology, sap flow and biomass). One of the Swiss FluxNet sites, situated in Davos, is embedded in the European Integrated Carbon Observation System (ICOS) network of such installations. Here, further partners monitor meteorology and multiple forest-related parameters, such as tree diameter, leaf area index and biomass.

These last parameters in particular make ICOS and the Swiss FluxNet an important asset for forestry in Switzerland. The current state and changes to the Swiss forest are recorded in the Swiss National Forest Inventory (NFI). The NFI contains data obtained through a systematic sampling inventory and enquiries at the local forest services. The NFI is compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) in collaboration with the Forest Division of the Federal Office for the Environment (FOEN). Moreover, WSL conducts Long-term Forest Ecosystem Research (LWF) to examine the effects of air pollution and climate change on forests, bridging the fields of biology and geosciences.

Other biodiversity and ecology monitoring sites with infrastructure in place include Calanda (University of Basel, University of Zurich, ETH Zurich), Lavey (Universities of Lausanne and Neuchâtel), a permanent plot network conserving historical data on permanent plots (University of Lausanne), Rechalp (University of Lausanne, ETH Zurich), AlpFor (University of Basel), Schynige Platte (University of Bern) and long-term forest sites (WSL). Monitoring without specific infrastructure is done by various universities and local research networks in sites such as the Alpine Biology Centre and the Swiss National Park, but also in the context of the Swiss Biodiversity Monitoring programme driven by the FOEN (involving InfoSpecies, Agroscope and others). Other important national structures are, for instance, the Swiss Soil Monitoring Network (NABO) and the Blue-Green Biodiversity (BGB) research initiative of WSL and Eawag.

For agricultural research, Agroscope, the Swiss centre of excellence for agricultural research, operates multiple long-term experimental sites for various grassland systems and for arable and horticultural crops located throughout the country. Nutrient management, plant protection, variety testing and the registration of physiological crop parameters and of yield are done in parallel to agro-meteorological observations, modelling and breeding activities. At the DOK site in Therwil, Agroscope – together with the Research Institute of Organic Agriculture (FiBL) – has performed a comparison between different arable crop management systems (e.g. organic versus conventional) since 1978. In addition, Agroscope runs Protected Site, a national research infrastructure to conduct field trials with genetically modified plants (GMPs). This highly regulated experimental research site makes it possible to investigate the benefits and risks of GMPs and how these plants behave in the environment in the long term.

Crop performance is also studied within the framework of the field phenotyping platform of ETH Zurich, which has been in operation since 2015 to develop imaging-based monitoring methods. Parameters of soil, meteorology and crop physiology have been monitored, and RGB, multi-spectral and thermal imaging procedures have been developed that are partly operated from drones and now used in other sites as well.

In conclusion, Swiss universities, as well as federal and cantonal research institutions, have established a variety of separate comparative and experimental facilities to address causes and consequences of changes in natural and managed ecosystems. Many of these facilities are maintained and used by several research groups and institutions. Nonetheless, the existing infrastructures are scattered and limited in scope, scale and observable time period. Nationwide coordination and streamlining would advance research in biodiversity, ecology, agriculture and forestry tremendously.

The existing Swiss infrastructures and research approaches are also well aligned with international approaches, such as EMPHASIS and LifeWatch ERIC. EMPHASIS is an ESFRI-listed European project that enables researchers to use facilities, resources and services for plant phenotyping across Europe. Switzerland recently signed a letter of intent to support further joint activities, such as creating a joint legal entity. This will mainly facilitate joint agricultural experiments, but also the creation of jointly used

Eddy Flux tower on the experimental site Chamau of ETH Zurich (photo Group of Grasland Sciences, ETH Zurich)

Rapeseed field and field phenotyping station of ETH plant research station in Lindau-Eschikon (photo Urs Brändle, ETH Zurich)

data standards and measurement protocols and intense exchange of ideas and researchers. A further refinement of the Swiss facilities for agricultural research, embedded in the SwissBioSites infrastructure, would strengthen the role of Switzerland in this development. LifeWatch ERIC is a European Infrastructure Consortium providing e-science research facilities to scientists seeking to deepen the understanding of biodiversity organisation and ecosystem functions and services in order to support civil society in addressing key planetary challenges. LifeWatch ERIC was established as a European Research Infrastructure Consortium by the European Commission Implementing Decision (EU) 2017/499 of 17 March 2017.

Internationally, the call for integrated research and research infrastructures has become more prominent. Switzerland, with its large geographical, biological and cultural diversity at a small geographic scale, with its rich agricultural and forestry tradition, and with its high density of excellent institutions and researchers, is in an outstanding position to become a model case for an integrated network of biology-oriented infrastructures. The planned infrastructures will complement national earth science infrastructures, as well as international networks of biology-oriented infrastructures.

8.2.1 Proposed developments

The full potential of research in biodiversity, ecology, agriculture and forestry to address fundamental, as well as global change-related and sustainability-related questions can only be realised if organisms, their communities and the interaction of natural and managed ecosystems with the environment are considered together. This requires interwoven research communities that take the interaction between natural and managed ecosystems into account. Switzerland, as a densely-populated country with natural and managed ecosystems of a widely varying nature located in close proximity to each other and with an excellent research and educational landscape, is an ideal model laboratory for the world. Due to its topology and vast number of natural water bodies, Switzerland can serve as a model to study both terrestrial as well as aquatic ecosystems. The purpose of such a laboratory is to determine ways to effectively conserve and restore biodiversity in the interest of human well-being, while at the same time allowing the use of natural resources in an efficient and sustainable manner. In addition, plots monitored over long periods, especially in terrestrial and aquatic natural sites, could become focal sites for discovering yet unknown biodiversity, especially in biota such as nematodes, arthropods, protists and prokaryotes. These might encompass genes or lineages that are only found in Switzerland. Once described (e.g. through the network of natural history collections) and studied (e.g. with field and laboratory phenotyping, as well as genome analysis methods), an overall framework could be developed in terms of the exploitation of genetic resources and conservation. This shows how SwissBioSites forms an important bridge between the infrastructures SwissBioCollection, SwissBioData and SwissBioImaging.

Therefore, a shared nationwide infrastructure of permanent plots, long-term experiments, and data acquisition and management is to be established to support lasting nationwide functional biodiversity and ecosystem research and to link environmental observations to socio-economic information on drivers and consequences of change. The currently existing infrastructure needs to be complemented by a central hub and by a permanent plot system to improve synergies. Moreover, this infrastructure will be aligned with the proposed infrastructure in integrated geosciences.

