



Croatian scientific productivity and visibility in the field of biology measured by journals indexed in WoS 1991–2005

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Abstract

Background and Purpose: The purpose of this research was to establish the characteristics and the trends of scientific activity in the field of biology in Croatia, using scientometric analysis of scientific papers published in biology journals indexed in WoS-SCI Expanded database for the period of 1991 to 2005. The results could serve as useful tool in defining a more acceptable model for the evaluation and stimulation of scientific work, as well as in highlighting possible directions for the development of biological sciences in Croatia.

Materials and Methods: The research sample consisted of 2,099 scientific papers which had a Croatian address, published in 342 biology journals indexed in WoS-SCI Expanded database from 1991 to 2005. The characteristics of scientific productivity and scientific impact, measured using citation analysis, were analysed in the field of biology as a whole, as well as in the various biological disciplines. The journal's status was determined using its IF from the JCR Science Edition database for 2005. As additional indicators, trends in co-authorship as well as international cooperation were determined.

Results and Conclusions: The evaluation of scientific work in the field of biology should be adapted to the specificities of scientific publishing in various biological disciplines. The number of papers in different disciplines varied considerably, as well as the average number of citation per paper and the average number of authors per paper. In the field of biology as a whole, on average 7.3 citations per paper and 4.1 authors per paper were observed. The majority of papers (90%) were co-authored publications. 32.2% of published papers were co-authored with a foreign institution. 7.7% of papers were published in the most prestigious journals by IF (the "top 10%" journals). Those papers published in the "top 10%" journals which were co-authored with a foreign institution obtained the highest impact (16.8 citations per paper).

INTRODUCTION

By using bibliometric and scientometric analysis of scientific publications, it is possible to gain an insight into the state and trends of the scientific activities of countries, institutions or scientists. As well as exploring the development of science, the results of this analysis also help to shape the scientific policy of a country or a region. The bases for

scientometric research worldwide are the commonly used multidisciplinary bibliographic and citation databases SCI, SSCI and A&HCI being, accessed via the Web of Science, which are compiled and maintained by Thomson Reuters. These databases cover the content of the world's leading journals in all fields of science and can be seen to represent the leading secondary source of scientific information. As this paper deals with biological research areas, a key source for scientometric analysis was the WoS-SCI Expanded database, which indexes journals in the natural sciences, technology and medicine. The database contains articles from around 10,000 the world's leading journals in these areas, covering approximately 150 disciplines.

The contents of the SCI Expanded and SSCI citation databases are used to construct the statistical database Journal Citation Reports (JCR). This database provides a number of statistical data for journals within a discipline, which are used to calculate various indicators, including the impact factor (IF) of the journal. IF is one of the most commonly used indicator worldwide for ranking journals; it represents a measure of the frequency with which the average article in a journal is cited in a particular year (1).

As scientific studies require financial investment, it is necessary to conduct an evaluation of scientific work. Excluding the financial element, the evaluation of scientific work is carried out to determine the importance of the scientific status of a country or institution or, in the case of scientists, professional advancement or tenure. According to Hemlin (2), the purpose of such evaluation in science is to create high-quality science, the science that creates new knowledge and advanced technology that impact on commercial utilisation of innovations and increase prosperity. Scientific work is evaluated by two main methods: peer-review process and scientometric analysis. In Croatia, the evaluation system in science is in the first instance based on a review by peers, who rely on the productivity data. Until recently, a fundamental shortcoming in the evaluation of scientific performance within natural sciences was due to an overemphasis on the importance of the database Current Contents (CC). CC was the only database which was conditioned in the regulations for the scientists' professional advancement. It is a bibliographic database, and as such it is not suitable for bibliometric and scientometric research. Since it does not contain citation data, it is not suitable for citation analysis, i.e. it has no indicators that are necessary for the compilation of the JCR database. In addition to this, there would be a high percentage of overlap with the WoS citation indexes. For the evaluation of scientific production, the globally accepted databases are: WoS, Scopus, Google Scholar, and specialised databases for scientific fields.

