The Library in the Information Ecosystem of Open Science

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Abstract—The results of an analysis of trends in the development of the information ecosystem of open science based on the study of the global document flow, open access resources and scientific data repositories, as well as initiatives in the field of open science, including during the COVID-19 pandemic, are presented. The directions of activity of libraries in these conditions are determined.

INTRODUCTION

Initiatives supporting the development of open science, the availability of data for the entire scientific community, as well as the transparency and reproducibility of research results, are gaining increasing recognition in the world, leading to significant changes in the infrastructure of scientific communications, the principles and methods of conducting scientific work, the recording and promoting of their results, as well as suggesting new solutions to problems related to improving the quality, support, and dissemination of scientific research. This information infrastructure of open science (open access resources, open educational resources, open research data in repositories, etc.), increases the transparency of the research process on the one hand, on the other hand, it modifies traditional social institutions and mechanisms, modifies the market of information resources and services, setting new rules, conditions, and prospects.

DEVELOPMENT OF THE ECOSYSTEM OF OPEN SCIENCE

Open Science Initiatives are promoted by various science foundations, national research councils, and government agencies (e.g., European Commission, Center for Open Science, FORCE11, and the Wellcome trust), as well as numerous university and national communities, major publishers and consortia; they have an impact on the formation of the ecosystem of science. NSNESKO prepared a roadmap for the development of Recommendations [1], in which it is planned to establish standards aimed at forming a coherent vision of Open Science.

FAIR Principles (Findable, Accessible, Interoperable, and Re-usable)[1] and international initiatives in the field of open science are implemented in the recommendations of the publishing houses of scientific journals on providing access to primary data, on the openness of peer review and in the requirements of scientific foundations on the openness of data as a prerequisite for obtaining international and national grants. Among these requirements is open access to published materials [2].

The number of organizations and projects that fund research is growing, as is the number of articles. In the process of searching for organizations funding scientific research, whose results were presented in the public domain in 2016−2020 and are reflected in the Scopus database, we have identified a list of the most common ones (Table 1), among which the scientific foundations of China, Japan, the United States, the European Union, and the United Kingdom prevail.

Depending on the subject area, the list of funding organizations changes. Thus, in the field of social and human sciences, the most common funding organizations are the 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 Program, Economic and Social Research Council, and in the field of natural and technical sciences, such specialized organizations as, U.S. Department of

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[1] *FAIR (Findable, Accessible, Interoperable and Re-usable):* **Findable** (findability) **— easy search for specific datasets,** *Accessible* (availability) **— convenient access (according to access conditions and storage possibilities** for a long time, *Interoperable* (interoperability) **—** compatibility with other datasets or software, *Reusable* (reuse) **— reusable (re) use in** further research.

Table 1. List of most frequently met funding organizations the results of which are presented open access in 2016−2020 and indexed in Scopus. Query PUBYEAR > 2015 AND (LIMIT-TO (OA, "all"))

Funding organization (sponsor/foundation/program)	Number of publications in Scopus from 2016 to 2020
National Natural Science Foundation of China	491 097
National Institutes of Health	459 398
U.S. Department of Health and Human Services	387 260
National Science Foundation	240 915
European Commission	222 544
Horizon 2020 Framework Programme	136 912
Japan Society for the Promotion of Science	134 283
Ministry of Education, Culture, Sports, Science and Technology	127 394
UK Research and Innovation	123 552
Deutsche Forschungsgemeinschaft	101 319
National Cancer Institute	89 921
Seventh Framework Programme	87 110
U.S. Department of Energy	85 732
European Research Council	84 713
Ministry of Science and Technology of the People's Republic of China	76 334
National Institute of General Medical Sciences	73 406
Engineering and Physical Sciences Research Council	72 975
European Regional Development Fund	65 039
National Research Foundation of Korea	62 529
National Key Research and Development Program of China	60 873
Government of Canada	59 170
Conselho Nacional de Desenvolvimento Científico e Tecnológico	58 637
National Heart, Lung, and Blood Institute	56 839
Fundamental Research Funds for the Central Universities	55 992
Ministry of Education of the People's Republic of China	55 698
U.S. Department of Defense	54 793
Medical Research Council	53 120
National Institute of Allergy and Infectious Diseases	50 407

Energy, Japanese Society for the Promotion of Science, and the Engineering and Physical Sciences Research Council.