The central hub of SwissBioSites, which will be located at one of the existing sites, will facilitate experiments in the interest of all related scientific communities. There, ecologists, agricultural scientists and researchers from related disciplines will collaborate experimentally. Their mission will be to stimulate all related research fields by strengthening networking in the biology community and by providing advice as to which new experiments and biodiversity monitoring campaigns should be set up. These researchers will need to have an excellent overview of the Swiss and international research landscape, and they will require access to state-of-the-art research infrastructures, such as analytical, physiological and remote-sensing devices.

This central hub will be the prime location for specialised environmental data analysis and processing. These aspects of research come with their own intrinsic challenges, as the complexities of the environment as a system mean that multiple organisms and environmental covariates need to be considered in analysis. The hub should provide analytical devices (to process samples taken from different sites, e.g. for genome and metabolome analyses) and imaging devices (mobile platforms, such as drones, equipped with state-of-the art sensors and cameras) and, most importantly, should employ well-trained staff who can operate these installations and who can teach students and Swiss researchers how to operate similar devices on their sites. In addition, data scientists, algorithms and hardware will be required at the hub to analyse and model environmental and organismic data from the genomic level (bioinformatics) to the ecosystem level. Analyses will need to include deep-learning routines to elucidate the presence, performance and effect of organisms, as well as species composition and abundance in natural and managed ecosystems. By fulfilling these functions, the central facility will be a globally unique hub for experimental and data science that provides a suite of services in ecology, agriculture and forestry.

The sites of this highly instrumented hub will be complemented by a network of research plots and facilities distributed across the country, which together represent the full diversity of natural and managed terrestrial and aquatic ecosystems in Switzerland. This plot network will make it possible to quantify the drivers of change (e.g. in land use and climate) and the diversity and performance of populations, communities and ecosystems, and to assess the services these ecosystems provide to humans. Moreover, the research plot network and the sites of the central hub will serve as the interface to efforts in integrated geosciences, complementing the infrastructures proposed in the Geoscience Roadmap. Geo-referenced information obtained through SwissBioSites will be linked with geo-referenced information from remote sensing, climate measurements and models, as well as with species and habitat information provided through SwissBioCollection. Further geographic and socio-economic information (e.g. on policies, regulations, and economic and social incentives) provided by cantonal or federal offices will be considered as covariates in analyses in order to draw comprehensive conclusions on further effects of global change and to help inform decision-makers on sustainability options. This will result in a data reservoir with enormous power to model drivers and scenarios of change in multiple domains, while also opening the door for further collaborations with the basic research efforts to be performed through the SwissBioData and SwissBioImaging infrastructures.

Relationships between research and the private business sector are well developed in agriculture and forestry. Based on these relationships and on the integrative design of SwissBioSites, research conducted within the framework of this infrastructure will undoubtedly benefit society by enhancing sustainability, biodiversity and ecosystem services for society at large. SwissBioSites will provide new opportunities for integrated education at all levels and for all relevant Swiss institutions. Furthermore, the causes and consequences of changes in natural and managed ecosystems are highly societally relevant in the context of the global Sustainable Development Goals, the Swiss Biodiversity Strategy and related cantonal strategies.

Internationally, SwissBioSites will guarantee the prominent role of Switzerland in existing networks for biodiversity monitoring and environmental, agricultural and forestry research. Networks, projects and activities, such as ICOS, EMPHASIS and LifeWatch ERIC, will profit enormously from SwissBioSites, further promoting the leading role of Swiss biological research in the international context.

8.3 SwissBioData

8.3.1 Enabling and fostering data-driven discoveries

The ongoing revolution in biology has been driven by -omics techniques. Towards the turn of the millennium, the development of more efficient sequencing and -omics techniques gave rise to an exponential increase of data, leading to the current revolution in biological sciences. Switzerland is currently at the forefront in the development of -omics techniques. The outstanding interdisciplinary Swiss research community, in combination with excellent base funding and third-party collaborations, have led to the establishment of -omics core facilities (wet laboratories) at many Swiss universities, including universities of applied sciences, as well as research institutes. These platforms specialise in generating high-quality datasets that describe living systems at the molecular, cellular and organismal level, along with interactions between organisms in the context of molecular and chemical ecology. Advanced analysis techniques now typically integrate different types of data and, consequently, knowledge from these large datasets.

The need to harness large datasets for biology has led to the establishment of a rich community of local and national bioinformatics infrastructures. In 1998, the SIB Swiss Institute for Bioinformatics was set up as a non-profit research infrastructure, embedded in and serving all major academic hubs in Switzerland. SIB entertains partnerships and collaborations with leading national and international research institutions. SIB also has internal service groups whose data scientists provide essential databases and software platforms, data management services, in-depth know-how in computational biology and software engineering, and training in bioinformatics to life science researchers. SIB's activities help to keep Switzerland at the forefront in the development of innovative techniques to support biological research. Although Switzerland has built a rich network of bioinformatics and -omics facilities, this network does not reach all biologists in Switzerland, and access and support for experimental biology is limited due to a lack of coordination and integration.

The increasing importance of computational methods to process and analyse these datasets has already been recognised in Switzerland, leading to the creation of bioinformatics core facilities (dry laboratories) in Swiss academic institutions and research centres. Several of these core facilities are affiliated with SIB. These local core facilities typically specialise in specific analysis techniques or data types, for which there is a considerable local need. Staff at these facilities work closely with local scientists, and in some cases the facilities are maintained directly by groups at research institutes and universities. The knowledge exchange that occurs through these collaborations and arrangements adds substantial value to (ongoing) research projects.

Currently, the affiliation of local bioinformatics core facilities with SIB facilitates collaboration in specific projects and/or the ad hoc exchange of best practices. However, since SIB's current focus is on databases and software tools, as well as on personalised health, the support that SIB can currently offer to the local core facilities is minimal due to financial constraints. Furthermore, the focus so far has mostly been on local expansion to meet local needs, rather than the creation of an inclusive network that fosters integration and synergies.

Integrative data sharing is important to generate value from large biological datasets. Efficient approaches to standardise workflows and share large biological datasets, including -omics data, are of central importance to exploit these datasets and maximise their value. In the past, several initiatives within Switzerland have illustrated this point.

The Swiss Pathogen Surveillance Platform (SPSP) was established in the context of the National Research Programme 72 (NRP72) on Antimicrobial Resistance, through a close collaboration between the University Hospitals of Basel, Lausanne and Geneva, as well as VetSuisse, the University of Basel and SIB. This secure One Health online platform enables near real-time sharing (under controlled access) of pathogen whole-genome sequences and their associated clinical/epidemiological metadata. It serves as a shared surveillance platform between human and veterinary medicine, including environmental and food isolates, thereby enabling detailed transmission and outbreak surveillance of pathogens in near real-time, with actionable results for public health. It also serves as a repository of structured, standardised and well-annotated data that can be used to answer specific research questions.