Bibliometric and scientometric analysis of research activities is commonly performed by analysing scientific productivity and scientific impact. Research productivity, as an indicator of activity in the research and potential contribution to development, is usually measured by the number of published papers, articles, books, patents and

innovations (3). In addition to the scientific field, scientific productivity of an individual author is dependent upon a number of variables, such as: individual characteristics (psychological, work habits and demographic), environmental and feedback process of cumulative advantage and reinforcement (4). It also depends on the system of funding of the research and the relevancy of the science within the national science policy. Scientific impact is most commonly measured by received citations and citation analysis. By analysing the number of citations, it is possible to determine to what extent a scientific paper attracts the attention of the scientific community. The number of citations is often used as a measure of the quality of a paper, as well as a measure of the success of scientists, although it is better to see the number of citations as a measure of the visibility, importance and impact of the paper (5), or an indicator of reputation (6). Only in-depth citation analysis and the opinion of competent peers can contribute to knowledge about the quality of work itself.

Communication in science can be studied through the analysis of cooperation, especially on an international level. Scientific cooperation is usually measured by the number of papers created as a result of the cooperation, i.e. the number of co-authored papers. Van Leeuwen (7) has analysed the different types of scientific publications in WoS from 1981 to 2005 and found that the scientific collaboration occupied an important place in the global scientific system. The share of papers that were carried out in collaboration of several institutions or countries rose from 30% in 1981, to almost 60% in 2005.

Increased cooperation between scientists gradually reduces single-authored papers and authorship becomes a collective activity. The multi-authored publications are the result of the professionalisation of science, the rise of interdisciplinary research, the requirement for large modern research laboratory teams, the pressure on scientists to publish, the development of communication technology and availability of the Internet, amongst other things. This phenomenon is especially pronounced in some natural and biomedical sciences.

Scientists working on the "periphery" looking to increase the visibility of their research should strive to link their research to the international research community, particularly through co-publications with international authors (5). This observation certainly applies to Croatia as a small country within a "scientific periphery", a fact that was recognised in the policy documents dealing with the direction of development of science, education and technology in Croatia over the last twenty or so years (8, 9).

The aim of this study was to establish the characteristics of scientific activity in the field of biology in Croatia, using scientometric analysis of scientific papers with Croatian addresses published in journals covering biological sciences that are indexed in WoS between 1991 and 2005. Based on the results, a need to define more acceptable model for the assessment of scientific performance in relation to the existing one is outlined. The current system

of the evaluation of scientific work in Croatia has not proved satisfactory due to the fact that it is not suited to the specificities of various scientific disciplines. Using determined conditions and trends in scientific activity in the field of biology it is possible to define the directions of development of the field, based on which Croatia could become recognizable in the international scientific environment.

MATERIALS AND METHODS

The research sample consisted of scientific papers classified in the field of biology according to the WoS/JCR classification, on which at least one of the authors had a Croatian institutional address, published in journals indexed in WoS-SCI Expanded database from 1991 to 2005. Papers published by Croatian scientists with the address of a foreign institution were not covered with this research. The search was conducted during the first week of February 2008.

Since biology is not a uniformly-defined field of science, a certain number of journals are classified in more than one subject category according to the WoS/JCR classification. In order to get a more comprehensive picture of scientific productivity across narrower fields, a specific journal was assigned to each subject category that it was classified in. Equally, all papers in a journal were assigned to all subject fields that the journal itself was classified in, regardless of the fact that in some journals the topic of some papers does not belong to the mentioned subject field.

All document types indexed by WoS-SCI Expanded were taken into account. Besides the data on the productivity, the data on the citation of papers were also retrieved from WoS, including self-citations.

The characteristics of scientific productivity and scientific impact were analysed and interpreted, in the field of biology as a whole, as well as in the various biological disciplines (WoS/JCR subject categories). The dynamic of publication and citation of papers was analysed, as well as the distribution of papers based on the number of the received citations. The status of journals that published papers with a Croatian address in 15-year period was determined using its IF from the JCR Science Edition database for 2005. We analysed productivity in the journals that had IF above the median IF of the subject category, as well as the productivity in the journals that were among 10% of the journals with the highest IF in a subject category (the most prestigious or "top 10%" journals). As additional indicators, trends in co-authorship as well as international cooperation were determined.

