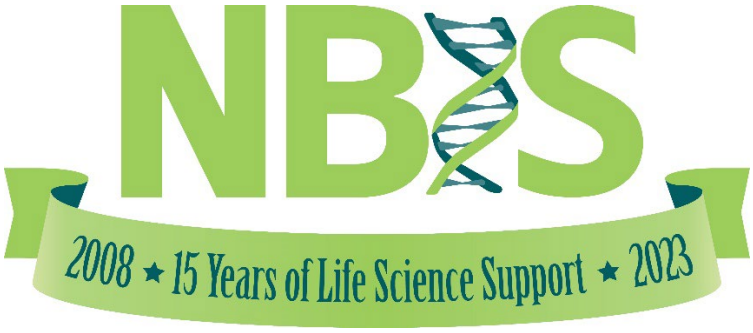

Annual Report 2024

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Introduction

NBIS (National Bioinformatics Infrastructure Sweden) is a distributed national research infrastructure, hosted by Uppsala University. NBIS constitutes the SciLifeLab Bioinformatics Platform. NBIS is formed by 11 partners: Uppsala universitet (hosting NBIS), Chalmers tekniska högskola AB, Göteborgs universitet, Karolinska Institutet, Kungl. Tekniska högskolan, Linköpings universitet, Lunds universitet, Naturhistoriska riksmuseet, Stockholms universitet, Sveriges lantbruksuniversitet, and Umeå universitet.

Funding is provided from the Swedish Research Council (VR), Knut and Alice Wallenberg Foundation, Science for Life Laboratory (SciLifeLab), Swedish universities, and user fees. In addition, we have funding from EU, ELIXIR, NordForsk (NeIC), and Chan Zuckerberg Initiative (CZI).

NBIS expanded 1 Jan 2021 with the SciLifeLab BioImage Informatics Facility (BIIF) and the AIDA Data Hub in Linköping joining us. These are funded outside the VR grant 2021–2024 with resources from SciLifeLab and other sources.

Vision and Mission

Enable world-class life science research and maximise scientific and societal impact of collected data by:

- Providing expert knowledge, innovative data integration, advanced training, efficient data publication for open science, and access to high-performance data analysis methods
- Coordinating bioinformatics support within Sweden and making bioinformatics easily accessible for life science researchers
- Swiftly responding to changes in support needs as new techniques are developed and utilised
- Forming the Swedish ELIXIR node and participating in relevant international projects

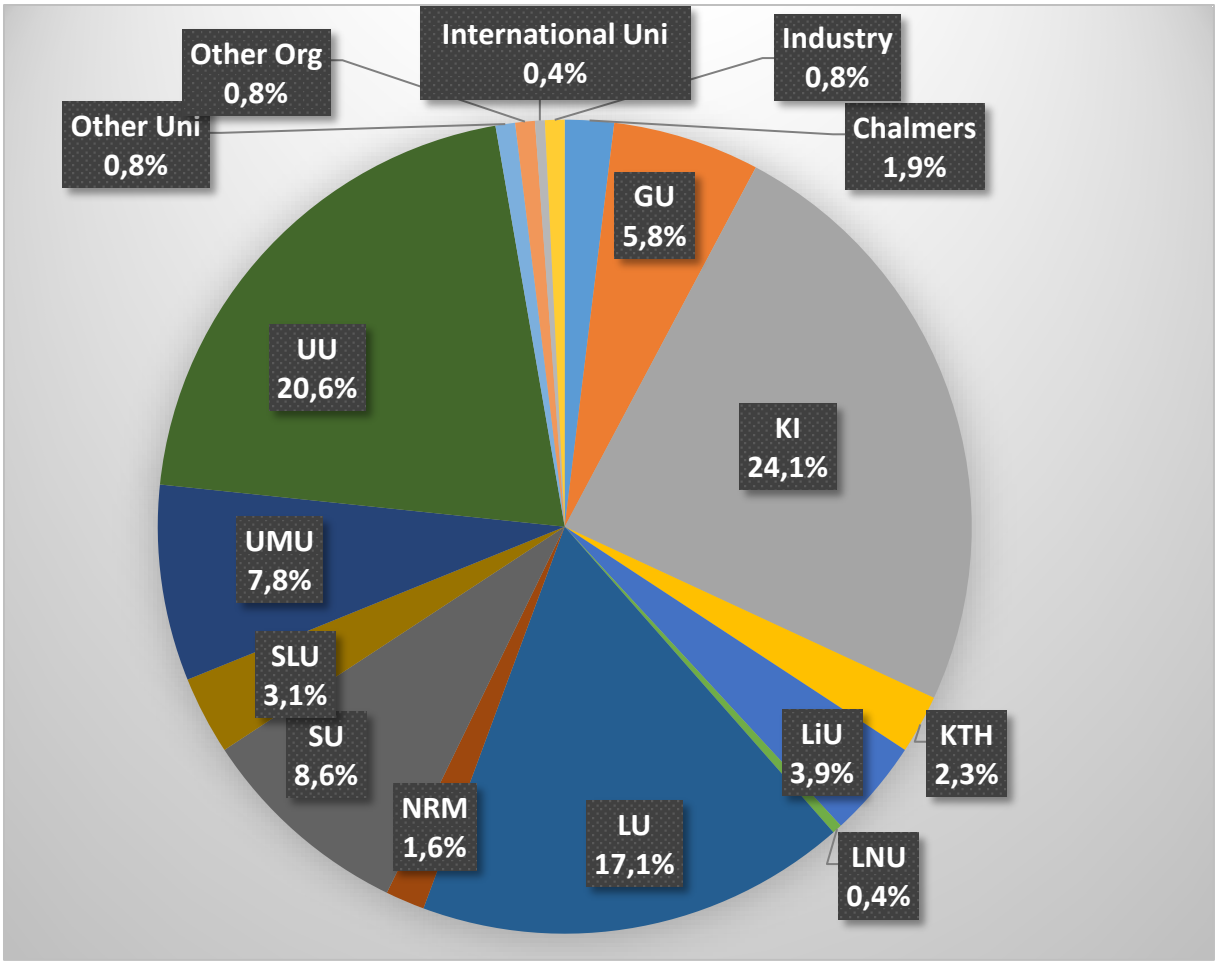
Support

One of the major activities is support, where our staff helps researchers with bioinformatics tasks in various projects. Currently, NBIS provides expertise in many areas within bioinformatics: genome assembly, genome annotation, genetic variation, comparative genomics, phylogenomics, transcriptomics, proteomics, metabolomics, epigenomics, metagenomics, systems biology, single-cell/spatial biology, structural biology, biostatistics, machine learning and multi-omics integration.

In the current funding landscape, the universities need to contribute a substantial part of infrastructure funding, in proportion to the utilisation of NBIS by the respective university. This is reflected in the increased university contributions from 2018 and onwards. NBIS obtains user fees on direct project-related support, with the exception of the KAW-funded peer review support track (LTS; cf. below). It is not feasible to apply user fees on the infrastructure, outreach and training activities, staff education and project management.

NBIS serves users at all major universities. In 2024, NBIS provided support to **257 PIs** (112 female, 142 male, 3 no info), which is an increase by ~10% compared to 2023. The distribution of the supported PIs is shown in Figure 1. The top three universities using NBIS are as previously Karolinska Institutet, Uppsala University and Lund University. The total number of active support

projects were 245, and in addition to those NBIS has also provided 64 study design consultations, 7 data management projects and 6 partner projects. These numbers are at about the same levels as previous years.