The emergence of open access (OA) initiatives is transforming the traditional scientific communication environment and is driving an increase in the number of open access journals and research articles. According to some reports [3], the share of OA in scientific literature is already estimated at 27% (approximately 19 million articles in total) and is growing mainly due to the golden and hybrid versions of the OA model, while it is noted that open access articles are cited 18% more than articles are on average; this effect is mainly provided by the green and hybrid variants of OA.

Our bibliometric analysis in the field of Social Sciences, including subject areas such as Arts and Humanities (ARTS); business, management and accounting (BUSI); Decision Science (DECI); Economics, Econometrics and Finance (ECON); psychology (PSYC); Social Sciences (SOCI), indicates a further increase in the flow of open access publications. At the time of collecting the information, the total volume of open access publications reflected in the Scopus database for 2012−2020 was 1 184 815 documents; their share in the total document flow in this branch of knowledge in 2020 exceeded 30% (Fig. 1).

The proliferation of open science initiatives is also shown by the emergence of an increasing number of open access resources: full-text and factual (Open DOAR, ScienceOpen, CORE, PubMed Central, arXiv, BioMed Central, DOAJ, Education Resources Information Center (ERIC), Bentham Open, PLOS, Hindawi, Springer Open, Science Direct, NISCAIR, DOAB, CyberLeninka, Socionet archive, a number of
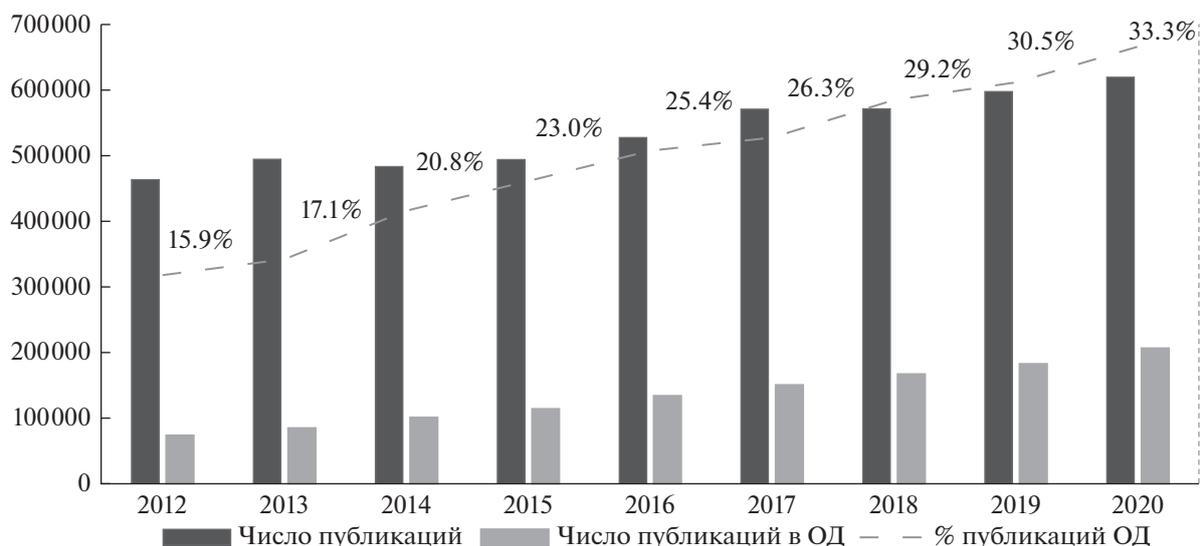
Fig. 1. Dynamics of growth in the number of open access publications indexed in Scopus (2012−2020) in the area of social sciences.

projects of the non-profit partnership (NP) National Electronic Information Consortium (NEICON), the elpub magazine platform, the preprints.ru preprint server, the national aggregator of open repositories (NORA), etc. The growing number of institutional repositories and open access publishing models are also helping to advance this approach, which improves access to the results of scientific research, promotes integration scientists to the world scientific community, avoids duplication and promptly verify results research, and accelerates innovation and development individual institutions and countries.

In early 2019, the global registry for research data warehouses (re3data.org) submitted 2250 repositories (1869 industry-specific and 563, institutional), of which humanities and social sciences equaled 689 per year, life sciences, 1207; natural sciences, 1110; technical sciences, 339; etc. In 2021, the number of repositories increased to 3108 (2113, industry-specific; 701, institutional; and 294, other). As the analysis shows, most of the data in the storages reflects scientific and statistical information, standard documents prepared in MS Office, images, etc. The leader in the number of such data warehouses is the United States (Table 2), 1119 (in 2019−1035). The number of international storage facilities has increased over 2 years, Russia is in 21st place in this rating; the number of storage facilities in which Russian research data is presented is 22 (this was unchanged compared to 2019).