In the field of biodiversity, the European BiCIKL (biodiversity knowledge library) project aims to link data from specimens, literature and -omics research. Led by SIB's literature services (SIBiLS) and the Swiss Plazi GmbH, it enables searches using publications from -omics and biodiversity research.

SwissBioData aims to significantly enhance our capacity to convert research data into knowledge and innovation (photo SIB Swiss Institute of Bioinformatics, Nicolas Righetti | Lundi13)

Workflow standardisation and interactions between -omics research in Switzerland are facilitated by the Swiss Metabolomics Society, founded in 2014, and the Swiss Proteomics Society, which joined Life Science Switzerland (LS^2) in 2016, as well as by SIB. On an individual level, Swiss scientists are also engaged in bottom-up European initiatives that include efforts to standardise workflows, albeit without a central infrastructure or coordination, and without dissemination of results on a national scale.

In conclusion, several limited-scale initiatives illustrate the added value of integrating -omics workflows and of integrating and sharing multi-dimensional biological datasets. Nonetheless, a broad coordinated initiative across Switzerland is currently lacking, thus limiting progress in biology.

The substantial value generated by integrated -omics approaches, but also the challenges associated with the democratisation of theses biotechnologies, are illustrated by diverse biological research fields, such as nutritional science and chemical ecology. These fields are characterised by the complex and dynamic nature of molecular interactions taking place within and between biological matrices and organisms. The integration of -omics technologies, such as genomics, transcriptomics and metabolomics, plays a crucial role in deciphering these processes and now needs an integrated biological data approach to advance.

The application of -omics technologies has moved the field of nutritional science towards personalised nutrition at the genetic and phenotypic levels, including the gut microbiome. Bioinformatics, together with -omics technologies, are playing a key role in international nutritional research, as illustrated by the current efforts of the European research community to build an ELIXIR Food & Nutrition Community. However, the Swiss nutritional research community is not yet well linked to other fields that use -omics approaches.

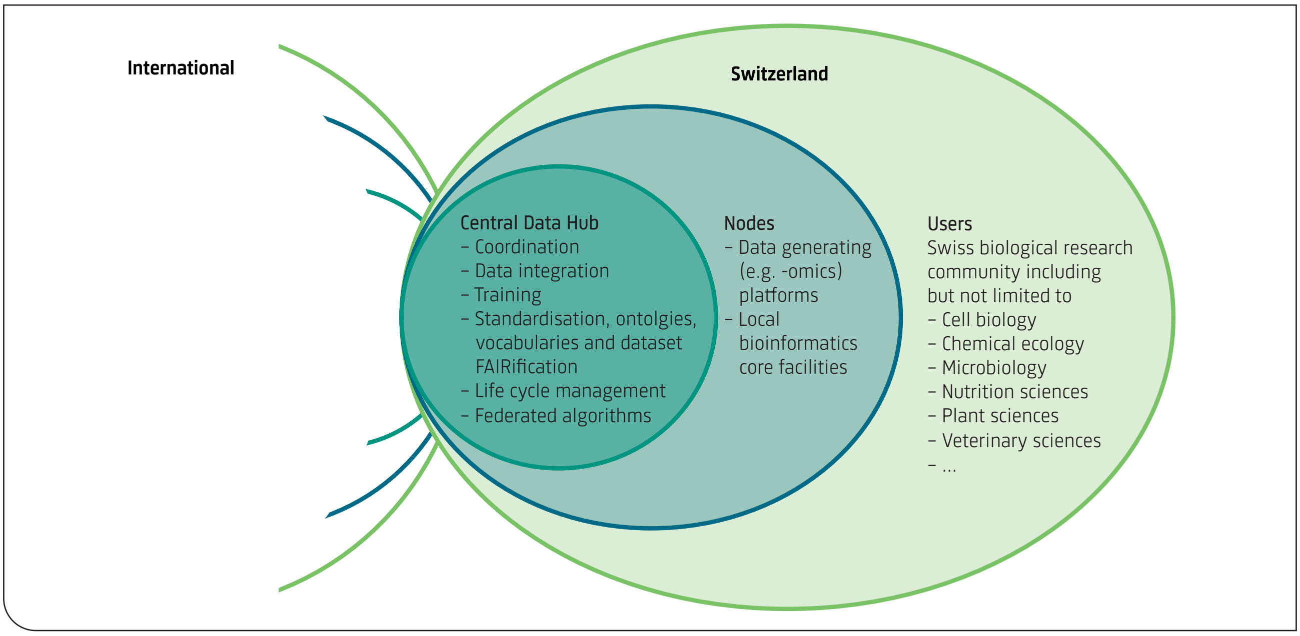
Similarly, the chemical ecology community has developed and successfully utilised -omics approaches to identify natural chemicals that determine interactions between plants, pests and biocontrol agents in natural and agricultural systems, and the emerging genetic understanding of these processes is fuelling efforts towards pesticide-free agriculture. A series of bottom-up metabolomics platforms and services have been established to push these discoveries.

The Earth Biogenome Project and its European node, the European Reference Genome Atlas (ERGA), plan to generate reference genome sequences of all eukaryotic species on the planet. ELIXIR has already reached out to ERGA to determine how the national nodes such as ELIXIR-Switzerland can provide essential expertise required for the project. The needs include the *de novo* assembly of tens of thousands of complex genomes, their annotation, significant IT infrastructure resources, tools and workflows to manage the data, as well as training.

What is missing is a unified Swiss framework to support hardware upgrades and link these platforms. Such a framework would improve access to the entire wealth of -omics data, thereby improving discovery pipelines towards a deeper understanding of chemical ecological processes. The same holds for other stakeholders of these platforms across biological disciplines, from plant and animal sciences to ecology.

While the establishment of a highly integrated workflow and data integration platform for biology may seem like a daunting task, a recent initiative within the domain of personalised health illustrates the feasibility of such an undertaking. The BioMedIT network, launched in 2017 and coordinated by SIB, established the infrastructure backbone for the Swiss Personalised Health Network (SPHN.ch), which is currently composed of three local nodes: SIS at ETH Zurich, sciCORE at the University of Basel, and Core-IT at SIB. These three nodes provide hardware, scientific project support and data analysis services. In addition, they are connected to each other, enabling the transfer of, and access to, large datasets from diverse locations. The network provides Swiss researchers with a secure high-performance computing environment. Furthermore, it facilitates data interoperability and exchange between data providers, such as Swiss healthcare providers, research institutions and technology centres, and data recipients, i.e. academic researchers from all over Switzerland. Extensive work on interoperability and workflows, led by the SIB Data Coordination Centre, means it is now possible to leverage knowledge from patient data at hospitals nationwide. One example is the SPHN Driver Project on sepsis, which integrates digital data from patients but also multi-omics data, following the previously mentioned requirements. The successful outcome of BioMedIT demonstrates that it is possible to make diverse data types, coming from very different sources and locations and requiring different levels of security, interoperable through common workflows. The knowledge and experiences gained with the BioMedIT project could be leveraged to help SwissBioData to establish a network that streamlines and integrates -omics technologies across diverse biological fields.

