

The Information Ecosystem of Open Science: Key Aspects of Development

N. S. Redkina*

*State Public Scientific and Technological Library, Siberian Branch
of the Russian Academy of Sciences, Novosibirsk, 630102 Russia*

**e-mail: redkina@spsl.nsc.ru*

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Abstract—This paper presents the results of an analysis of trends in the development of the information ecosystem of open science based on the study of the practices of the main actors (research and educational organizations, publishers, sponsors of scientific research, and libraries), the dynamics of the number and prevalence of open access publications by fields of knowledge, scientific institutions and countries. Areas of development of the open information space of Russian science are identified.

Keywords: open science, information ecosystem, scientists, publishing houses, libraries, scientific foundations, universities, ratings, open access, scientific data, publications

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INTRODUCTION

The metaphor of the information ecosystem is widely used in the academic study of libraries and has become almost ubiquitous in discussions of information systems that support scientific communication and various forms of data and publications exchange [1]. As a result of a systematic literature review that covers 67 articles from journals included in the databases *Web of Science – Core Collection* and *Scopus*, as well as 8 official publications from databases of inter-governmental organizations, R. Vicente-Saez and C. Martinez-Fuentes concluded that open science entails transparent and accessible knowledge that is shared and developed through collaborative networks [2]. This definition is comprehensive and up-to-date since, allowing new trends and components of open science, such as open source, open data, open access, data reuse, alternative reputation systems, open lab notes, science blogs, collaborative bibliographies, civic science, open peer review, etc., hosted on various open platforms that enable extensive research collaboration.

In general, the information ecosystem of open science is to be understood as a complex, self-organizing, self-regulating, and self-developing system, resting on the interconnection and interdependence of the main actors (scientific foundations, publishing houses, libraries, and scientific and research organizations), as well as the open-access information resources generated by them, their initiatives, and open science support services. The main actors in open science contribute to the creation of open electronic resources and

their promotion in global information spaces through the implementation of the FAIR principles,¹ the organization of institutional data warehouses and centers for scientific cooperation, and activities aimed at effectively presenting the results of scientific research in a single information ecosystem of knowledge.

TRANSFORMATION OF THE INFORMATION ECOSYSTEM OF SCIENCE

In recent years, the information ecosystem of science has transformed: the general principles of open science are being redefined; investment in open science and shared information infrastructures is increasing; a legal harmonization of intellectual property rights and support for the free licenses Open Creative Commons is taking place; international scientific communications and cooperation are developing to a greater and greater extent; various models have emerged to support open access publishing; and a culture of open science is emerging. Scientists have begun to feel that the scientific and social benefits of presenting results in the public domain (in particular, the increase in citation) are improving the quality of research through transparency and reproducibility in research practices. Open access (OA) today constitutes

¹ That is, findable, accessible, interoperable, and re-usable: findability indicates easy search for specific data sets, accessibility is convenient access (according to access conditions and storage capabilities over a long time), interoperability denotes compatibility with other datasets or software, and reusability is multiple (repeated) use in further research.

the opportunity to not only freely obtain information and data but also to repeatedly analyze and use them, including for commercial purposes. The research landscape is changing, and all interested parties (researchers, publishers, sponsors, and librarians) are actively participating in these changes.

Scientific Foundations and Initiatives

The number of organizations and projects that are funding research for future publication is growing. An analysis of sponsorship by country shows that scientific foundations from China, Japan, the United States, the European Union, Great Britain, etc. predominate. Depending on the subject area, the list of funding organizations varies: the most common funding organizations in the field of social and human sciences are National Institutes of Health, U.S. Department of Health and Human Services, European Commission, National Science Foundation, National Natural Science Foundation of China, UK Research and Innovation, Horizon 2020 Framework Programme, Economic and Social Research Council, and in the field of natural and technical sciences there are also specialized funding organizations such as the U.S. Department of Energy, Japan Society for the Promotion of Science, Engineering and Physical Sciences Research Council [3].