In the re3data.org registry, research data is presented for almost all scientific disciplines. However, repositories with data on life sciences (biology, medicine, agriculture, etc.) equaled 1473; natural sciences (chemistry, physics, mathematics, earth sciences, geophysics and geodesy, computer science, electrical

engineering, etc.), 1349; humanities and social sciences, including the humanities in general, history, economics, linguistics, etc., 951. The distribution of repositories by the most developing subject areas is presented in Table 3. In 2021, data on COVID-19 appeared in 68 repositories (in the subject areas of clinical trials, biochemistry, epidemiology, etc.).

The critical importance of international scientific cooperation, free access to scientific data, research results, educational resources and research facilities was noted during the global COVID-19 pandemic. Acting in accordance with the Budapest Open Access

Table 2. Distribution of databanks by geography in re3-data.org

Country	Years	
	2021	2019
USA	1119	1035
Germany	457	347
United Kingdom	305	295
European Union	283	201
Canada	259	186
International	254	214
France	116	98
Australia	94	35
Switzerland	80	68
Netherlands	62	52
Japan	61	56
India	51	49
China	48	40

Table 3. Distribution of repositories over subject areas in re3data.org in 2021 (fragment of most frequently met subject areas)

Subject area	Number of repositories
Biology	900
Earth sciences, including geography	772
Medicine	630
Fundamental biology and medicine	523
Engineering	515
Social and behavioral sciences	441
Atmospheric science and oceanography	410
Medicine	401
Humanitarian sciences	312
Physics	312
Social Sciences	290
Geophysics and geodesy	262
Zoology	244
General genetics	222
Chemistry	221
Microbiology, virology, and immunology	218
Botany	215
Economy	207
Agriculture and forestry, horticulture, and veterinary science	193
Astrophysics and astronomy	179
Bioinformatics and theoretical biology	176
Oceanography	172
Geography	160
Informatics, electrotechnics, and systems engineering	149
Water studies	144
Public health studies and social medicine	133
Atmospheric science	131
Agriculture and forestry, horticulture, and veterinary science	129
Human genetics	117
Linguistics	106
History	103
Empirical social studies	103
Geodesy, photogrammetry, remote sensing, geoinformatics, cartography	99
Genetics of animals, cell biology, and developmental biology	93
Geochemistry, mineralogy, and crystallography	90
Computer science	89
Cell biology	85
Animal ecology, studies of biodiversity and ecosystems	84
Neurology	82
Geology and paleontology	80

Initiative, the Berlin Declaration on Open Access to Scientific and Humanitarian Knowledge, as well as relying on previous documents of international organizations, Russia adopted the Declaration on Uniting the Efforts of the Scientific Community in the Fight against COVID-19 [4], which was signed by many publishing houses, libraries, and universities in order to counteract the spread of inaccurate information on the topic of the new coronavirus infection, as well as to facilitate the prompt provision of the scientific community and society as a whole with up-to-date information and materials about it.

In 2020, several initiative projects of publishers and scientific organizations were created for the prompt publication of works related to COVID-19, with a prerequisite for the availability of data [5–7]. Publishers are committed to facilitating the exchange of information reflected in COVID-19 documents in accordance with FAIR principles, working with FAIRsharing, Research Data Alliance and Force11 through the joint RDA/Force11 FAIR sharing working group (for example, providing recommendations for relevant repositories and using appropriate data standards and metadata), and aim to ensure the openness of all peer-reviewed scientific publications related to the coronavirus outbreak, as well as the availability of raw data through preprint services or platforms that make articles open before peer review. These initiatives facilitate the rapid exchange of interim and final research results related to COVID-19, as well as the protocols and standards used for data collection, with a significant impact on the science information ecosystem.

The open science movement in its various forms is changing the information ecosystem itself of open science in terms of differences in disciplines and branches of knowledge, regional specifics and prevalence, expanding the range of formats, types and types of publications, data, and results. Open access resources are reflected in the information systems of publishing houses, vendors, news agencies, scientific and educational institutions, and libraries. Open access to information is of great importance for the formation of a knowledge space, in the construction of which the main role belongs to publishing houses, libraries, and educational institutions [8].