Many countries are currently exploring and building -omics services and data analysis platforms. However, comprehensive networks that comprise data infrastructures facilitating the generation, storage, sharing and analysis of data from biology, nutritional sciences and biomedical research remain rare. Whereas certain countries are more advanced in this respect, others are catching up, benefiting from the experience of countries with more mature infrastructures.



SwissBioData builds on the expertise of the local nodes at Swiss research institutions, and the expertise of the SIB as host of the central hub to make advanced data analysis support and training available to all experimental researchers in Switzerland (SwissBioData working group)

SwissBioData will facilitate the exchange of knowledge on specialised data analysis methods between experts and researchers (photo SIB Swiss Institute of Bioinformatics, Nicolas Righetti | Lundi13)

Collaborations between public and academic partners and the big players in cloud services, such as Amazon and Google, are already starting in order to create interconnected data ecosystems that overcome silos related to the generation, analysis and sharing of research data. The biodiversity research community is using CERN's Zenodo repository and its option to create a highly customised repository to generate FAIR data from information extracted from biodiversity literature, such as figures and taxonomic treatments, and digital specimens. These data constitute over 50% of all datasets in GBIF. The SPHN initiative and the strategic focus area Personalised Health and Related Technologies (PHRT) of the ETH Domain have led Switzerland to build its own 'private Swiss cloud', rather than outsourcing data to commercial environments.

Within biology, -omics approaches currently mostly rely on local infrastructure and workflows, and better integration across Switzerland without commercial outsourcing is highly desirable. It is important to sustain the current efforts and align the research infrastructure with the evolutions in society, such as digitisation, and the need for integration of knowledge bases in research workflows. In order to coordinate the production of -omics data, as well as other data types, and fully exploit and integrate them to generate biologically meaningful insights, further expertise development, standardisation and capacity building is essential. SwissBioData will help to achieve this critical requirement by leveraging and enhancing the current data generation and analysis infrastructures across Switzerland.

8.3.2 Proposed developments

The current revolution in biological, nutritional and biomedical research is driven by large (-omics) datasets and advanced, integrated analyses. Research infrastructure-based on high-quality data serves as a major driver for innovation, accelerating both science and linked entrepreneurship. Our capacity to accelerate progress in biology rests on the ability of researchers across Switzerland to generate, share and access high-quality genomics, epigenomics, transcriptomics, proteomics and metabolomics data and biological knowledge, and on their ability to access the latest data analysis techniques. For this purpose, we need a scalable and sustainable network that enables researchers in basic and applied biological sciences to generate, share, combine, analyse and act on biological datasets in molecular biology, physiology, ecology and evolution, including information contained in databases and the scientific literature. The proposed developments will foster synergies between the different biological domains, help dissolve boundaries between them, and maximise the use of existing resources.

SwissBioData is a research infrastructure that will build on the expertise within SIB, as well as the existing -omics platforms and local bioinformatics core facilities. By upgrading and interlinking these infrastructures, SwissBioData will structure the generation and use of data for Switzerland's biological research of the future. SwissBioData will consist of local nodes, including core facilities and local analysis platforms, and a central data hub.

Local nodes will include bioinformatics core facilities and -omics platforms that are situated within Swiss institutions of higher education and research institutes. The nodes will include units that primarily serve the biology community, but also units that are at the interface of biology and medicine, such as the BioMedIT nodes. The local nodes will retain autonomy and will be able to operate independently, thus optimally accommodating local needs. Their role within SwissBioData will be to:

- Build and maintain a strong local capacity for high-quality data generation in accordance with the needs of their scientific communities.
- Coordinate hardware renewal and updates to enhance compatibility and comparability of datasets, in particular for highly context-dependent approaches, through a joint procurement and funding plan within SwissBioData.
- Advise on, plan and execute analyses of biological samples in the context of individual or joint research projects.
- Provide computational and data analysis services for which there is a great need locally and/or and facilitate the exchange of knowledge on specialised data analysis between researchers at different institutions/nodes.
- Maintain, update and run data analysis tools and pipelines locally.
- Make large datasets available within the network, following FAIR data sharing principles.

The local nodes will be connected to a central hub that could be hosted by SIB. The central hub will be used to identify, develop and disseminate standard tools and workflows for biology, and it will enable joint efforts. Tasks that are currently executed locally but that could be centralised and standardised will be taken care of by the central hub. The central hub will also make advanced data analysis support available to all experimental researchers in Switzerland, regardless of the existence and/or the competencies of a core facility in their host institutions. The central data hub will provide:

- Coordination of SwissBioData.
- State-of-the-art bioinformatics tools and standardised pipelines/workflows, as well as the associated training.
- Life-cycle management and quality control of the data resources and software tools in the network. This will ensure that the 'fittest' resources are kept and that those that are no longer up-to-date are phased out.
- Data management services.
- Common ontologies, vocabularies and data formats, and standard data models for data types in different biological domains, to ensure interoperability and integration.
- Tools and expertise for dataset FAIRification.
- Storage of FAIR datasets that do not have an obvious 'home' in interoperable repositories or curated knowledgebases.
- Documentation of best practices and guidelines.
- Links to experts and advisors that facilitate data standardisation and analysis, to complement the local expertise and leverage the knowledge present at the other nodes.
- A federated analysis system, including for artificial intelligence (AI) and machine learning.
- Structuring and annotation of datasets, in collaboration with their providers, to ensure the power and the accuracy of the AI algorithms that will feed on them.
- Connection of the existing computational infrastructures hosted at different academic institutions to optimise the sharing of data and of computational resources.
- Sustainable data governance to ensure the long-term health of the data network.

Building upon the recent explosion in the areas of high-throughput technologies, cloud computing and big data analytics, SwissBioData has the potential to dramatically accelerate discoveries that will ultimately support general research and innovation in the Swiss biology community. SwissBioData will help researchers to expand their knowledge through the accumulation and integration of much larger and more diverse datasets, and it will help to ensure that the technologies that are applied are state-of-the-art. Whenever possible, SwissBioData will provide links to data contained in biobanks, the scientific literature and international knowledgebases and deposition databases.