A significant contribution to the development of open science has been made by the *coAlition S* program [4]—the initiative of an international consortium of research sponsors built around Plan S, which consists of one goal and ten principles. The Plan S open access initiative [5] requires that scientific publications based on research funded by government grants be placed in appropriate open access journals or platforms or be immediately available through open access repositories without embargo. Researchers have noted that, despite the clear advantages of Plan S, it also has many disadvantages associated with the transformation of journals in the transition to fully open access: in particular, deadlines, equally strict rules in different subject areas, violation of the principles of academic freedom, and legal risks [6–9]. The European Research Council (ERC) has announced that it is ending support for Plan S [10] following a similar decision by the Riksbanksens Jubileumsfond in 2019 [11]. The ERC calls for open access plans to take into account the needs of researchers, especially young ones, as well as the need to maintain equality between scientific communities and European countries, given the problems of countries with more limited national research funding [12]. This project has been called premature, but discussing it has made it possible to determine not only the problems, but also the prospects for the development of open science.

Publishers

More and more scientific journals are in open access or offer options for publishing articles under open licenses. At the beginning of 2022, there were more than 17000 titles on the platform of the international aggregator of open access journals Directory of Open Access Journals—DOAJ (<https://doaj.org>). The largest publishers offer models for improving the visibility of, sharing of, and open access to data, which increases the transparency and reliability of research, urging authors to share more than research data [13]. Since 2017, users of the Scopus Database have been able to see links to research data if they are used in an indexed article. Elsevier has more than ten research data dissemination projects and is an active member of projects of the Research Data Alliance (www.rd-alliance.org), which is implementing social and technical initiatives to ensure open data sharing; Force11 (www.force11.org), which is bringing together scientists and libraries to implement new principles for working with data; and the National Data Service (www.nationaldataservice.org), which links data archiving and dissemination initiatives with available tools and software [14].

Open science, which implies the openness of the entire research process, is extremely important for the scientific ecosystem. The research community, at least in science, technology, engineering, and mathematics subjects, is actively developing in this area, with an increase in the use of preprint servers, the spread of repositories for data exchange, journals with a more and more liberal policy regarding preprint updates, and a general understanding of the importance of open science among researchers and its application in practice [12].

A growing number of institutional multi-content repositories, including scientific articles, datasets, abstracts, lab notes, open access publishing models (gold, green, hybrid, etc.), and open peer review platforms (e.g., F1000Research) are helping advance the open science paradigm.

Libraries

The role of scientific libraries in open science is recognized by the professional and research community and is indicated in the documents of the European Commission, the Organization for Economic Cooperation and Development and other acts at the international and national levels [3]. Librarians have expanded the range of services in accordance with the open access policies adopted by universities; developing institutional repositories; creating research data management services; participating in regional, national, and international initiatives such as *HathiTrust* to expand access to scientific collections; and implementing forms of supporting open data, open

source software, open educational resources, and open knowledge.

Research and Educational Organizations

In recent years, several studies have been conducted to identify the level of awareness and use of open access resources among scientists from different countries [15–19]; these have identified obstacles to the spread of open access practices. For instance, scientists do not publish their articles in open access journals because they are not familiar enough with this type of journal in their field of study, do not use institutional repositories with open access, preferring to store research results and laboratory data in their own secure archive; are biased against open access, believing that open access (OA) journals have lower prestige and peer review quality; express national security concerns; need advice on copyright or external funding requirements; do not know the concepts associated with open access journals and types (green, gold, bronze open access, etc.), do not know about the DOAJ directory of open access journals; are unfamiliar with the concepts related to the Directory of Open Access Books (DOAB), self-archiving, institutional open access repositories, Open Access Theses and Dissertations (OATD) for retrieval of theses and dissertations (6 191 206 titles in 2020) in open access from over 1100 colleges, universities and research institutes. At the same time, scientists are publishing more, due to the presence of developed institutional strategies for open access and roadmaps for managing research data, as well as the felt need to comply with the requirements of grantors and the conditions for publishing articles in leading world journals.