Distribution of PIs that have received support during 2024

In 2024, our user fee support track (SMS) had 153 projects and our peer review support track (LTS) had 92 projects. In addition, the BioImage Informatics unit provided support and consultations to 44 projects, and the AIDA Data Hub unit has provided AI support in 18 projects. A wide variety of projects were supported, with gene expression studies being the single biggest category. About half of all support is provided from one site to another, emphasising the importance of a national infrastructure.

Our weekly drop-in sessions plus on-site drop-in in Stockholm and Lund are very popular. A survey shows that 99.8% of the users would recommend this service to a colleague (657 accumulated responses).

Analysed data were from a range of sequencing-based methods, and also other large-scale data, such as proteomics, metabolomics and cell imaging. Projects including single-cell RNA sequencing (scRNA-seq) and human whole genome sequencing data remain in high demand of support, while emerging areas include ancient DNA (aDNA) and cell image analysis.

Examples of important achievements from NBIS support projects

NBIS has a total of **100 publications** in 2024 from our direct project support work (excluding Compute & Storage), listed in the Annex. A few achievements are shortly highlighted here.

ProBio - Androgen Receptor Pathway Inhibitors and Taxanes in Metastatic Prostate Cancer: We have aided J. Lindberg (KI) and colleagues in a large prospective clinical study recently published in *Nature Medicine*, exploring the efficacy of combining androgen receptor pathway inhibitors and taxanes in metastatic prostate cancer, providing critical insights into treatment optimization. The study utilised a randomised platform trial design to evaluate outcomes and identify predictive biomarkers for treatment response. This work has already had impact for clinical diagnostics procedures nationally and may improve patient outcomes globally.
https://doi.org/10.1038/s41591-024-03204-2

Spatially Resolved Multiomics on Neuronal Effects Induced by Spaceflight in Mice: This study, published in *Nature Communications*, investigates the molecular changes in the brains of mice exposed to spaceflight conditions, revealing insights into how space travel affects neural function. By applying spatially resolved transcriptomics and proteomics, we were able to map out the effects of space-induced stress on the central nervous system, leading to a deeper understanding of spaceflight-induced neuroplasticity. https://doi.org/10.1038/s41467-024-48916-8

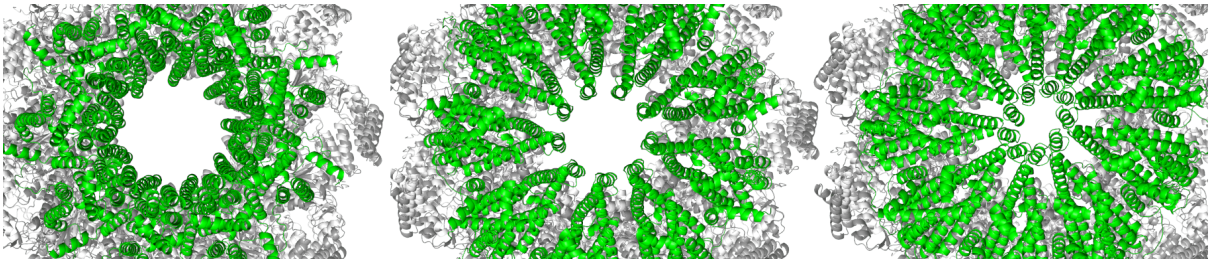
Ecological Genomics in Northern Krill Reveals Loci for Local Adaptation Across Ocean Basins: Published in *Nature Communications*, this study explores the genetic basis of local adaptation in Northern krill, a species of massive ecological importance, but with sparse genomics resources due to its large genome size. The research identified specific loci linked to environmental factors such as temperature and salinity, providing new insights into the evolutionary dynamics of these marine species, uncovering how krill populations are evolving in response to changing oceanic conditions, with fundamental implications for global marine ecology in the face of climate change. https://doi.org/10.1038/s41467-024-50239-7

Photographer: Andreas Wallberg

Origin, structure, and composition of the spider major ampullate silk fiber revealed by genomics, proteomics, and single-cell and spatial transcriptomics: This study uncovers the structure and composition of spider major ampullate silk fibers using a range of molecular technologies. Our bioinformatics team supported the project from genome assembly to single-cell and spatial data integration and interpretation, revealing a layered fiber structure as fundamental to the unique combination of strength and flexibility seen in spider silk. This study opens new avenues for artificial spider silk production and design. https://doi.org/10.1126/sciadv.adn0597

Dynamics of the blood plasma proteome during hyperacute HIV-1 infection. Sub-saharan individuals representing different stages of disease progression in HIV-1 infection were studied for protein expression differences. Several proteins involved in inflamammatory repsonses, immune regulation, and cell motility were identified as significantly altered comparing pre- to post-infection. The study provides insight into early host responses in hyperacute HIV-1 infection, and presents

potential biomarkers and mechanisms linked to HIV-1 disease progression and viral load. https://doi.org/10.1038/s41467-024-54848-0



Unmasking AlphaFold to integrate experiments and predictions in multimeric complexes. AlphaFold has since its release been actively refined with new functionalities and optimisations, but is still limited in specific areas. This study presents the tool AF_unmasked, developed by NBIS in collaboration with Swedish researchers. The tool improves on AlphaFold's ability to predict large protein complexes by better integrating experimental data and facilitates new, more confident, discoveries in these protein structures. https://doi.org/10.1038/s41467-024-52951-w

Multimodal analysis and visualization of spatial omics data. Combining spatial transcriptomics with quantitative image analysis and efficient visualization can increase the understanding of health and disease. NBIS BIIF gave support to 10.1016/j.cell.2024.02.030, a study on evolving neuroinflammatory lesions in multiple sclerosis and 10.1158/1078-0432.CCR-23-3461, a study on the interaction between metastatic and healthy tissue in colorectal cancer liver metastases.

Biodiversity

NBIS is heavily involved in biodiversity-focused projects, both on the Swedish and European level. High quality reference genomes are produced to enable research otherwise restricted to model organisms. Population genomics analyses support sustainable use of commercial fish species and also facilitate studies on threatened species, with results being fed directly into ongoing conservation efforts in Sweden. Samples from biodiversity hotspots in the Mediterranean area are also analysed by our support team in collaborative efforts with researchers in Spain and Slovenia in the Biodiversity Genomics Europe project.

Earth Biogenome Project Sweden – pilot (VR-EBP): With funding from VR to increase accessibility of existing infrastructures, VR-EBP has been running 2020–2024 to introduce a Biodiversity service track at SciLifeLab. Several use cases of Swedish species were selected together with biodiversity researchers, representing different organism groups such as fish, insects, and fungi, and for all of these species, reference genomes were assembled and detailed population genomic analyses were conducted. This has resulted in a highly streamlined cross-platform workflow at SciLifeLab, and new scientific results that have already influenced conservation projects in Sweden as well as laid ground-work for sustainable fishing of commercially important fish species.