For the purpose of testing statistical significance of differences and correlation, in most analysis we used nonparametric tests: Mann-Whitney test, chi-squared test and Spearman's rank correlation coefficient (Spearman's rho). Although the distribution of variables used in this study is extremely skewed, in order to test the differences in average number of citations per paper and average number of authors per paper for three 5-year

periods we used one-way analysis of variance (ANOVA 3x1) for dependent samples, as it has greater power in detecting differences than nonparametric procedures. Moreover, we tested the differences between three groups of data with *post hoc* Scheffé's test.

The data was collected and analysed using Microsoft Office Excel 2007 programme. For the statistical analysis of data we used software Statistical Package for Social Sciences (SPSS), version 17.0.

RESULTS AND DISCUSSION

Scientific productivity

In the time span 1991–2005 the WoS-SCI Expanded database indexed 2,099 papers with at least one Croatian address, published in journals classified in the field of biology (average number of papers per year was 140). During the 15-year period the Croatian scientific output in the field of biology showed mostly continuous increase (Figure 1). Annual publication output rose from 68 papers in 1991 to 262 papers in 2005, showing an annual average publications growth rate of 12.7%.

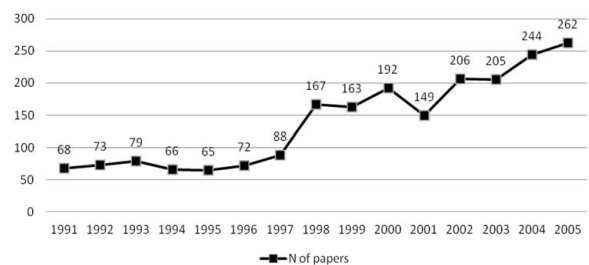


Figure 1. Publishing frequency of Croatian biology papers in WoS journals from 1991 to 2005.

The sharp increase in the number of papers, almost double, from 1997 to 1998 is due to the fact that WoS-SCI Expanded included again the Croatian journal *Periodicum biologorum* in 1998 after it stopped indexing it in 1993. In 1998 the journal accounted for 56 papers, which is 33.5% of the total amount of Croatian papers in biology published in that year. The increase in number of Croatian publications indexed by WoS is most visible in the number of papers for the time span 2000–2005, which is 1,258 and accounts for 59.9% of all papers analysed in this research. Jokić *et al.* (10) found as well that the biggest increase in the number of Croatian papers across all scholarly fields indexed in WoS from 1991 to 2005 was registered for the time span 2000–2005.

Journals

A total of 2,099 papers were published in 342 biology journals indexed in WoS in the time period 1991–2005. The number of published papers in an individual journal ranged from 1 to 531, with the average number of 6.1 papers per journal (median 2).

TABLE 1

Journals with 20 or more published Croatian papers.

Journal Title	N papers	N citations (citations per paper)	IF in 2005	IF higher than M/CC
Periodicum Biologorum	531	394 (0.7)	0.219	–/–
European Journal of Human Genetics	46	97 (2.1)	3.251	+/+
Science of the Total Environment	44	506 (11.5)	2.224	+/+
Biologia	40	98 (2.5)	0.240	–/+
Cytogenetics and Cell Genetics	39	16 (0.4)	–	–/–
Fresenius Environmental Bulletin	39	79 (2)	0.509	–/+
Chemosphere	29	524 (18.1)	2.227	+/+
Journal of the Marine Biological Association of the United Kingdom	28	92 (3.3)	0.745	–/+
Cybiurn	27	34 (1.3)	0.515	–/+
Faseb Journal	24	55 (2.3)	7.064	+/+
Chemico-biological Interactions	23	108 (4.7)	1.968	+/+
Acta Biologica Cracoviensia Series Botanica	21	33 (1.6)	0.368	–/+
Journal of Biological Chemistry	21	654 (31.1)	5.854	+/+
Marine Ecology-progress Series	21	520 (24.8)	2.315	+/+
Life Sciences*	20	156 (7.8)	2.572	+/+

IF higher than M – journals with IF above the median IF of the subject category

CC – journal indexed in Current Contents database

* No available data for 2005–2572 is the median IF for 2008 and 2009.