In the context of the development of a modern information ecosystem associated with the ideas of open access, traditional social institutions and mechanisms are being modified, the market of information resources and services is changing, and new rules, conditions, and prospects for the development of the scientific field of activity are being set. "The information society as a multidimensional, complex contradictory phenomenon generated by new high-tech technologies, a new type of communication, new opportunities, requires a thorough revision of the existing methods of organization, existing social institutions, reform of the usual types of communication,

the transition to innovative management technologies" [9, p. 9]. According to analysts of The Wall Street Journal (2014 review "Good Bye, Berlin"), open access did not harm large publishers; everyone needs it: librarians, to solve the problems of the journal crisis; scientists, to increase the level of citations and facilitate the dissemination of knowledge; economists, because it opens up access to new knowledge and technologies for small and medium-sized enterprises; political activists, as a way to reduce the superprofits of capitalists; and activists from developing countries, as a way to prepare doctoral dissertations in these countries [10].

These factors determine the need for a comprehensive scientific analysis of the activities of various social institutions, in particular libraries, traditionally aimed at supporting, presenting, and promoting the results of scientific research in a unified information ecosystem of knowledge.

A CONCEPTUAL FRAMEWORK FOR THE ROLE OF THE SCIENTIFIC LIBRARY IN OPEN SCIENCESE

The documents of the European Commission (European Commission), Organization for Economic Cooperation and Development (Organization for Economic Co-operation and Development (OECD), International Federation of Library Associations and Institutions (IFLA), other acts of international and national levels, the professional community has designated and recognized the role of scientific libraries in open science [11−15]. Libraries adapt to the external open information environment, reflecting open access resources in their catalogs and databases. For example, the Online Computer Library Center (OCLC), in cooperation with Europeana collections, HATHI Trust, DOAJ (Directory of Open Access Journals), DOAB (Directory of Open Access Books), etc., provides searching for open access resources through the WorldCat directory (https://www.worldcat.org/).

The International Federation of Library Associations and Institutions (IFLA) has recognized open access as a key issue on its information agenda, as evidenced by the work of librarians in ICT infrastructure development, service delivery, and capacity building through information literacy and security programs [11, 16]. The open access movement for scientific literature is based on the conviction that scientific and technological information is the most important global public good that should be freely available to all.

At the same time, the existing technologies for supporting open science in libraries, which occupy an important place in the information market of resources and services, are still fragmented; there is no systematic understanding of the strategies and methods for the development of information, bibliographic and reference services, and various resources that allow a comprehensive approach to effectively provide researchers with the necessary infrastructure and services. Thus, the purpose of our research is to develop conceptual approaches to the functioning of a scientific library, contributing to the creation of an effective information and communication infrastructure for supporting open science, managing scientific content, providing open access to information and data, providing high-quality information services in the research life cycle based on an analysis of the existing international experience, the prospects for the development of open science in Russia, and systematization of existing and new tools and their implementation in the framework of cooperation of library specialists with research teams.

It should be noted that these issues continue to be relevant, considering the increase in the interest of researchers in the topic as evidenced by the results of issuing documents to the SCOPUS database.

Open access issues continue to be discussed in the library community. In the period from 2012 to 2021, the number of publications reflected in the Scopus database almost tripled (Fig. 2). Analysis of the species structure of the stream on the topic "Libraries and Open Access" (a total of 2018 documents based on the search results in the Scopus database from 2012 to 2020) revealed the following distribution of the share of publications by type of publication: articles, 1534; reviews, 150; conference proceedings, 144; and chapters from books, 106. Articles of serial publications occupy a significant place in the species structure of the document flow. An analysis of the repertoire of professional journals reflecting open access topics in libraries is presented in Table 4: more than 11 journals published 20 articles on the topic, the leader was the magazine *Library Philosophy and Practice*.

The main problems of the articles are connected with the study of the problems of development of business models of access to open content [17, 18] and legal issues governing the open science movement; organization of user service; indexing in databases and publishing systems; distribution, search and access; payment for articles [19]; generation and use of open access repositories [20]; research data management and the role of librarians as collaborators and digital curators [21, 22]; etc. The results of the bibliometric analysis of the document flow indicate a steady increase in publications on the topic considered here, the dominance of the number of publications in journals (the rating is built by their number in publications in library and information sciences), which confirms the relevance and need for a comprehensive study of the role of libraries in the development of open science.