The NBIS genome assembly pipeline: A pipeline for genome assembly has been developed as a part of NBIS work in the European Reference Genome Atlas (ERGA), a biodiversity initiative aiming to make reference genomes available for a large number of European organisms. The pipeline greatly facilitates fast and reproducible genome assembly, with all aspects covered from QC of raw data to automated writing of a report. It significantly lowers hands-on time needed,

providing users lower cost and faster turn-around times, with retained, to enable high-quality genome assemblies at scale. https://github.com/NBISweden/Earth-Biogenome-Project-pilot

The European Reference Genome Atlas: piloting a decentralised approach to equitable biodiversity genomics: The European Reference Genome Atlas (ERGA) is a truly decentralised, equitable, and inclusive organization which succesfully connects over 1000 reserachers in Europe interested in the assembly of reference genomes. To build the foundation for ERGA, a pilot project was launched in which 98 species from 33 countries were assembled and annotated, and NBIS was involved as an infrastructure for all of the Swedish species, providing assembled and annotated genomes to the highest Earth Biogenome Project standard. The publication highlights processes involved in building a decentralised organisation and provides a suggested strategy for similiar intiaitives going forward. https://doi.org/10.1038/s44185-024-00054-6

User Fees

NBIS has five support tracks:

- Study Design Consultation (≤ 3h)
- User Fee Support (SMS)
- Partner Projects (PP, part of SMS)
- Peer Review Support (LTS)
- BioImage Informatics (BIIF)

For User Fee Support, PP and BIIF, NBIS charges user fees, while Peer Review Support is provided for free according to the funding requirements by the Knut and Alice Wallenberg foundation. In 2024, the income from user fees was 12.0 MSEK, thus an increase compared with 2023.

Data Management and Open Science Support

During 2024, the Data management unit consisted of eleven data stewards and one data manager (totalling 10 FTEs during 2024).

NBIS has continued its mission to provide data management support and training, in collaboration with key national and international stakeholders to enable Swedish life science researchers to apply good data management practices so that the research outputs produced are available to the global research community, and to society at large, according to the principles of Open Science, Reproducible Research, and FAIR (Findable, Accessible, Interoperable, Reusable). A strategy for the Data management unit operations and activities going forward, was published during 2024 (https://doi.org/10.17044/scilifelab.27604476).

On the support side, we have continued providing Data Management Planning (DMP) support, as well as FAIRification and data publication support to research projects. A large focus has been put on submission of genome sequence data to support the international evolution and biodiversity efforts that NBIS and NGI are engaged in. Together with the SciLifeLab Data Centre, activities have been focused on developing and improving tools functionality for data management, such as the Data Stewardship Wizard for DMPs and sample metadata handling

NBIS has also made significant progress in strengthening Sweden's capacity for handling sensitive human data. A major milestone was the launch of FEGA Sweden, making the national repository fully operational, followed by the first successful data release featuring datasets from

Barntumörbanken (the Swedish childhood tumour biobank). To further facilitate data sharing, NBIS has made intensified efforts to onboard selected universities, enabling their researchers to deposit data into FEGA Sweden. Our engagement in international collaborations around sensitive human data has also continued through our contributions to the European Joint Program on Rare Diseases (EJP-RD) project (concluded in 2024), European Genomic Data Infrastructure (GDI) project and the Genome of Europe (GoE) project. Contributions have also been made to TEHDAS2, a new EU project focused on shaping the European Health Data Space. Additionally, NBIS has been active in outreach and training activities to support researchers working with human data, reinforcing best practices in secure and ethical data management.

On the training side, we have continued to provide the course on Introduction to Data Management practices, as well as running a tailored edition of this course for the NGI Stockholm unit at NGI. A large number of outreach events have also been performed, nationally and internationally, among them two-day RDM Roadshow events at the Umeå and Lund SciLifeLab sites in collaboration with the SciLifeLab Data Centre and local data management staff at the sites. A regular online RDM seminar series was launched together with the SciLifeLab Data Centre. Together with the SciLifeLab Data Centre we have also continued to develop and improve the joint support portal and guideline knowledge-base for research data management for Swedish life science (https://data-guidelines.scilifelab.se/).

In the European landscape, NBIS has continued to lead the activities of the ELIXIR Research Data Management Community, which functions as a pan-European competence network for research data management in the life sciences with over 200 RDM professionals in over 20 participating national nodes. This competence community has a focus on knowledge sharing, capacity building, and training for data management. Since the beginning of 2024, NBIS has also taken a leading role in related activities in ELIXIR's Scientific Programme 2024–2028, including the ELIXIR's Data and Interoperability Platforms and the ELIXIR-STEERS project. The data management team has continued its contributions in other international collaborations such as the EOSC and the Research Data Alliance (RDA). Notably, the team has joined EOSC Association's new Health Data Task Force and stepped forward to lead the EOSC Opportunity Area Expert Group on Metadata, Ontologies and Interoperability (OA2) to coordinate related challenges across the wider EOSC stakeholder community. The team has also continued its commitments in the RDA Life Science Data Infrastructures Interest Group, RDA's Technical Advisory Board, and the related ELIXIR RDA Activities Focus Group to promote global alignment and collaboration with national and European initiatives.

Human Data

NBIS contributes to Swedish and major European efforts for handling sensitive human data, and has since long been engaged in building these infrastructures.

Late 2023, NBIS submitted the first synthetic datasets to the **Federated European Genome-phenome Archive (FEGA)**, https://fega.nbis.se/. Federated EGA Sweden is an NBIS service and the deployed software is a result of our long-standing collaborative development with the Nordic ELIXIR Nodes, EMBL-EBI and CRG (Centre for Genomic Regulation (Spain), through the NeIC Tryggve and NeIC Heilsa Tryggvedottir projects. During 2024, the first real dataset was released, featuring large-scale genomic datasets from the Swedish Childhood Tumour Biobank in FEGA Sweden, providing a first important resource to aid further research and developments of new diagnostics and treatments.

To support the **European 1+Million Genomes Initiative (1+MG)**, EU funding has been obtained – 2020–2023 with the B1MG coordination and support action for writing recommendations on standards and methods; Nov 2022 – Jan 2027 with the subsequent implementation project GDI (Genomic Data Infrastructure), having a total budget of 40 MEUR; and 2025–2027 with B1MGplus for preparing the legal framework and increase contacts with clinicians, in Sweden NBIS will work together with GMS in the B1MGplus.

A major part in the GDI project is construction of the human genomic data infrastructure, led by NBIS as ELIXIR-SE together with ELIXIR-FI, building on experience from B1MG and FEGA. During 2024, NBIS has organised an on-site technical workshop for sharing expertise of the infrastructure and plan for the next improvements, as well as the expectations on the involved deploying countries. The workshops engaged about 90 European project members. Sweden is one of the "vanguard nodes" in GDI. In October 2024, NBIS and five other partners demonstrated the ability to run the infrastructure in its current state with synthetic data based on a relevant use case identified in the project.

GDI workshop in Brno

Genome of Europe (GoE): The most extensive EU-funded program on population genomics to date, "Genome of Europe" (GoE), was officially launched in October 2024 and will provide a unique data resource for the Life Science community. 27 countries join forces to establish a unique pan-European reference database containing 100,000 genomes representative of European citizens. This will deepen our understanding of variations in the human genome and be of benefit for personalized health care and research. NBIS is leading the international work on developing submission tracks to feed the data into the European Genomic Data Infrastructure (GDI), and the NBIS data stewards will collaborate with NGI, who coordinates the Swedish data generation.