In order to gain an insight into of the international visibility of Croatian papers in WoS, we categorized the journals by the number of Croatian papers published in the researched time span. The sample of 15 journals with 20 and more published Croatian papers was recognised as potentially visible. It consisted of 4.4% of all analysed journals (45.4% of all analysed papers) (Table 1).

Croatian journal *Periodicum biologorum* published 25.3% of analysed papers. The journal was indexed in SCI database from 1974 to 1994 and then again from 1998. It was indexed in the Current Content database from 1974 to 1992. *Periodicum biologorum*, which is classified in the *biology* subject category, throughout the

observed 15-year span had IF less than 1. According to the data from the JCR Science Edition database, the journal was ranked in the fourth quartile (Q4) on the IF scale in its subject category. To be more precise, in 2011 the journal had an IF of 0.192, and a 5-year IF of 0.346. For the sake of comparison, the median IF in the *biology* subject category was 1.540, and the highest IF was 11.452 (*Plos Biology*).

In the evaluation process of scientific work, the global status of a journal is critical. It is a commonly-held belief that Croatian natural scientists do not publish their best papers in Croatian journals, since they are mostly ranked in the third (Q3) and the fourth quartile (Q4) in the subject category based on their IF. That is, the system of scientists' professional advancement in the field of natural sciences in Croatia stimulates the publishing of papers in journals with higher IF values. For that reason, scientists take steps to publish their papers in international journals with a high IF, which in return has a negative effect on the status of Croatian journals in WoS. However, national journals are the indicators of the position of the science in a given country and the reflection of the scientific environment they belong to. They have an important role in dissemination of scientific information in the fields of natural sciences that are committed to regional or local topics, for example conservation biology (11).

For a reason that until recently the scientists' professional advancement in the field of biology was conditioned by the representation of papers published in journals indexed in Current Contents database, we analysed that indicator. Within the sample of journals with 20 and more published Croatian papers it was established that 13 journals were indexed in the aforementioned database (*Cytogenetics and Cell Genetics* was excluded from the analysis since there was no available data for that journal). They published 41.9% of papers demonstrated in Table 1.

Productivity across WoS/JCR subject categories

Journals included in this research were classified in 23 WoS/JCR subject categories assigned to the field of biology. This implies a certain level of activity and recognition of various biological disciplines that are performed in Croatia.

Figure 2 shows that the scientific output varied significantly in various biological subject categories. The highest share of papers (31.9%) was published in journals classified in the widest subject category, *biology*. The substantial productivity in the *biology* subject category is due to the fact that the journal *Periodicum biologorum* is classified in the aforementioned category; that is 79.1% of papers belonging to this category were published in the stated journal. The *biochemistry and molecular biology* subject category follows with 20.9% of papers from the analysed corpus. Among categories that showed higher productivity were *environmental sciences*, *marine and freshwater biology* and *cell biology*, that each comprised approximately 10% of papers from the analysed corpus.

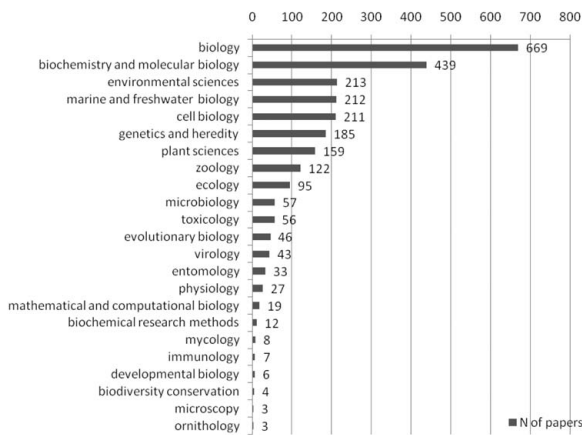


Figure 2. Scientific productivity across subject categories.