AI will be a key tool in biology-related research in the coming years. Building an analysis framework based on AI, close to the concrete applications, will help to focus the development of AI towards practical outputs. SwissBioData will counteract the current generation of data and algorithm monopolies, where only a limited number of people are able to explore the collected data. The power of the full system of decentralised servers could be leveraged for future research applications by implementing federated algorithms, e.g. for machine learning/AI, where processing is distributed across multiple nodes. In this model, data could be distributed across the network of nodes, the analysis split and run in parallel on the network, and the results returned to the originating node. An important

At the forefront on the level of -omics techniques with excellent wet-laboratory platforms, the amount of data generated in Switzerland exceeds the data management and analysis capacity (photo SIB Swiss Institute of Bioinformatics, Nicolas Righetti | Lundi13)

feature of such a system is that an analysis could be initiated from any of the nodes in the system, meaning that computing power would not be limited to local computational infrastructure. This is an opportunity for close collaboration between the life science community and SDSC.

The opportunities offered by SwissBioData to the industry are substantial and accommodate societal digitalisation as a whole. SwissBioData will provide an excellent platform for pharma and biotech companies (including start-ups) to take part in the development of a digital research infrastructure and to benefit from the opportunities that it brings. It will give access to structured, high-quality data, an excellent driver for innovation, all while respecting data privacy regulations. For illustration, Switzerland has a large investment in wearables, apps and other sensor technologies. The next generation of low-voltage sensors are being developed by Swiss start-ups, in collaboration with institutions such as the Swiss Center for Electronics and Microtechnology (CSEM). These sensor developments will filter down to all areas of biological research and generate an immense source of exploitable data. A Digital Innovation Hub (DIH) has been set up in order to foster public–private partnerships and developments in that domain and to leverage European collaborations and funding opportunities. The biology community also collaborates with industry in the development of automated mass spectrometry and robotics systems. Expanding such collaborations to high-quality bioinformatics workflows would be beneficial to both science and industry and could further enhance and promote joint ventures. Overall, several Swiss-based industries apply -omics approaches in their R&D efforts and have established collaborations with academic and federal research institutes. They could greatly benefit from a more coordinated and centralised data processing platform, with well-defined workflows, that also optimises data access control and management.

In summary, many research fields within the Swiss biology community, including molecular and chemical ecology, microbiology, nutritional science, personalised health, plant science and veterinary science, make use of state-of-the-art tools in molecular biology and will benefit from a strong network for data generation, analysis and sharing. Nodes across the Swiss research landscape will be upgraded and organised to optimise the interactions between users and the central data hub. The resulting insights will be of major importance for society, as they will help to find solutions to pressing problems concerning biotechnology, food safety, animal health, sustainable agriculture, human health and other topics.

8.4 SwissBioImaging

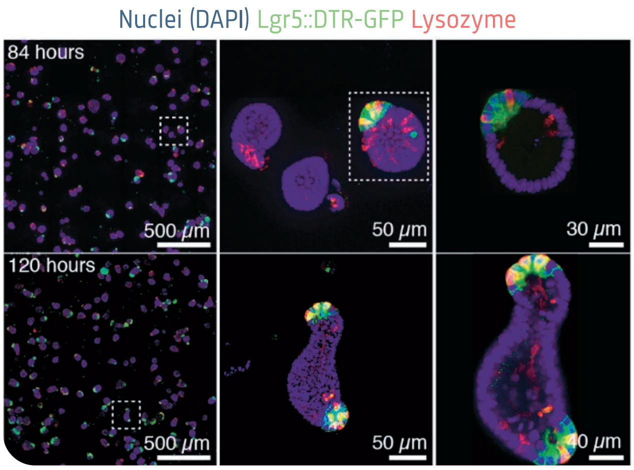
8.4.1 Image-driven discoveries

The wealth of information in imaging data is of incredible value to biological research. The ongoing microscopy revolution is making previously unobtainable insights possible. Laboratories across Switzerland are generating datasets that are in the terabyte range per day, which dwarfs genome and proteome datasets. Moreover, when compared with DNA and protein sequencing data, where the core information is stored in one-dimensional strings of ATCG and amino acid variables, respectively, imaging generates films of three-dimensional data that are incomparably rich in qualitative and quantitative variables, including shape, the intensities of multiple signals, and context. When images are captured from living samples, they additionally provide insights into essential system dynamics that are impossible to obtain by other means. Another unique benefit of imaging is its multi-scale nature, which potentially enables a comprehensive understanding of living systems, from the level of single molecules to entire organisms and communities. Such unprecedented data volumes and data richness demand fundamentally new approaches in data handling and analysis, since the tools and procedures established for the -omics type of large biological datasets, as described in the previous section on SwissBioData, are not applicable.

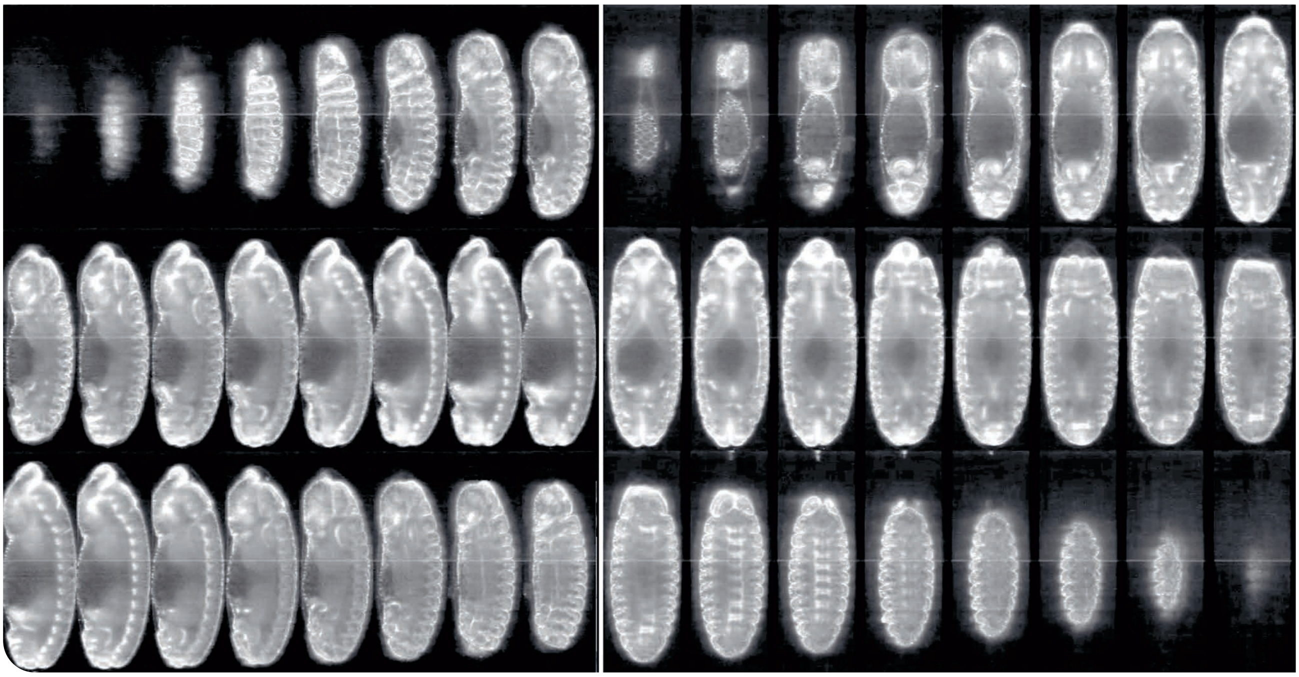
The diversity of novel imaging technologies come with high hardware costs (e.g. specialised microscopes). As a consequence, all Swiss universities have established centralised bioimaging facilities and imaging centres, mostly focused on microscopy but also covering numerous other digital acquisition technologies. These are generally well equipped and staffed with specialists that provide the respective training in image acquisition to a range of users, often including doctoral students, post-doctoral associates and representatives of the private sector. In addition, these specialists can often offer support to scientists requiring customised image acquisition hardware solutions. While the main purpose of all such facilities is to enable and optimise image data acquisition, scientific discoveries only emerge after such data are analysed. Currently, this challenge is left to the individual biologists and laboratories, which generally lack the necessary expertise. For this reason, image data analysis has become a bottleneck that substantially limits scientific progress.