Bigpicture is a European flagship project for establishing a Petabyte platform for digital pathology AI, engaging partners from academia, healthcare and industry. The Bigpicture platform is now receiving contributions from the pharmaceutical industry partners, on track to reach the end goal of storing 3 million digital pathology slides, which will amount to 4.5 Petabytes. We are utilizing the same technologies as used in the Federated EGA setup, demonstrating the versatility the underlying software we developed can be repurposed for several data sharing applications across research fields.

EUCAIM is a 4-year 36 MEUR EU project started in 2023 in order to build a European cancer image federation similar to GDI. AIDA Data Hub contributes a collaboration platform on its DSP (Data Science Platform) in collaboration with the SysDev unit. Furthermore, our SysDev unit will also work on interoperability with GDI.

ASHA is a 4-year 73 MSEK VINNOVA systems demonstrator started in 2023 to construct interconnected spaces for primary and secondary use of standardized health data, engaging Swedish healthcare regions, EHR systems provider Cambio, and start-up company PredictMe. AIDA Data Hub provides secondary use health data spaces on DSP, with driver use cases in PredictMe development of innovative epigenetic/multimodal AI tools for personalised medicine in long COVID and other systemic diseases, and in development of quality register data production for clinical echocardiography. In a parallel 2 MSEK MedTech4Health funded focus area collaboration with East Sweden Medtech (ESMT), AIDA Data Hub develops business models for scaling out this type of use of DSP to further businesses and efforts.

AIDA Data Hub has implemented support for sharing datasets containing synthesised medical images, for example as supplementary data to support scientific publication of generative AI algorithms. The value of such data is not so much in the shared synthetic images themselves, but more in the capability of the AI algorithms to produce much more data of the same kind on demand, showcasing defining characteristics of images from a specific clinic or cohort, but where no synthetic image has a 1-to-1 correspondence to any specific real person. This would mean that the synthetic images would not constitute personal data in the GDPR sense. Such synthetic images could therefore be shared more easily than the original, very sensitive, real images. The vision is that if larger quantities of such synthetic images were made available, from more sources, then new ideas for research or AI development could be "tried out" or "roughed in" using only the more easily accessible synthetic data, and any prototype showing promise could then potentially be "fine-tuned" using real data.

Computational Infrastructure

A fundamental part of NBIS is the formation of a sustainable compute infrastructure for life sciences, consisting of access to tools and data. The infrastructure is typically constructed as domain-specific supporting layers utilising resources from the national e-infrastructure providers NAISS and SUNET. Our computational and storage needs are set up in close collaboration with these infrastructures, in order to avoid duplication of efforts and to benefit from the competences within NAISS and SUNET.

Computational Resources

The AIDA Data Hub has prepared for a 15 MSEK extension of our Sensitive Data Services (SDS) during 2024 to a full-blown Data Science Platform (DSP) based on Bigpicture / GDI technologies such as SDA, REMS, Beacon network, and Life Science Login. These technologies, originally developed for genetics and extended in Bigpicture to support also pathology, will thereby be further extended to also support use cases in radiology using for example Grand-Challenge.org software components, and open standards health data using OpenEHR (ASHA). The original AIDA Data Hub Sensitive Data Services are tailored to suit the needs of leading-edge national expert AI researchers. However, the plans for DSP include feature additions to make the service more usable by further user competence profiles (such as clinicians) and other usage patterns (such as through a locked-down EHDS conformant remote desktop, or project private SaaS web applications like an open-source or Sectra PACS).

Computational Support

High throughput biomedical science depends on high-performance computers for bioinformatics analysis. The hardware is maintained by NAISS but NBIS provides expertise needed for domain scientists to efficiently access and use the computational and storage resources. Notably, over 1300 bioinformatics-related software packages are installed and maintained on NAISS compute clusters Dardel at Parallelldatorcentrum (PDC, Royal Institute of Technology) and, for sensitive data, Bianca at UPPMAX, Uppsala University. Support for Computational Resources also administers resource allocations and participates in help-desk support at the major national compute clusters, handling 2552 omics research projects with 984 unique PIs in 2024. These projects have used a total of over 9 million core hours each month and over 12 PB of storage.

During 2024, NBIS was instrumental in supporting the highly successful migration of the life science research community from UPPMAX to PDC. In addition to directly assisting users and working to set up the environment on Dardel, NBIS worked to deepen its involvement with NAISS support service, especially at PDC. To NBIS knowledge, no research projects suffered losses or significant interruptions during this migration.

Currently, the focus of this activity is to consolidate the gains and learnings from the previous year. Contacts and interfaces with NAISS will be formalised, and NBIS will start similar collaborations with other relevant support providers, such as Berzelius support. Gaps have been identified in NAISS services, which NBIS will work to resolve.

Systems Development & Tools

The systems development team at NBIS is dedicated to supporting the life science community by deploying tools and facilitating large scale analyses. They develop custom-made tools for researchers and user-friendly pipelines for stable and efficient analysis. The team works towards promoting reproducible research through the deployment of stable workflow systems and compute environments. They follow the scrum methodology in managing both internal and external projects and aim to make cutting-edge bioinformatics accessible to all.

The combination of bioinformatics experts, who can appraise the scientific value and usefulness of tools, with developers who have the capability of making tools stable and accessible, allows us to develop projects for the scientific community in a better way, since we can understand the needs of the user and provide our unique set of knowledge to help them. The development team also assists in internal development projects, *e.g.* for integrating data services with other initiatives. Furthermore, the team is active in the Global Alliance for Genomic and Health (GA4GH), working with technical standards and frameworks. The system development teams also serve NBIS infrastructure internally.

NBIS maintains a software repository for internal purposes and also public repositories for programs and scripts that are developed by our staff in order to get them to spread to the scientific community. For the latter, we have an organisational account on GitHub. We are also in charge of registration of relevant tools developed by Swedish research groups into the ELIXIR Tools Registry. Below we list a number of resources developed by NBIS.

PLUPP – the collaboration between NBIS and the Swedish Museum of Natural History (NRM) is continuing to create a single, comprehensive platform for pollen data. The new Open Pollen API (https://api.pollenrapporten.se/docs) developed during 2023 was published in early 2024.

Enhanced with new functionality, we have seen it being frequently used by third-party developers during 2024's pollen season. The API enables its users to incorporate real-time pollen forecasts into a wide range of applications, national media among them, making a big impact for allergic people and other interested users all over the country. PLUPP's advanced pollen prognosis system is currently also being incorporated into NRM's newly relaunched website to make it even more accessible for the broad public. This work also includes enhancements to the pollen level graphs. During 2024, the pollen prognosis system had 190 000 unique users.

NBIS is also developing a range of tools and workflows for other data types. For example, our workflows for metabolomics and metagenomics are openly available and have been applied in many projects (see https://www.nbis.se/about/resources/tools).

The AIDA Data Hub provides compute services for AI research on sensitive personal data in diagnostic imaging. Among many resulting publications, one example is an effort on self-supervised learning for pathology. Moreover, the infrastructure is providing policy support and other guidance for the domain. Current developments include plans to be a strategic collaborator to the SCAPIS project for data sharing of their unique imaging data collections.

The AIDA Data Hub has supported a Region Skåne led AIDA project aiming at constructing a database facilitating AI research and innovation in mammography. This collaboration served as one of the cornerstones for the AIDA led and VINNOVA funded incubator for validation environments for clinical imaging diagnostic AI (VAI), where AI providers can install tools that national healthcare providers can then evaluate in private using real clinical data. The VAI-B mammography environment is in production, and working to transition to sustainable operations mode, potentially as a national quality register.