As the priorities of academic institutions evolve, the role of research libraries is changing. They become key partners in the long-term future of open science because they have an idea of what their founders want.
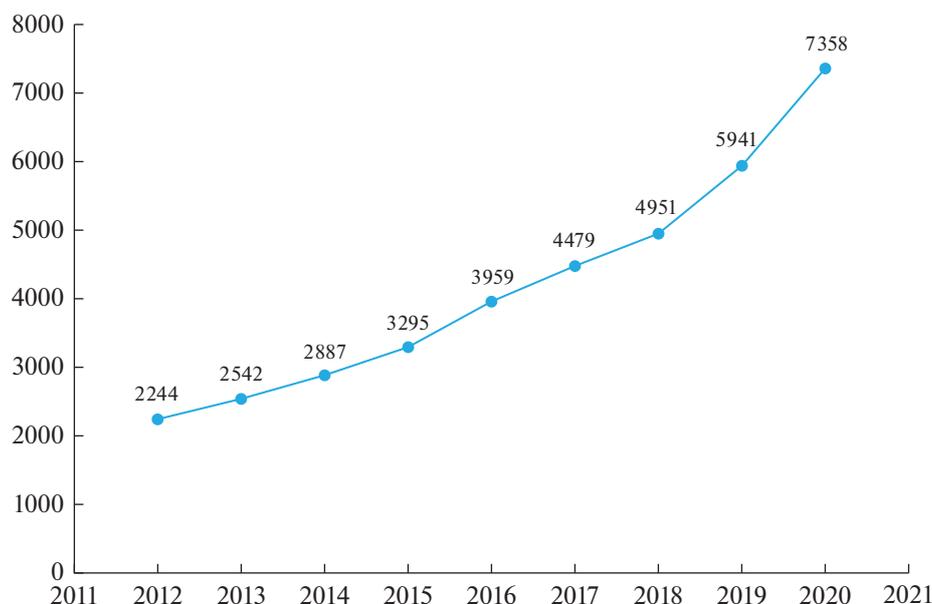
Fig. 2. Dynamics of publications on topic of Library and Open Science (subject area of social sciences) in Scopus (2012−2020).

[23]. Over the years, the relationship between open science and research libraries has grown significantly. Academic librarianship has evolved into a distinct area with its own set of goals and commitments in the academic community [23, 24] developed by mechanisms that allow universities and scientific organizations to work more efficiently in the area of *production and exchange* knowledge, data, thereby promoting institutional research [25−27], *service delivery* from teaching individual information literacy to data mining [27], *"Embedding" librarians* in the research process and joint research [27− 29], *participation in the creation*

Table 4. List of periodicals in which more than 20 articles were published on the topic of Library and Open Science in 2012−2020

No.	Edition name	Number of publications
1	*Library Philosophy And Practice*	103
2	*Insights The Uksg Journal*	62
3	*Serials Librarian*	59
4	*Liber Quarterly*	48
5	*Evidence Based Library and Information Practice*	43
6	*Electronic Library*	40
7	*Serials Review*	40
8	*Voeb Mitteilungen*	39
9	*Journal of Academic Librarianship*	34
10	*Interlending And Document Supply*	32
11	*Library Hi Tech News*	29

and maintenance institutional repositories [30, 31], *conducting altmetric studies* [32, 33], creation of alternative editions (loading research results into repositories [20]), etc.

Content analysis of publications on the problem allowed us to conclude that open access as a new model for the dissemination of scientific information affects the change in the role of academic libraries in the information support of science and allows us to determine promising directions for their development [34]. For libraries, both key functions of open access systems are important: as a means of disseminating and delivering information (in this case, it is the formation of repositories on the basis of university libraries) and as a provider of information for readers and users of the library (in this case, it is help in navigating and providing library readers with journals open access, as well as materials from repositories) [8, 10]. In libraries, "new" specialists appear: the data steward, data manager, metadata manager, Research Data Management Librarian, data curator, archivist/digital data scientis*t*, content curator, co-investigator, collaborator, digital/information intermediary, digital curator, knowledge engineer, subject librarian, etc.

Below are just a few of the new specializations for librarians in research libraries, indicating that the open science that librarians are influencing allows them to at the same time demonstrate new and more important roles, given the appropriate competencies. Basic librarian skills in finding, collecting, organizing, evaluating, and disseminating information have a major impact on the creation, development, and management of digital content and open access resources. However, in the context of the development of open

science, the competence of librarians is significantly expanding [35], new tasks and requirements for their knowledge and skills appear [36, 37]. For example, when working in an institutional repository, knowledge of software, project planning and management, collection definitions, metadata guides, presentation analysis, and author training are essential [38].