The majority of imaging facilities are staffed with one or two image analysis specialists at most, which falls short of what is needed. In addition, their support is generally limited to standard analysis pipelines that are poorly suited and underperforming. This leads to a 'cottage industry' of home-made solutions that are tailored, usually in an autodidact manner or at best by a specialist hired by individual laboratories, to extract only a small subset of the vast richness of information contained in images. As these analysis solutions are usually bespoke designs for specific imaging challenges, disseminating or generalising them is extremely inefficient, meaning that maximum benefit is not achieved. Occasionally, such specialists are embedded in small local communities that can provide some coordination, teaching and knowledge transfer. However, without a dedicated national infrastructure, networking with other scientists with the required expertise is limited. The situation is worsened by the rapid rise of uncoordinated AI-based approaches, which are already revolutionising the way one can analyse image data.

The current situation involves numerous parallel research efforts, each embedded in a specific research grant. Standards are set individually and are not discussed. There is little coordination of efforts between individual laboratories or universities/research institutions. This fragmentation prevents the generation of critical mass and makes everyone underperform. As a result of such specificity, current image analysis barely scratches the surface of the full information pool present in a given image dataset. Furthermore, once established, such solutions frequently disappear again when their inventors leave the laboratory, which leads to existing solutions being reinvented in another context in another laboratory. This process uses



Highly multiplexed, high-throughput time course imaging of intestinal organoids at high temporal and spatial resolution (photo Prisca Liberali, FMI, Basel)



Sections through a developing fly embryo, extracted from two selected viewing angles. Shown is a low-resolution overview of one of 900 film frames (photo Damian Brunner, University of Zurich)

financial resources and personnel in a highly inefficient manner.

Worst of all, numerous laboratories do not even have the means to implement any computational analysis of their images, owing to a lack of expertise and dedicated funding. This is especially the case for smaller and newly founded research groups, such as those financed by the SNF Ambizione, Eccellenza and Prima programmes. Such laboratories are often left with classical qualitative assessments and a lack of statistical rigour. If unaddressed, one can envisage a future schism in the community, between the laboratories that have access to such quantitative analysis tools and the more qualitative 'have nots'. Here, 'democratisation' is urgently needed.

Not only has the importance of the bioimaging revolution been recognised in a number of recent Nobel Prizes (fluorescent proteins 2008; super-resolution microscopy 2014; Cryo-electron microscopy 2017, including Jacques Dubochet from the University of Lausanne), but progress in this area has resulted in notable changes to the scientific landscape. Worldwide, microscopy-based imaging centres are sprouting up everywhere. For instance, the US has launched the Janelia Research Campus, which is dedicated to visually mapping, quantifying and modelling the brain and is almost exclusively driven by modern microscopy technology and computational approaches. Furthermore, there are numerous initiatives worldwide that aim to provide infrastructure to handle and analyse imaging technology. The current situation is comparable to the rise of Systems Biology at the turn of the millennium, when large genome and proteome datasets could suddenly be acquired, leading to the uncoordinated establishment of various databases and the implementation of different standards. Only later did this work become coordinated and standardised in a major international effort. These investments in turn formed the foundation for the implementation of new technologies, such as the single-cell sequencing-based approaches that are currently revolutionising genome research. It is important that such efforts occur at an earlier stage for imaging data, not only to optimise the current efforts but also to facilitate emerging developments and spark unforeseeable discoveries.

Thanks to the financial possibilities and, in particular, the universities' foresight in establishing top-notch imaging facilities, Switzerland is certainly at the forefront in terms of image acquisition technologies. However, only a few laboratories have been able to sufficiently invest in the development and implementation of new internationally recognised analysis approaches to fully exploit the datasets produced. The bioimaging field is growing at such a breath-taking pace that it is hard to predict where it is heading – as is the case for many cutting-edge sciences. In particular, the implementation of AI has already started to fundamentally transform the way scientists analyse and quantify their imaging data. This is true not only in the life sciences but in all image-based research and applications. Approaches like AI, especially for quantitative image analysis, will undoubtedly lay the foundation for sophisticated computational modelling of processes with unprecedented predictive power. This will substantially increase our understanding of underlying processes and will have a major impact on new developments in all aspects of human life. Currently, many branches of industry are investing heavily in the usage of AI to analyse images. Typical applications include images acquired in a military context, images posted in social networks, images acquired in diagnostic medicine, and images from surveillance cameras, not only in relation to crime but also in monitoring the spread of infections. Such analysis is usually designed to recognise selected features, but organisations like Google are probably implementing less biased AI analyses of all kinds of images, not only from social media, to recognise unprecedented and unforeseeable patterns. Also, AI operates ahead of image acquisition in most digital cameras to recognise and optimise image features.