AIDA Data Hub has also supported a Region Skåne led AIDA project aiming to develop and evaluate an AI algorithm for automatic identification of gold fiducial markers in an MRI-only prostate radiotherapy workflow. In an extension to this project, Region Skåne transitioned to an MRI-only workflow in its clinical practice for prostate radiotherapy, obviating the need for complementary CT-scans and reducing the time and complexity of the clinical workflow.

AIDA Data Hub has provided secure storage and GPU processing to a LiU-led AIDA project aiming to develop AI algorithms for automatic time-resolved cardiovascular segmentation of 4d flow MRI. This project is ongoing, and is currently receiving AI development support from the AIDA Data Hub, where initial results using 2D Generative Adversarial Networks are promising and were accepted to ISMRM 2024.

Advanced Training

Training is a core pillar of NBIS, reflecting the breadth and depth of bioinformatics and data science expertise within our staff. Beyond individual training integrated into the majority of our project-related support, empowering researchers to effectively utilize new tools and enhance their existing skills, NBIS leverages its unique concentration of expertise to deliver cutting-edge advanced training. This positions NBIS at the forefront of bioinformatics training in Sweden, supporting life-wide learning within the life sciences. Training activities, engaging the majority of NBIS staff, comprise approximately 13% of our overall effort. This encompasses our own NBIS training program, collaborative training ventures (e.g. supporting the SciLifeLab/KAW-funded DDLS program and the AIDA community), and contributions as invited lecturers and speakers at external training events. Furthermore, NBIS extends its training impact internationally, actively

participating in initiatives like ELIXIR. These international efforts involve not only delivering training but also developing frameworks and guidelines for educators and learners alike, promoting FAIR and Open training practices within the broader life science research infrastructure.

In 2024, NBIS primarily delivered training events in an on-site format, while a few were online. We increased the implementation of a third, multi-site hybrid format, where there are on-site classrooms at several locations which are virtually connected. Lectures are streamed from one site to the others while teaching assistants are present on all sites. This hybrid model has proven highly effective in expanding the reach of our training programs. Beyond our traditional multi-day courses, we also piloted shorter, 1–2 hour workshops focused on specific topics designed to address the growing demand for targeted training. Furthermore , in collaboration with the National Genomics Infrastructure (NGI), NBIS created recorded bite-sized webinars for project design and re-initiated the BiG Talk keynote webinars featuring leading experts. This enhances accessibility and creates opportunities for on-demand training.

Our training catalogue caters to graduate students, post-docs, and researchers, while also welcoming participants from the non-academic sector. This year, we introduced two new courses. *A primer on cryo-EM data processing using cryoSPARC on BerzeLiUs* and *Training material made FAIR by design*.

RaukR course 2024

In total, NBIS held 48 training events, comprising 20 courses within the NBIS training program, 8 workshops and 20 collaborative efforts (see table below). Across all these training activities in 2024, we had 1029 participants. Specifically, within the NBIS training program, we saw 422 participants with a 75% acceptance rate. Gender distribution among accepted participants was nearly equal, with 53% female representation. In addition, NBIS staff were invited to 26 additional training events with 803 participants.

The PhD advisory mentor programme in bioinformatics is a long-term initiative in NBIS with an increasing demand from is highly appreciated in the life science community. PhD students get bioinformatics mentorship guidance from NBIS experts over a period of 2 years. In 2024, there were 34 PhD students from 10 universities enrolled in the programme.

Course	From date	To date	Location	Participants
NBIS Training Programme (20 events, 422 participants)				
A primer on cryo-EM data processing using cryoSPARC on BerzeLiUs	2024-04-15	2024-04-16	Online	17
Epigenomics Data Analysis: from Bulk to Single Cell	2024-09-16	2024-09-20	Online	24
Introduction to bioinformatics using NGS data	2024-03-18	2024-03-22	Online	39
Introduction to bioinformatics using NGS data	2024-11-25	2024-11-29	Linköping	22
Introduction to Biostatistics and Machine Learning	2024-04-22	2024-04-26	Uppsala	19
Introduction to Data Management Practices	2024-04-23	2024-04-25	Stockholm	16
Introduction to Data Management Practices	2024-11-19	2024-11-21	Uppsala	16
Introduction to DM Practices for NGI	2024-05-08	2024-05-21	Stockholm, Online	15
Neural Nets and Deep Learning	2024-05-20	2024-05-24	Uppsala	20
Omics integration and Systems Biology	2024-10-14	2024-10-18	Lund	37
Programming Formalisms	2024-04-22	2024-04-26	Online	10
Programming Formalisms	2024-11-18	2024-11-22	Online	10
Python programming with applications to bioinformatics	2024-11-11	2024-11-15	Uppsala, Umeå, Lund	41
R Programming Foundations for Data Analysis	2024-10-28	2024-11-01	Uppsala, Lund	28
RaukR, Advanced R for Bioinformatics Online Workshop	2024-06-10	2024-06-20	Visby	34
RNAseq data analysis	2024-03-11	2024-03-15	Uppsala	17
Single Cell RNAseq data analysis	2024-02-12	2024-02-16	Uppsala	24
Snakemake bring-your-own-code workshop	2024-05-27	2024-05-29	Online	12
Tools for Reproducible research	2024-11-25	2024-11-29	Stockholm	13
Training material made FAIR by design	2024-09-18	2024-09-19	Uppsala	8
Workshops organised by NBIS (8 events, 205 participants)				
AIDA Technical Workshop on Constrastive Learning	2024-03-19	2024-03-19	Online	30
AIDA Workshop on profiling for computation efficiency	2024-03-20	2024-03-20	Online	10
AIDA Workshop on Reproducible Machine Learning Research	2024-09-03	2024-09-03	Online	48
AIDA Workshop on Model computational optimization	2024-09-04	2024-09-04	Online	45
RDM roadshow Workshop on Data Management Plans	2024-05-14	2024-05-14	Umeå	20