Let us consider the development of the open science information ecosystem in more detail, taking the viewpoint of the analysis of open access publications in the world and in Russia.

RANKING THE OPENNESS OF UNIVERSITIES WORLDWIDE

An analysis of the world's leading universities is reflected in the Leiden Ranking (CWTS Leiden Ranking, <https://www.leidenranking.com>). This ranking, based on publications included in the Web of Science database, offers a complex set of bibliometric measure to provide statistics on the scientific impact, collaborations, open access publications, and gender characteristics of universities, as well as providing the following open access publishing metrics:

P—the total number of university publications;

P(OA) and PP(OA)—the number and share of university publications in open access;

P (gold OA) and PP (gold OA)—the number and share of university publications in gold open access;

P (hybrid OA) and PP (hybrid OA)—the number and share of university hybrid open access publications, i.e., publications in subscription journals that are in the public domain with a license that allows the publication to be reused;

P (bronze OA) and PP (bronze OA)—the number and share of university publications in bronze open access. Bronze open access publications are publications in a subscription journal that are in the public domain without a license to reuse the publication;

P (green OA) and PP (green OA)—the number and share of university publications in green open access. Green open access publications are publications in a subscription journal that are publicly available not in the journal itself, but in the repository;

P (OA is unknown) and PP (OA is unknown)—the number and share of university publications for which the open access status is unknown. These publications usually do not have a DOI in the Web of Science database.

When calculating the P(OA) and PP(OA) indicators, a publication is considered to be open access if it has gold, hybrid, bronze, or green open access. The open access status of a publication is determined based on data from Unpaywall (<https://unpaywall.org/>).

Based on the statistical data available in the Leiden Ranking, including publications for the period 2016–2019, we have created a ranking of universities worldwide in terms of the number of publications in all sciences (Table 1). A detailed study of the ranking showed that the share of open access publications was weakly correlated with the total number of university publications. Thus, the first lines of the ranking in terms of the number of publications are occupied by the Harvard University (United States), University of the Chinese Academy of Sciences (China) and University of Toronto (Canada). However, the leaders in terms of the share of open access publications (PP(OA)) are the Bilkent University (Turkey)—94%, London School of Hygiene and Tropical Medicine (United Kingdom)—93.7%, and University of Portsmouth (United Kingdom)—93.3%, which may indicate the existence of particular university policies and the development of an open science culture.

The research results of P.G. Arefiev and A.Ya. Nazarenko's "On the Positions of RAS Journals in Subject Rankings of International Science Citation Bases" [20] show that the number of articles with Russian affiliation is growing in "quartile" journals from the *Web of Science Core Collection*. In 2020, there were approximately 27000 such articles, which is 19% higher than in 2019. Of these 27000 articles, only 20000 were in subscription-based journals, and 7000 (26%) were foreign *Open Access* journals. Researchers note that the sector of Russian articles in *Open Access* journals is growing at a faster pace (by 49% in 2020), which they believe accounts for most of the 19% of the total increase in the number of Russian articles in 2020

Table 1. Ranking of universities worldwide by the number of publications (according to the *CWTS Leiden Ranking*), 2016 – 2019 (fragment)

№	University	Number of publications		
		total/P	in open access/P(OA)	share in open access/PP(OA), %
1	Harvard University	82476	59599	72.3
2	University of Chinese Academy of Sciences	63167	22879	36.2
3	University of Toronto	47429	25563	53.9
4	Shanghai Jiao Tong University	45645	19712	43.2
5	Zhejiang University	43033	17289	40.2
6	Johns Hopkins University	42900	30344	70.7
7	University of Michigan	41266	28065	68.0
8	University of Oxford	41154	35031	85.1
9	Tsinghua University	40386	14320	35.5
10	London University College	40263	35448	88.0
11	Stanford University	39938	27390	68.6
12	Universidade de São Paulo	38628	18784	48.6
13	University of Washington	38208	26335	68.9
14	Peking University	37357	18190	48.7
15	University of Cambridge	35202	29673	84.3
16	University of Tokyo	34967	20649	59.1
17	University of California, Los Angeles	33599	22930	68.2
18	Duke University	33415	23069	69.0
19	Columbia University	33011	22631	68.6
20	University of Melbourne	32871	18780	57.1
21	University of Pennsylvania	32731	22401	68.4
22	London Imperial College	32217	27103	84.1
23	Sun Yat-sen University	32100	15468	48.2
24	Seoul national university	31869	15410	48.4
25	Sorbonne Université	30681	22862	74.5