THE OPPORTUNITIES AND PROSPECTS OF LIBRARY ACTIVITIES IN THE CONTEXT OF OPEN SCIENCE

In the cycle of production, exchange, and dissemination of information and knowledge libraries play an important role as they navigate information resources, conduct consultations, search for information, training, subject support, resource management, and monitoring. It seems that by choosing a clear strategy for the development of libraries (mostly scientific) in the conditions of a modern information ecosystem associated with the ideas of open science, libraries have every chance of being in demand by users.

Information support on open access resources, which is carried out by librarians, allows the user navigate open scientific content: Open Access Journals Directory (http://doaj.org); Open Access Repository Directory (http://www.opendoar.org); Data repository directory [re3data] (http://service.re3data.org); aggregators for various OpenAIRE open source resources (https://www.openaire.eu), Zenodo (https://zenodo.org) and etc.; open magazine aggregators − Paperity (http://paperity.org), Cyberleninka (http://cyberleninka.ru), a number of projects of the NEICON non-profit partnership (the elpub magazine platform, the preprints.ru preprint server, and the national aggregator of open repositories (NORA)). In addition, open source resources are reflected in library-generated catalogs and databases, for example through the WorldCat catalog.

Librarians have the ability to recommend existing services or create their own services for managing research data that provide seamless access to data and platforms that support open science, and cover the entire cycle from searching to storage in repositories, management (registration, access and efficient use of computing services, services for annotation, and data discovery based on metadata), analysis (sets of computing tools and applications for various fields of knowledge, for example, DARIAH Science Gateway in Arts and Humanities or WeNMR Package for Structural Biology), exchange, and reuse in different scientific fields.

Librarians already offer guidance, training and services in the following areas: providing information at all stages of the research life cycle, opportunities and requirements for financing scientific foundations and publishing houses, bibliography and data management, creation and use of metadata, definition of open

research methods and tools for analysis, data exchange, publication of results, data citation, licensing and other intellectual property issues, preparation of data for deposition and long-term storage, etc.

Library specialists give advice on types of open access, which are differentiated depending on their availability and cost: Libre OD (read and reuse articles), Gratis OD (read only articles), Gold OD (journals with direct OD), Green OD (journals with self-archiving permission), Hybrid OD (OD after payment of an article processing fee), Delayed OD (OD after the time of embargo), Academic Social Networks (online communities), and Black OD (illegal pirate sites) [39, 40].

Librarians can contribute to the acquisition of skills and knowledge in such subject areas as options for publishing materials in the open access, use of open licenses (for example, CC0 or CC-BY), sharing preprints (for example, in OSF, arXiv, or bioRxiv), shared codes (for example, on GitHub with a GNU/MIT license), data exchange (for example, in Dryad, Zenodo), altmetric assessment methods, etc. Open science seminars, workshops, conferences and continuing education programs organized by a library will help to raise awareness of open science concepts, terms, models for promoting research results, funding agency policies and principles of data sharing, tools and resources of open science, research data management, to develop open access publishing skills in the context of open science, to stimulate the use of digital infrastructures, and ultimately contribute to the implementation of the open science paradigm.

Developing the directions of library activity in the context of open science, one cannot but take note possible problems: (1) The declared functionality cannot be performed without the appropriate skills, knowledge and professional competencies of librarians; (2) incomplete/inaccurate metadata of information resources of open access and unreliability of information resources of open access [41]; (3) insufficient awareness of researchers about open access and a low level of their information literacy; (4) financial restrictions for publishing open access; (5) undeveloped infrastructure for integrating open access information resources into library catalogs and databases; and (6) ignorance of legal issues and information needs of users with organizational and infrastructural support of open science, etc. The development of these areas and the solution of these problems will allow the library to become one of the key actors in the creation and maintenance of the infrastructure of open science.

CONCLUSIONS

The open science movement in its various forms is reshaping the information ecosystem and represents a promising direction for libraries, which have always played an important role in the cycle of production,

exchange and dissemination of information and knowledge. The growing number of open access resources, open science initiatives, and projects is driving a significant change in the way libraries work, creating electronic resources based on open access publications and data, providing guidance on access to information and data, managing subscription budgets and generating updated reporting on resource use, development of services to support the entire research life cycle, and subject-oriented training of scientists and specialists.

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