RDM roadshow Workshop on Data submission to public repositories	2024-05-14	2024-05-14	Umeå	20
RDM roadshow Workshop on Data Management Plans	2024-12-12	2024-12-12	Lund	20
RDM roadshow Workshop on Data submission to public repositories	2024-12-12	2024-12-12	Lund	12
Co-organised training events (20 events, 402 participants)				
An Introduction to Bioimage Analysis: Tools & Applications:	2024-10-30	2024-11-01	Belo Horizonte, Brazil	20
Bianca intermediate	2024-05-24	2024-05-24	Online	15
Bianca intermediate	2024-11-11	2024-11-11	Online	10
Bianca Intro course	2024-04-19	2024-04-19	Online	20
Bianca Intro course	2024-09-25	2024-09-25	Online	20
Bioimaging and Cell Analysis	2024-09-02	2024-10-01	Uppsala	30
Ethical, Legal and Social implications in Research Infrastructures and Core Facilities	2024-10-14	2024-10-16	Online	14
Genealogies and Ancestral Recombination Graphs	2024-08-17	2024-08-12	Oslo	25
Intro to Python	2024-01-18	2024-01-18	Online	20
Intro to UPPMAX	2024-08-27	2024-08-30	Online	20
Introduction to AI	2024-09-19	2024-10-24	Linköping	30
Introduction to QuPath	2024-12-10	2024-12-19	Uppsala	10
Introductory course to Image Analysis in Life Science	2024-09-23	2024-09-27	Göteborg	30
LCI microscopy course - From sample preparation to image analysis	2024-01-29	2024-02-16	Online/Stockholm	25
Python for HPC	2024-03-12	2024-03-12	Online	20
Python for HPC	2024-10-22	2024-10-22	Online	20
R for HPC	2024-03-14	2024-03-14	Online	20
R for HPC	2024-10-24	2024-10-24	Online	20
To awk or not	2024-01-22	2024-01-23	Online	20
To awk or not	2024-08-22	2024-08-23	Online/Uppsala	13
Invited lectures/University courses (26 events, 803 participants)				
Bioinformatics	2024-09-01	2024-10-30	Linköping	63
Advanced bioinformatics	2024-09-01	2024-10-30	Linköping	25
DNA Sequencing Informatics II	2024-03-15	2024-03-15	Lund	20
Workshop on Genomics 2024	2024-01-07	2024-01-19	Cesky Krumlov Czechia	65
Omics - Analysis of Large-scale Biomolecular Datasets	2024-11-04	2025-01-10	Lund	26
Applied Deep Learning in Physics	2024-11-14	2025-01-06	Uppsala	147
Systems Biology	2024-10-14	2024-10-14	Götebory	30
Molecular Techniques and Data Analysis in Precision Medicine I	2024-01-25	2024-01-25	Uppsala	15
Health Systems Design Summer School	2024-06-24	2024-06-28	Stockholm	20
Reproducibility in Research with a focus on data analysis using the program R	2024-10-22	2024-10-22	Online	7

Genome Analysis	2024-03-18	2024-03-18	Uppsala	40
Genome Analysis	2024-05-14	2024-05-14	Uppsala	40
Bioinformatics	2024-04-10	2024-04-10	Uppsala	15
Structural Biology	2024-09-02	2024-09-13	Stockholm	15
Structural Biology	2024-09-02	2024-09-13	Stockholm	15
AI Course for Radiologists and Pathologists	2024-05-13	2024-05-15	Linköping	20
Bioimaging and Cell Analysis	2024-09-02	2024-10-01	Uppsala	30
BK0001 Bioinformatics	2024-11-22	2024-11-22	Uppsala	15
Deep Learning for Image Analysis	2024-05-14	2024-05-14	Online	20
Ethical, Legal and Social implications in Research Infrastructures and Core Facilities	2024-10-14	2024-10-16	Online	14
Gene expression at spatial resolution	2024-03-04	2024-03-08	Heidelberg, Germany	25
Introduction to AI	2024-03-22	2024-03-22	Online	40
Introduktion till bioinformatik	2024-09-06	2024-09-13	Uppsala	21
JUST Data Synthetic and Health Data Day	2024-09-19	2024-09-19	Linköping	20
LCI microscopy course - From sample preparation to image analysis	2024-01-29	2024-02-16	Online/Stockholm	25
The Nordic Radiotherapy Diploma program for Clinical oncologists, part 1	2024-10-23	2024-10-25	Sigtuna	30

To address the growing demand for bioinformatics knowledge and skills, NBIS employs a training co-production model. This involves collaborating with other training providers, both nationally and internationally, to deliver comprehensive training programs. This model not only enhances capacity and knowledge building for researchers but also fosters valuable networking opportunities for both infrastructure staff and course participants, connecting them across different research infrastructures and organizations. Internal training is also a vital component of NBIS training efforts, facilitating knowledge transfer within the organization. In 2024, this primarily took place within individual teams and through cross-team technology groups.

We will continue to follow the vision for NBIS Training, which is to offer high quality training programmes aimed at the Swedish Life Science research community in order to grow bioinformatics capacity and competence in Sweden.

SciLifeLab Training Hub has grown and strengthened during 2024 and remains an important collaboration partner with NBIS. Much of what the Training Hub at SciLifeLab will offer and provide will be built collaboratively with the NBIS Training team. Also, Training Hub will make use of the open source and open educational resources established by ELIXIR, where NBIS plays a significant role. During 2024 training material on how to make Make Training material FAIR by design was co-developed by ELIXIR-BE and a course was delivered to an international audience in Uppsala during the fall.

NBIS Training members play a leading role in the ELIXIR Training Platform Work Programme 2024–2026, co-leading several key tasks and activities. During 2024 the focus has been on launching ELIXIR Training SPLASH, a centralised, digital environment, a "one-stop-shop," for ELIXIR Training Platform resources and ELIXIR Training metrics Database.

NBIS also remains an active and engaged contributor to the Train-the-Trainer instructor network.

NBIS Training members are leading contributors to the ELIXIR Training Platform Work Programme 2024–2026, co-leading several activities. In 2024, their focus has centred on the launch of two important resources: ELIXIR Training SPLASH, a centralised digital environment serving as a "one-stop-shop" for ELIXIR Training Platform resources, and the new version of ELIXIR Training Metrics Database. NBIS also continues its active engagement and contributions to the Train-the-Trainer instructor network.

NBIS has during 2024 continued to strengthen the connection to the Open Science scene in Sweden and with EOSC in particular. This is done in collaboration with SciLifeLab Training Hub and the Open Science team at SciLifeLab Data Centre. In 2024, NBIS co-delivered 2 workshops on Open Science at the SciLifeLab Facility Forum and co-delivered a course module within the RITrainPLUS programme on Open Science. The target audience for these activities was Research Infrastructure staff. In addition, a collaboration with Swedish National Data Service on a national course on *Open Science in the Swedish context* was established during 2024 and will be delivered in May 2025.

NBIS remains actively engaged in the EOSC association brain pool network, contributing to Opportunity Areas (OA2 Metadata, Ontologies and Interoperability [Wolmar Nyberg Åkerström]; OA5 Skills, Training, Rewards, Recognition and Upscaling [Elin Kronander/Jessica Lindvall]) and Task Forces (Health Data [Wolmar Nyberg Åkerström]; Technical and Semantic Operability [Jonas Söderberg]) which aims to provide crucial expertise for EOSC implementation and to support the development of the EOSC ecosystem.

Outreach

Outreach activities have proven important to inform the scientific community about the support that NBIS can provide, to increase collaborations and to increase the number of users and quality of projects. The activities consist of involvement in local community initiatives that provide the possibility to meet staff representing our wide variety of competences, presentations at events and conferences and weekly Bioinformatics Drop-in sessions enabling face-to-face contact between researchers and our experts, which many times is the first contact in a support case. During 2024, we arranged 36 national drop-ins via Zoom, as well as many physical drop-ins in Stockholm and Lund.

The Swedish Bioinformatics Workshop (SBW) 2024 took place in Uppsala and was once again sponsored in part by NBIS. The appreciated recurring event mixes renowned keynote speakers with workshop sessions and poster sessions.

The NBIS Artificial Intelligence and Integrative Omics seminar series, AI&IO, has become co-hosted together with Data Centre and changed name to the “SciLifeLab AI Seminar series”. In 2024 there were 9 seminars, with presenters from UU, LiU, UmU, KTH and one international. Notably two DDLS fellows presented. The seminars had an average audience of 26 people.