[20]. We have identified Russian universities that are available in the Leiden ranking and have a share of open access publications that is >50%: Moscow Institute of Physics and Technology, National Research Nuclear University “MEPhI”, “Higher School of Economics” National Research University, and ITMO National Research University (Table 2). At the same time, the leader in the total number of publications is the Moscow State University (45.8%), which is followed by the St. Petersburg and Novosibirsk State Universities with shares of 43% and 47%, respectively, which confirms the earlier conclusion that there is no relationship between the total number of publications and the share of articles in open access.

Thus, the information infrastructure of open access in Russia is developing, as is the understanding of the importance and advantages of open science practices. This is also seen in the questions raised about the creation of the Russian Academic Publishing House, the main goal of which must be to publish the best Russian

journals in the Open Access mode (including the Russian and English versions). In this case, according to A.R. Khokhlov, budgetary funds will be used to develop a system of high-quality Russian journals and not to pay for the services of foreign publishing companies that produce dubious journals [21]. Next, we present the open information space of Russian science in more detail.

OPEN INFORMATION SPACE OF RUSSIAN SCIENCE

Using the Scopus International Database, we analyzed the openness of the results of scientific research by Russian scientists. In all, 1 773 713 documents had an affiliation with a Russian organization in the Scopus Database as of March 1, 2022 was. At the same time, the number of publications over 10 years (2012–2021) had increased almost 8-fold, and the share of open access publications is also growing, reaching 47%

Table 2. Rating of Russian universities by the share of university publications in open access (according to the *CWTS Leiden Ranking*), 2016–2019

№	University	Number of publications		
		total/P	in open access/P(OA)	share in open access/PP(OA), %
1	Moscow Institute of Physics and Technology	4526	2974	65.7
2	National Research Nuclear University “MEPhI”	4115	2571	62.5
3	HSE University	2986	1710	57.3
4	ITMO University	3104	1559	50.2
5	Novosibirsk State University	6389	3001	47.0
6	Lomonosov Moscow State University	13465	6169	45.8
7	Kazan Federal University	3081	1370	44.5
8	St Petersburg University	6818	2934	43.0
9	National Research Tomsk Polytechnic University	2685	1110	41.3
10	Ural Federal University	2928	883	30.2

Table 3. Share of open access publications by Russian researchers in the *Scopus* Database for 2012–2021 (AFFILCOUNTRY (russia*) AND (LIMIT-TO (OA, “all”))) (data as of March 1, 2022)

Year	Number of publications		
	OA	total	the share of OA, %
2021	56815	121 500	47
2020	56496	127 650	44
2019	47898	119 474	40
2018	38350	106 559	36
2017	29984	92 171	33
2016	23241	84 035	28
2015	17336	69 405	25
2014	11 025	59 236	19
2013	9 474	50 494	19
2012	7 717	45 401	17

in 2021 (Table 3). Most of these publications are in green access (189 129), followed by bronze open access publications (132 218), and gold open access publications (129 596).

Among the organizations that are funding research involving Russian scientists, the results of which are publicly available and reflected in the *Scopus* Database, we have identified funds and institutions in Russia, in particular, the Russian Foundation for Basic Research, Russian Science Foundation, Ministry of Education and Science of the Russian Federation, Council for Grants of the President of the Russian Federation, foreign funds of China, the United States, Germany, Japan, as well as European programs (Seventh Framework Program, *Horizon 2020* Framework Program) (Table 4). The distribution by types of open access documents is as follows: articles—249 338, conference proceedings—98 184, reviews—16 827.