The finding that the scientific output of different biological disciplines are not comparable, could be indicative of the science policy in Croatia. Specifically, it is not reasonable to expect that all biologists would be able to obtain equal productivity by publishing their papers in prestigious international journals, which is part of the regulations for scientists' professional advancement. According to the results of our research, a molecular biologist, for instance, would publish more papers in journals indexed in WoS in comparison to a microbiologist, and especially in a comparison to an ornithologist. Previous studies already established that biologists with the PhD degree in Croatia occupy themselves with the wide range of subjects and that equal productivity is not to be expected from all biologist, as each of a narrower biological field has its own specificities in scientific communication (12,13).

The representation of papers in journals according to IF

The status of journals in which Croatian scientists published their papers during the observed time span was determined according to their impact factor (IF), for the fact that it is the most frequently used indicator in journals' evaluation, as well as because of its significance in the assessment of scientific work in Croatia. In a given year, the IF of a journal is the average number of citations received per paper published in that journal during the two preceding years (the standard or the Garfield IF) or five preceding years (5-year IF).

For a better understanding of the significance of journal's IF, we have to emphasise that subject categories have differing IF values. According to *JCR Science Edition* database for 2005, IF of the best ranked journals in specific subject categories belonging to field of biology varied from 1.838 in *ornithology* to 47.400 in *immunology*. The median IF of the subject categories ranged from 0.600 in *ornithology* to 2.667 in *virology*. The percentage of journals that had IF 1 or higher than 1 varied significantly in various subject categories, as well. The highest percentage of journals with IF 1 and higher than 1 was

observed in the following subject categories: *virology*, *mathematical and computational biology* and *evolutionary biology* (more than 90%). Subject categories with less than 50% of journals that had IF 1 and more than 1 were *ornithology*, *entomology*, *zoology* and *mycology*.

The aforementioned data confirm that specificities of a subject field should be taken into consideration when a journal's IF is used for the assessment of a journal. Gisvold (14) points out that certain fields have more citations than others; this will particularly be the case in rapidly developing fields, which will have much higher journals' IF. For instance, papers in biochemistry and molecular biology obtain the highest citation rate two years after publication, consequently journals in those fields have higher IF. In addition, papers in more dynamic fields have higher citation density (the average number of references cited per source article), which is, besides the age of the literature cited, one of the key determinants of IF (15).

Productivity in the most prestigious ("top 10%") journals

In the time span 1991–2005 authors with Croatian addresses published 161 papers (7.7% of the total number of papers) in the most prestigious journals, that were among 10% of the journals with the highest IF in a subject category ("top 10%" journals). 161 papers in question were published in 47 "top 10%" journals (13.7% of the total number of journals) classified in various subject categories assigned to the field of biology. On average 3.4 papers were published per journal (with the range of 1 to 24).

Productivity in the journals with IF above the median IF of the subject category

According to the regulations for scientists' professional promotion in the field of biology in Croatia, the status of a journal is defined with the median IF of the subject category that the journal is classified in. We analysed the share of the papers published in journals that had IF above the median IF of the subject category (journals classified in the first (Q1) and the second (Q2) quartile on the IF scale) within the sample of journals with 20 and more published Croatian papers (Table 1). Out of 14 analysed journals (*Cytogenetics and Cell Genetics* was excluded from the analysis since there was no available data for that journal), 8 journals (57.1%) had IF above the median. Those journals published 228 papers (25% of papers from the analysed sample).

Co-authorship

Analysis of co-authorship patterns of the Croatian papers published in biology journals in WoS during the investigated 15-year period, showed that the average number of authors per paper was 4.1 (median 4). The trend of the substantial increase of the number of authors per publication (16), was confirmed in this research as well. In 1991 on average 3.6 authors per paper was observed in the body of biology papers with a Croatian address, while in 2005 the average number of authors per paper was 4.4.