NBIS is engaged in multiple local activities across the country. In **Gothenburg**, NBIS is involved in managing the local bioinformatics network GOTBIN. NBIS is also active in the SciLifeLab Gothenburg site and provides input in the advisory board for the Core Facilities at University of Gothenburg and Sahlgrenska Academy. NBIS staff has also contributed to the establishment of a DDLS Data Science Node at Chalmers.

In **Linköping,** NBIS participates in the recent local bioinformatics gathering, the Bioinformatics Bash. NBIS is also in the infrastructure group of Linköping SciLifeLab site which is organising a series of seminars focused on local platforms.

In **Umeå**, NBIS has a strong presence at local events and has presented at KBC days and the PALS meeting, Program for Academic Leaders in Life Sciences, during 2024.

Finally, NBIS has a community coordinator to oversee and plan NBIS outreach activities and two local site coordinators. NBIS has internal Outreach group meetings which maintain a GitHub repository of outreach materials and presentations as well as discuss NBIS outreach strategy, visual profile and more.

Collaboration with industry

NBIS continues to proactively strengthen its relationships with life science companies by offering access to its resources on a full-cost basis. These resources include advanced tools, specialised expertise, and comprehensive training programs, enabling companies to benefit from NBIS's extensive support.

To better understand the challenges and opportunities in collaborating with small and medium enterprises (SMEs), NBIS conducted an internal SWOT analysis and, based on the results, directed their industry outreach efforts accordingly. We have also implemented improvements in our internal projects accounting system to better understand the needs of our industry partners. Moreover, NBIS actively participated in the WP5 activities of the Industry and Innovation ELIXIR Group, with the task of contributing analyses of the bioinformatics support for industry landscape in Sweden.

In 2024, we introduced new and refined existing policies for providing advanced training to industry users. The growing interest in our training offerings has been evident, with participation from industry data scientists in our courses. For instance, the RaukR Advanced R for Bioinformatics Summer School welcomed participants from Lantmännen, a major Swedish cooperative specialising in agriculture, bioenergy, and food production, and Gubra, a Danish company focusing on preclinical contract research and peptide-based drug discovery. We also established a successful collaboration with Pixelgen Technologies, which presented their cutting-edge spatial proteomics technology and sponsored a social event for RaukR students.

Throughout 2024, NBIS provided technical feedback on RNA-seq pipeline optimisation to a start-up company and engaged in an ongoing dialogue with another SME regarding machine learning applications in proteomics. We also received a request from a company specialising in immunological assays, regarding custom-tailored course on advanced statistical modelling, and discussions are ongoing. Additionally, NBIS continued supporting a large industry actor in analysing and visualising data from their spectroscopy equipment.

Internally, NBIS has fostered collaboration with the SciLifeLab External Relations Office (ERO) to enhance industry outreach efforts. Our Industry Outreach Coordinator now participates in an ERO-led working group. We also contributed to the SESAM project (Svensk Samverkan för Tillgång till Labbinfrastruktur) by providing feedback on industry access to bioinformatics infrastructure in Sweden and by being a part of SciLifeLab-SESAM working group.

Our internal Outreach Group has been developing targeted outreach materials for current and prospective industry partners. We have also established connections with university innovation incubators. A notable example is our joint presentation with Key2Brain at the Karolinska Institute Science Park After Work event, which effectively showcased NBIS's project support and engaged potential SME collaborators.

International

NBIS is the Swedish node in the European infrastructure ELIXIR. NBIS also aims at strengthening the Nordic collaborations, and since 2011, we have regular meetings between the Nordic ELIXIR Heads of Nodes. During the period 2013–2024, we have had funding from NeIC (Nordic eInfrastructure Collaboration) for development and provision of infrastructure for sensitive data (current project NeIC Heilsa Tryggvedottir). On the bioimage analysis side, the BIIF unit of NBIS is involved in Euro-Bioimaging, GloBIAS, Ai4Life, and Chan-Zuckerberg image analysis initiatives, as well as in the international initiatives driving the standardisation of file formats (OME-NGFF) and usage of pipelines (e.g. nf-core) in image analysis.

ELIXIR is unique in Europe encompassing all European national bioinformatics infrastructures into a coordinated distributed research infrastructure with currently 23 partners and more expected to join.

ELIXIR-SE was hosting the 2024 All Hands Meeting in Uppsala 10–12 June – a very successful event with over 400 attendees.

ELIXIR All Hands Meeting 2024 in Uppsala

During 2024, ELIXIR-SE has continued maintaining and updating the Human Protein Atlas – which is officially named as an ELIXIR Core Data Resource – in the ELIXIR landscape.

ELIXIR-SE has been very active in the systems development for and coordination and support of Federated EGA (FEGA) in collaboration with other Nordic ELIXIR nodes, ELIXIR-Spain and ELIXIR-EBI. Since February 2024, the Swedish FEGA node is in production.

Furthermore, NBIS as ELIXIR-SE has been active in multiple EU projects (as described above), e.g. GDI (Genomic Data Infrastructure), Bigpicture for digital pathology, EUCAIM providing infrastructure for cancer image data, and PHENET (where NBIS provides training on the European level).

During 2024, two EU projects were finalised – EJP-RD and EHDS2 Pilot. Furthermore, four new EU projects involving NBIS were started – ERDERA for rare diseases, which is the successor of EJP-RD, TEHDAS2 for outlining the details for EHDS, GoE (Genome of Europe) to collect a large European cohort of DNA from healthy individuals to be included in the 1+MG, and CANDLE for establishment of national cancer data nodes.

Staff

The table shows the number of staff in FTE (full time equivalents) during 2024 for the different functions in NBIS. Gender balance is 69% male and 31% female (same as 2023). Number of FTEs has increased from 94.3 in 2023 to 104.6 in 2024.

NBIS	Staff (FTE)
1 Central functions, incl. management	7.0
2A User fee Support (SMS)	23.1
2B Peer review Support (LTS)	16.8
3A Data management	3.3
3B Human data	16.4
4A Systems development	4.3
4B Pipelines & Tools	3.3
5 Support for Computational Resources	5.8
6 Training	13.6
7 ELIXIR	3.6
8A BioImage Informatics	5.1
8B AIDA Data Hub	2.5
TOTAL	**104.6**

Economy report for 2024

NBIS	2024	Result 2024	Budget 2024	Result 2023
Incomes	VR Infrastructure grant	24 536 232	20 000 000	20 000 000
	VR grant EGA-SE	3 449 765	1 404 000	2 093 946
	VR grant Biodiversity	612 975	1 000 000	2 368 913
	SciLifeLab National	30 809 896	29 760 000	28 850 000
	Universities + SciLifeLab SFO	20 142 000	20 142 000	19 273 000
	KAW	27 328 242	27 600 000	26 498 748
	Vinnova (incl. Co-funding EU-proj.)	4 597 703	5 018 000	2 657 710
	EU + ELIXIR	12 953 672	12 351 000	12 190 014
	NeIC NordForsk	932 405	600 000	2 011 395
	Chan-Zuckerberg	1 000 000	1 000 000	1 000 000
	User fees	12 015 495	12 100 000	8 923 588
	Balance from 2023 and earlier	3 810 714	7 594 000	
	SUM Incomes	**142 189 099**	**136 165 000**	**125 867 313**
Expenses	Personnel	95 408 400	100 862 963	81 707 508
	Equipment	5 408 164		3 567 277
	Travel	2 050 996		3 358 247
	Other costs	5 021 415		3 569 889
	Office space	5 917 933	35 302 037	5 948 944
	Indirect costs	28 382 191		25 420 555
	SUM Expenses	**142 189 099**	**136 165 000**	**123 572 420**