The study of the number of open access articles by affiliation to a scientific institution showed a greater number of articles from scientific organizations with affiliation of the Russian Academy of Sciences, including the Siberian Branch of the Russian Academy of Sciences. Among the publications of individual institutions, the notable place is occupied by the leading universities of the country (Moscow State University, St. Petersburg State University, etc.), as well as two institutions in the field of nuclear research (Joint Institute for Nuclear Research, Dubna Joint Institute for Nuclear Research and National Research Nuclear University “MEPhI”) (Table 5).

Analysis of the distribution of open access publications by fields of knowledge indicates a high proportion (more than 30%) of articles on veterinary medicine, dentistry, nursing, multidisciplinary sciences, immunology, and microbiology being placed in open access. This is followed by subject areas such as eco-

Table 4. The list of the most frequently found organizations that fund research with the participation of Russian scientists, the results of which are publicly available and reflected in the *Scopus* Database. Query: AFFILCOUNTRY (russia*) AND (LIMIT-TO (OA, "all")) (specification FUND-SPONSOR)

№	Organization	E-mail of an organization	Number of OA articles
1	Russian Foundation for Basic Research	https://www.rfbr.ru/rffi/ru	47360
2	Russian Science Foundation	https://www.rscf.ru	27199
3	Ministry of Education and Science of the Russian Federation	https://minobrnauki.gov.ru/grants	17949
4	National Science Foundation (US)	https://www.nsf.gov	10716
5	Deutsche Forschungsgemeinschaft (Deutschland)	https://www.dfg.de	7990
6	Russian Academy of Sciences	http://www.ras.ru	6323
7	Science and Technology Facilities Council (UK)	https://stfc.ukri.org	6241
8	Seventh Framework Programme (European Union)	https://cordis.europa.eu/programme/id/FP7	5193
9	National Natural Science Foundation of China	https://www.nsf.gov.cn/english/site_1/index.html	5188
10	U.S. Department of Energy	https://www.energy.gov	4799
11	European Commission	https://ec.europa.eu	4385
12	Japan Society for the Promotion of Science	https://www.jsps.go.jp/english	4110
13	European Research Council	https://erc.europa.eu	3893
14	Bundesministerium für Bildung und Forschung (Deutschland)	https://www.bmbf.de	3704
15	National Institute of Health (US)	https://www.nih.gov	3582
16	Horizon 2020 Framework Programme	https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en	3536
17	Council on grants of the President of the Russian Federation	https://grants.extech.ru	3069

nomics (28%), pharmacology (27%), medicine (27%), informatics (25%), etc. (Table 6). The smallest share of OA publications is typical for areas of research such as engineering (14%), earth sciences (15%).

The publication of scientific research on open platforms greatly increases the number of citations [22]. Our study based on the example of the subject area "Astronomy and Astrophysics; Nuclear Physics; Physics of Fields and Particles" also showed that OA articles had a high citation rate. Thus, the publications in the WoS Database, where scientists from Russian scientific institutions act as co-authors, included an article prepared in collaboration with 186 authors with affiliation of 228 researchers from Germany, South Korea, Poland, Mexico, Taiwan, and others, as well as a number of authors from Russian scientific organizations, including Moscow State University, Joint Institute for Nuclear Research (Dubna), B.P. Konstantinov St. Petersburg Institute of Nuclear Physics, Institute for Nuclear Research of the Russian Academy of

Sciences, Institute for Theoretical and Experimental Physics, P.N. Lebedev Physical Institute of the Russian Academy of Sciences, and Institute of High Energy Physics. By 2022, this article has been cited 6901 times.

Chatrchyan, S. et al. Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC (2012) // *Physics Letters, Section B: Nuclear, Elementary Particle and High Energy Physics*, 716 (1), pp. 30-61. DOI: 10.1016/j.physletb.2012.08.021

For example, the article with the greatest number of citations in this subject area has 12872 references and is also publicly available.