8.4.2 Proposed developments

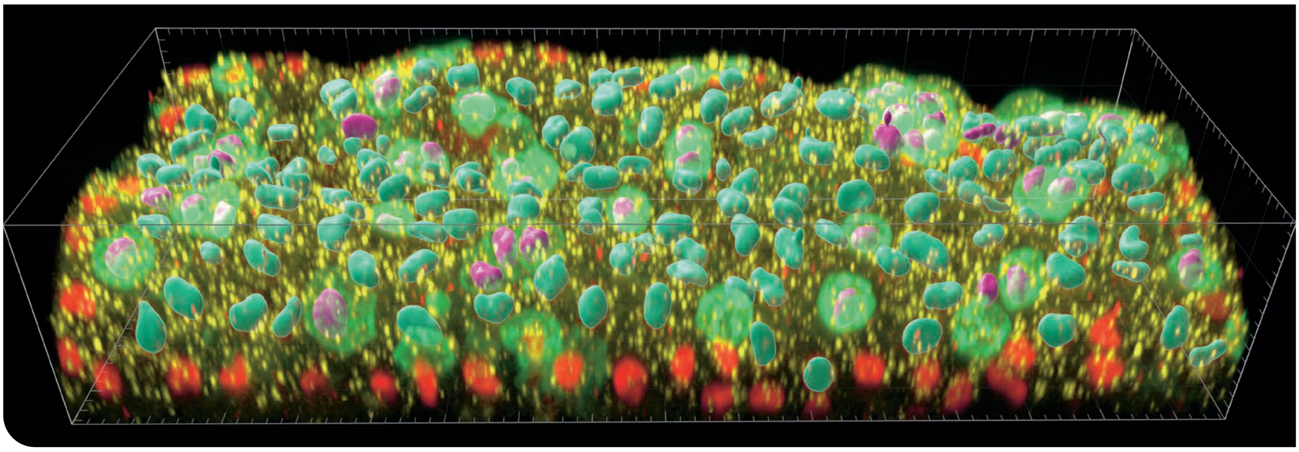
Biological imaging, similar to medical imaging and probably other image-based sciences, is reaching a point where individual laboratories can no longer manage to comprehensively quantify the large amounts of data they produce. There is a strong desire in the Swiss life science community to coordinate the many isolated efforts leading to the development of powerful image analysis tools, to set standards in image acquisition, processing, analysis, handling and storage, to ensure reproducibility, and to better reach out to the international communities in order to rapidly access new developments. This comes with the need for efficient information dissemination and specialised teaching. All this could be best implemented with a centralised infrastructure that can simultaneously serve all these needs.

The implementation of SwissBioImaging, a national infrastructure dedicated to bioimaging, will be an important step towards coping with such demands. SwissBioImaging will:

- Play a role in coordinating and supervising national and international community efforts in image data processing and handling.
- Perform, in close collaboration with the national community, cutting-edge research in generalisable image analysis methods of the future, in particular including AI technologies.

SwissBioImaging will not only 'democratise' bioimaging data and next generation bioimage data analysis tools but also provide the highest level of scientific support to all life science researchers, analogous to how CERN is crucial to all of particle physics. One fundamental difference, of course, is that at CERN data collection is rate limiting, while the standard decentralised collection of biological image data at present has hardly any limits, except for the need for more electron microscopes in the context of structural biology.

Due to the overarching demand for image data analysis and handling solutions, it is imaginable that such an infrastructure could be embedded in a larger context, additionally covering respective efforts in medical imaging and in agricultural, biodiversity, taxonomic and environmental sciences. This would generate a hub of critical mass with worldwide impact and visibility, giving the Swiss research community a substantial competitive advantage, which can be expected to translate to industrial applications as well.



Angular fragment of developing zebrafish skin, showing segmented nuclei of deliberately manipulated (light green) and wild type (dark green) basal keratinocytes with their changing mRNA transcripts (yellow dots) (photo Darren Gilmour, University of Zurich).

The highly sophisticated analysis methods, which need to be developed in the context of bioimaging-driven research, will directly feed back on numerous industrial applications. This is particularly interesting in the context of three-dimensional image content, where modern microscopy is far ahead of the standard image acquisition technologies. As for the converse flow of information, however, it is unlikely that the imaging software developed by the industry will be made publicly and freely available to the scientific biomedical community.

Humans are strongly motivated and convinced by visual input. It is clear that any kind of development in the context of imaging technology will have an impact on society and education in numerous ways. Complex processes are more accessible when illustrated by series of annotated images. For example, human development can be understood through images of a developing embryo that are linked to detailed multi-layered information on molecular mechanisms and on the genome, transcriptome, proteome or metabolome. Additionally, this example illustrates how in the longer term the SwissBioImaging infrastructure will naturally connect with the above-mentioned SwissBioData infrastructure and with the general goal of placing mechanisms back into their native context.

The simultaneous development of advanced visualisation methods, an important spin off of this infrastructure, will provide a greater understanding of living systems that will be intuitively accessible to the general public. It can be expected that, in the near future, such computer visualisation developments will replace traditional textbooks to accelerate learning and the dissemination of information.

Recently, researchers from the European Molecular Biology Laboratory (EMBL) have established Euro-BioImaging as a European Research Infrastructure Consortium (ERIC). By integrating national imaging facilities as nodes, Euro-BioImaging will coordinate and optimise all European efforts on image data acquisition and exploitation and provide a link to similar efforts worldwide. Currently, Switzerland is not involved in Euro-BioImaging, but a direct link to this international infrastructure would provide a connection to all other relevant European imaging nodes and give Swiss researchers access to the rapidly evolving expertise, particularly regarding image analysis technologies. Moreover, this link would allow Swiss researchers to contribute to the establishment of international standards. Notably, the initiators of Euro-BioImaging previously contacted several Swiss researchers in an effort to integrate Swiss bioimaging. Unfortunately, this first connection did not result in concrete engagement. A SwissBioImaging infrastructure dedicated to image analysis would not only serve as a perfect link to Euro-BioImaging but, because of its specialisation, represent a unique and prestigious node within the European network.

9 Conclusions

The present Biology Roadmap for Research Infrastructures outlines the results of intensive meetings and discussions that took place between 2019 and 2020 among representatives of many disciplines in biology. The infrastructure needs for the years 2025–2028 were identified. In order to stay at the forefront of worldwide research, Swiss biological research needs to be supported in a concrete and targeted way through the establishment of the following highly complementary large research infrastructures described in the present document:

- → SwissBioCollection
- → SwissBioSites
- → SwissBioData
- → SwissBioImaging

The proposed infrastructures will be accessible to the entire Swiss biological and biomedical community in academia and the private sector and to international research collaborators. They will serve as the basis for studying and responding to ongoing environmental and societal challenges: climate change, biodiversity loss, sustainable production of food, fodder and fibre, and health issues such as the SARS-CoV-2 pandemic.

SwissBioCollection, SwissBioSites, SwissBioData and SwissBioImaging constitute an ensemble of infrastructures that fill identified gaps in the present Swiss research landscape. Common to all four infrastructures is the challenge of comprehensive data exploitation, which often constitutes a limiting bottleneck. In all areas of research, the configuration and setup of instrumentation should go hand-in-hand with the development of data analysis procedures that match data acquisition schemes and data exploitation goals. Coordinated data management should lead to interoperable research datasets while still respecting the specific requirements of the numerous specialised sub-fields of biology. Therefore, four separate, dedicated network infrastructures are proposed to keep Switzerland at the forefront of international research in biology.