Distribution of costs on the different NBIS activities

Activity	kSEK	Budget
1 - Central functions[1]	10 528	9 500
2A – User fee Support (SMS)	32 986	32 917[2]
2B – Peer review Support (LTS)	23 439	36 150[2]
2C – Support Sysbio	included in 2B	
3A – Data management	4 692[3]	8 660[2]
3B – Human data	21 888[4]	
4A – Systems development	6 028	17 920[2]
4B – Pipelines & tools	4 239	
5 – Compute & Storage	5 210	7 370[2]
6 – Training & Nat networking	18 470	[2]
7 – ELIXIR + EU projects	5 173	9 264
8A – BioImage Informatics	6 470	5 850
8B – AIDA Data Hub	3 066	8 534
9 – Other	0	0
SUM	**142 189**	**136 165**
SUM (excluding new modules 8A 8B)	**132 653**	**121 781**

[1]Central functions also include project management for Support
[2]Training costs are included in budget of modules 2–5
[3]Several activities in data management are filed under 6 Training and 7 ELIXIR
[4]Human data activities have been budgeted in modules 3, 4, 7 and 8B

Annex – Key performance indicators

1. Number of projects

During 2024, we have worked on 245 support projects and provided 64 consultations, involving a total of 257 unique PIs (112 female, 142 male, 3 no info). In addition, the BioImage Informatics unit provided support and consultations to 44 projects, and the AIDA Data Hub unit has provided AI support in 18 projects.

2. Number of PIs distributed on universities

Univ	# Unique PI
Chalmers	5
GU	15
KI	62
KTH	6
LiU	10
LNU	1
LU	44
NRM	4
SU	22
SLU	8
UMU	20
UU	53
Other Uni	2
Other Org	2
International Uni	1
Industry	2

3. Number of projects distributed on SCB codes

SCB code and subject	
102 Computer and Information Sciences	3
105 Earth and Related Environmental Sciences	2
106 Biological Sciences	107
107 Other Natural Sciences	4
209 Industrial Biotechnology	3
211 Other Engineering and Technologies	1
301 Basic Medicine	61
302 Clinical Medicine	42
303 Health Sciences	21
304 Medical Biotechnology	8
305 Other Medical and Health Sciences	4
403 Veterinary Science	1
501 Psychology	1

4. Gender balance

A total of 257 unique PIs have received support and/or consultations, of which 112 female (44%) and 142 male (55%).

5. Number of users that have applied for access but not being prioritised

Here we show numbers from the WABI part of NBIS, since other users have the option of paying user fees as long as their project is technically feasible and NBIS has capacity. In 2024, a total of 78 applicants of which 29 were granted peer review (LTS) support (37%). Female: 31 applicants of which 9 were granted (29%). Male: 47 applicants of which 20 were granted (43%). Thus, there was during 2024 somewhat lower success rate among female PIs. The number of PIs are small, and it varies from year to year (in 2023, there was no difference in success rate), but we will keep monitoring if there is a systematic bias over time. As a side note, as of 2025, we have implemented a new and more formally regulated process of appointing the members of the evaluation committee (currently 5 men and 5 women).

6. Publications

A total of 100 publications in 2024 have been published from our direct project support work (excluding Compute & Storage); DOIs provided in the table below.

10.1002/art.42683	10.1038/s41597-023-02825-5	10.1111/trf.17840
10.1002/cyto.a.24884	10.1038/s41597-024-03465-z	10.1126/sciadv.adn0597
10.1002/iid3.1162	10.1038/s41598-024-54724-3	10.1136/rmdopen-2023-004039
10.1007/s10592-023-01586-3	10.1038/s41598-024-56096-0	10.1158/1078-0432.CCR-23-3461
10.1007/s11259-024-10321-3	10.1038/s41598-024-63566-y	10.1158/1078-0432.CCR-24-0384
10.1016/j.biocon.2024.110694	10.1038/s41598-024-64352-6	10.1158/2767-9764.CRC-24-0201
10.1016/j.bja.2024.07.040	10.1038/s41598-024-64846-3	10.1186/s12864-023-09924-y
10.1016/j.cell.2024.02.030	10.1038/s41598-024-68479-4	10.1186/s12864-024-10380-5
10.1016/j.cell.2024.05.033	10.1038/s41698-024-00594-x	10.1186/s12864-024-10682-8
10.1016/j.ebiom.2024.105144	10.1038/s42003-024-06558-y	10.1186/s12879-024-10279-2
10.1016/j.ebiom.2024.105217	10.1038/s43588-024-00714-4	10.1186/s12943-024-02091-y
10.1016/j.immuno.2024.100046	10.1038/s44161-024-00448-6	10.1186/s13059-023-03135-0
10.1016/j.isci.2024.109344	10.1038/s44161-024-00478-0	10.1186/s40168-024-01762-8
10.1016/j.isci.2024.110659	10.1038/s44185-024-00054-6	10.1186/s40635-024-00675-y
10.1016/j.jas.2024.106001	10.1038/s44321-024-00104-3	10.1242/dev.202525
10.1016/j.jaut.2023.103166	10.1093/bioinformatics/btae187	10.1242/jcs.262322
10.1016/j.jlr.2024.100669	10.1093/bioinformatics/btae477	10.12688/f1000research.146301.2
10.1016/j.stem.2024.11.013	10.1093/bioinformatics/btae586	10.1369/00221554241274856
10.1021/acs.jproteome.3c00636	10.1093/bjsopen/zrae004	10.1371/journal.pgen.1010719
10.1021/acschemneuro.4c00636	10.1093/evlett/qrae023	10.1371/journal.pgen.1011285
10.1021/acsomega.4c08215	10.1093/gbe/evad235	10.1371/journal.pone.0296672
10.1038/s41388-024-03165-3	10.1093/gbe/evae031	10.1371/journal.pone.0299075
10.1038/s41467-024-46076-3	10.1093/gbe/evae049	10.1371/journal.pone.0308521
10.1038/s41467-024-46384-8	10.1093/gbe/evae143	10.1371/journal.ppat.1012709
10.1038/s41467-024-48916-8	10.1093/glycob/cwad098	10.26508/lsa.202302128
10.1038/s41467-024-50239-7	10.1093/ismeco/ycad016	10.3389/fendo.2024.1454006
10.1038/s41467-024-52951-w	10.1093/molbev/msae087	10.3389/fnagi.2024.1337365
10.1038/s41467-024-53752-x	10.1093/nar/gkae009	10.3390/antibiotics13121226
10.1038/s41467-024-54848-0	10.1093/nar/gkae589	10.3390/cancers16132289
10.1038/s41531-024-00707-0	10.1093/nar/gkae662	10.3390/cancers16223816
10.1038/s41586-024-08247-6	10.1111/aji.13814	10.3390/ijms25189886
10.1038/s41591-024-03204-2	10.1111/mec.17205	10.3390/md22050199
10.1038/s41592-024-02493-2	10.1111/mec.17348	
10.1038/s41593-024-01678-4	10.1111/mec.17479	