Riess, A.G., Filippenko, A.V., Challis, P., Clocchiatti, A., Diercks, A., Garnavich, P.M., Gilliland, R.L., Hogan, C.J., Jha, S., Kirshner, R.P., Leibundgut, B., Phillips, M.M., Reiss, D., Schmidt, B.P., Schommer, R.A., Smith, R.C., Spyromilio, J., Stubbs, C., Suntzeff, N.B., Tonry, J. Observational evidence from supernovae for an accelerating universe and a cosmo-

Table 5. Number of open access articles of Russian scientific institutions in the *Scopus* Database (data as of March 1, 2022)

№	Scientific institution	Number of OA articles in the <i>Scopus</i> DB
1	Russian Academy of Sciences	65545
2	Lomonosov Moscow State University	32294
3	Siberian Branch Russian Academy of Sciences	16238
4	Joint Institute for Nuclear Research, Dubna	15594
5	Saint Petersburg State University	15371
6	National Research Nuclear University MEPhI	10269
7	Alikhanov Institute for Theoretical and Experimental Physics	10247
8	Novosibirsk State University	10089
9	P.N. Lebedev Physical Institute of the Russian Academy of Sciences	9483
10	Moscow Institute of Physics and Technology	9353
11	HSE University	9166
12	Sechenov First Moscow State Medical University	8305
13	Kazan Federal University	8284
14	B.P. Konstantinov Petersburg Nuclear Physics Institute PNPI	7765
15	Ural Federal University	7753
16	Peter the Great St. Petersburg Polytechnic University	7680
17	Tomsk State University	7425
18	Tomsk Polytechnic University	7156

Table 6. Distribution of open access publications with affiliation of a Russian scientific organization in the *Scopus* Database (data as of March 1, 2022)

№	Area of knowledge	Number of publications		
		OA	total	share of OA, %
1	Physics and Astronomy	125974	538586	23
2	Engineering	52232	369186	14
3	Earth and Planetary Sciences	50339	335892	15
4	Materials Science	50326	269614	19
5	Medicine	48021	179132	27
6	Environmental Science	39037	178987	22
7	Mathematics	34667	169033	21
8	Biochemistry, Genetics and Molecular Biology	34183	158868	22
9	Social Sciences	30749	137995	22
10	Chemistry	24357	98698	25
11	Computer Science	21188	85265	25
12	Agricultural and Biological Sciences	20568	83539	20
13	Arts and Humanities	16902	82987	20
14	Energy	16294	82114	20
15	Chemical Engineering	10370	44046	24
16	Immunology and Microbiology	9767	32873	30
17	Economics, Econometrics and Finance	9007	31616	28
18	Multidisciplinary sciences	7278	23075	32
19	Pharmacology, Toxicology and Pharmaceutics	5640	20985	27
20	Psychology	4482	18720	24
21	Neuroscience	3900	17485	22
22	Business, Management and Accounting	3892	16270	24
23	Health Professions	1890	10780	18
24	Decision Sciences	1879	10160	18
25	Nursing	962	2920	33
26	Veterinary	483	1304	37
27	Dentistry	164	482	34

logical constant (1998) *Astronomical Journal*, 116 (3), pp. 1009–1038. DOI: 10.1086/300499

Thus, based on the analysis of the open information space of Russian science, we can conclude that the scientific ecosystem promoting open access and open research is developing and growing in popularity.

CONCLUSIONS

The emergence of an increasing amount of journals, publications, data, and educational resources in open access; the promotion of initiatives by scientific foundations, national research councils, and government organizations, as well as by university and scientific communities, major publishing houses, and consortiums; and the transformation of the market for information resources and services are leading to significant changes in scientific communication and in the principles and methods of conducting research, developments in the provision and promotion of scientific results, and solutions to problems associated with improving the quality, support, and dissemination of scientific research. All interested research actors (representatives of scientific and educational institutions), publishers, sponsors (scientific foundations, grant givers, etc.), and library employees are taking an active part in the development of the open science information ecosystem, and their interaction is of paramount importance in the formation of an open knowledge space.

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Translated by L. Solovyova