Competitive research is not possible without international networking and the ability to attract worldwide attention. Regarding international infrastructures, European initiatives and programmes are considered the most important for Swiss biologists. Therefore, it is crucial to establish strong national infrastructures that can serve as significant nodes in European networks, thus strengthening the ties between Swiss and foreign researchers. Consequently, Switzerland should join and participate further in the following international infrastructures: DiSSCo, EMPHASIS, BBMRI, LifeWatch ERIC and Euro-BioImaging. In addition, it should maintain its membership in ICOS, ELIXIR, EMBL, EMBO and GBIF, as they provide excellent, innovative research programmes and shared resources for biologists, especially young researchers, and facilitate major collaborations.

The present roadmap is the first of its kind for the Swiss biology community and represents the view of scientists from many sub-disciplines of biology. After this challenging and stimulating first exercise, it is clear to all of the authors that this work should continue in the future to further coordinate and consolidate biological research and research strategies. The continued process will allow additional sub-communities to organise themselves and join the Round Table Biology with their specific considerations and propositions.

10 Appendix

Appendix 1: Detailed description of the establishment of the Round Table Biology (RoTaBio) and the elaboration of the Biology Roadmap for Research Infrastructures

The elaboration of the present document began with the identification of sub-fields of biology and existing national and international infrastructures/programmes focusing on biology to invite researchers from all these fields to participate in the Round Table Biology – RoTaBio (Table 1). High-profile representatives of the biological subfields, Swiss representatives of national platforms and international programmes, and the presidents of the specialised societies and national committees of the International Science Council (ISC) of the SCNAT's Platform Biology were invited to participate in the RoTaBio, with the aim to write a roadmap for research infrastructures for biology. In total, more than 50 people were invited, representing all Swiss universities and all institutes of the ETH Domain. In the inaugurating meeting of the RoTaBio (July 2019, 30 interested persons invited), the community was informed about the mandate and numerous topics were identified which would potentially profit from new infrastructures. This resulted in the formation of 12 specialised sub-roundtables, which each, in a self-organised procedure, evaluated the interest of the Swiss research community in their specialised field (Table 2). In the second RoTaBio meeting (November 2019), the representatives of these 12 sub-roundtables were invited to present their requests for national research infrastructures. The collected information was condensed in a matrix showing biological communities/topics and requested infrastructures. In the third meeting (February 2020), four working groups were formed based on the matrix and the general structure of the RoTaBio roadmap was agreed on. The leaders of each sub-group then elaborated the first draft of a proposal for the required infrastructure, including discussions and ideas of the interested communities. In the fourth meeting (May 2020), the four proposals were presented and synergies, overlaps and contradictions were identified. The four proposals were then joined in a single draft and reviewed by the authors (members of the four sub-groups), before a broader research community was asked to comment on the roadmap and incorporate missing information. More than 130 scientists were invited to review the document. During the whole process the entire biology community had the opportunity to join the working groups and to integrate missing propositions.

Table 1. Biological sub-fields, national platforms, international programmes and member societies of the SCNAT's Platform Biology invited to participate in the Round Table Biology

Sub-fields of biology
Big data
Biochemistry
Biocomputing / artificial intelligence
Bioinformatics
Biophysics
Cellular and developmental biology
Cellular biology
Chemical ecology
Ecology and environmental biology
Ethology
Evolution
Evolutionary ecology
Genetics
Human biology
Mathematical modelling
Microbiology
Molecular biology
Neurobiology
Plant biology
Structural biology
Synthetic biology
Systems biology / -omics
Virology
National platforms
InfoSpecies
Metabolomics and Proteomics Platform (MAPP)
Plant Science Center (PSC)
Swiss Biobanking Platform (SBP)
Swiss Institute of Bioinformatics (SIB)
Swiss Natural History Collections Network (SwissCollNet)
International programmes with Swiss participation
Blue Brain Project
CETAF
DiSSCo
EMBO / EMBC
EMBL
ELIXIR
Global Biodiversity Information Facility (GBIF)

Specialised societies and national committees of the International Science Council (ISC)
Life Science Switzerland (LS^2)
Schweizerische Arbeitsgemeinschaft für wissenschaftliche Ornithologie (SAWO)
Schweizerische Gesellschaft für Wildtierbiologie (SGW)
Swiss Association of Bryology and Lichenology (BRYOLICH)
Swiss Botanical Society (SBS)
Swiss Entomological Society (SES)
Swiss Laboratory Animal Science Association (SGV)
Swiss Society for Anthropology (SSA)
Swiss Society for the History of Medicine and Sciences (SGGMN)
Swiss Society for Microbiology (SGM)
Swiss Society of Agronomy (SGPW)
Swiss Society of Anatomy, Histology and Embryology (SSAHE)
Swiss Society of Pharmacology and Toxicology (SSPT)
Swiss Society of Phytiatry (SSP)
Swiss Society of Tropical Medicine and Parasitology (SSTMP)
Swiss Systematics Society (SSS)
Swiss Zoological Society (SZS)
National Committee of the International Union of Biochemistry and Molecular Biology (NC IUBMB)
National Committee of the International Union of Biological Sciences (NC IUBS)
National Committee of the International Union of Food Science and Technology (NC IUFoST)
National Committee of the International Union of Nutritional Sciences (NC IUNS)
National Committee of the International Union for Pure and Applied Biophysics (NC IUPAB)

Table 2. List of initial sub-roundtables of RoTaBio

Agriculture and ecology
Biobanking
Bioimaging
Bioinformatics
Evolutionary biology
Metabolomics and analytical chemistry
Neural networks
Stem cells
Structural biology
Swiss natural history collections
Synthetic cells and life forms
Systems biology and large research infrastructures

Appendix 2: Current and recommended Swiss status in international research infrastructures

Table 3: International programmes/infrastructures identified as being important for Swiss participation

Infrastructure / Programme	Abbreviation	Current status of Switzerland	Recommended status
Biobanking and Biomolecular Resource Research Infrastructure	BBMRI	Observer	Full member
Distributed Systems of Scientific Collections	DiSSCo	Participation of individual scientists	Full member
	ELIXIR	Full member	Full member
European Infrastructure for Plant Phenotyping (planned)	EMPHASIS	Supportive	Full member
European Molecular Biology Laboratory	EMBL	Full member	Full member
European Molecular Biology Organisation	EMBO	Full member	Full member
European Reference Genome Atlas	ERGA	Full member	Full member
Euro-BioImaging		None	Full member
Global Biodiversity Information Facility	GBIF	Full member	Full member
Integrated Carbon Observation System	ICOS	Observer	Full member
LifeWatch ERIC		None	Participation

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..