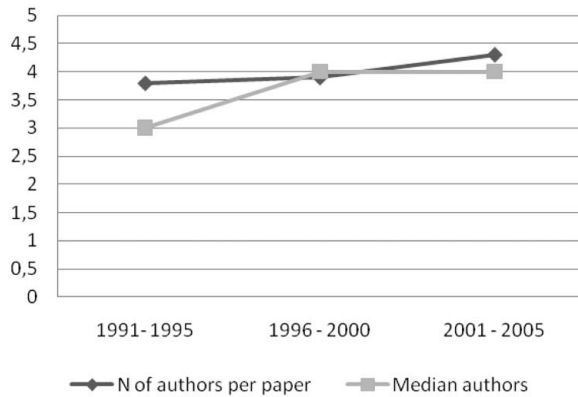


Figure 3. Average number of authors per paper in the 5-year periods.

TABLE 2

Average number of authors per paper across subject categories.

Subject category	N of authors per paper
microscopy	6.3
genetics and heredity	6
virology	6
toxicology	5.7
evolutionary biology	5.6
developmental biology	5.5
immunology	5.1
biochemistry and molecular biology	4.8
cell biology	4.8
physiology	4.4
microbiology	4.1
plant sciences	3.9
environmental sciences	3.8
marine and freshwater biology	3.7
zoology	3.7
biology	3.5
entomology	3.5
biochemical research methods	3.2
ecology	3.2
mathematical and computational biology	2.9
mycology	2.3
biodiversity conservation	2
ornithology	1.7

Figure 3 shows the trend of growth in the average number of authors per paper in three 5-year periods. One-way ANOVA for three analysed periods confirmed significance in the increase of average number of authors per paper through time ($F(2,1)=7,102; p=0,001$). *Post*

hoc test found that a difference was not statistically significant only between the first and the second time interval.

In our research sample 9.9% of papers were single-authored, which means that the majority of papers (90.1%) were co-authored publications. The prevailing were the papers co-published by three (20.3%) and four (18.3%) authors. In collaboration with 10 or more authors 1.5% papers were co-published. Only 5 papers (0.3%) were published in co-authorship of more than 25 scientists.

In-depth analysis showed that the trends in co-authorship differ significantly depending on the subject category (Table 2). For instance, *genetics and heredity* is among categories that registered the largest average number of authors per paper (6 authors per paper). Furthermore, it was the category with the largest total number of authors on a single paper (38 authors). Our result is in the accordance with the data for genetics in the world, as it is the field of science characterized with the teamwork and big projects, so called *Big Science* (17).

From a pragmatic point of view, measuring scientific productivity can bring into focus the issue in multi-authored publications, as it raises the question of allocating authorship credit according to the contribution of authors. The aforementioned problem can be addressed in a number of different ways, for example by allocating a certain proportion of authorship credit to each author, or by giving the priority to a project or a team leader, which can itself give rise to issues.

International collaboration

In the investigated body of papers, 676 or 32.2% of papers were published in co-authorship with foreign institutions. This result is compatible with the results of studies in the mid-1990s and the early 2000s, which reported the considerable share of international co-publications in the transition countries in Europe (18, 19).

Furthermore, our results show that internationally co-authored papers are published with great frequency in the leading journals. Out of the 161 papers published in "top 10%" journals, 65.2% were co-authored with a foreign institution. The share of papers that Croatian authors published in the collaboration with foreign institutions in "top 10%" journals is consequently double the share of internationally co-authored papers in the total analysed body of papers. The obtained result suggests that, as far as biological sciences in Croatia are concerned, there is an increased need for international collaboration for a paper to be published in the most prestigious journal than in an average journal covered by WoS, as already shown by Glänzel (20). We emphasise this fact as we suppose that papers carried out in international collaboration to a larger extent meet rigorous criteria of the most prestigious journals.

Scientific impact measured by citation analysis

Analysed papers from our sample published from 1991 to 2005, in the period from 1991 to the end of January

2008 received the total of 15,235 citations, which is the average of 7.3 citations per paper (median 2, range from 0 to 189).

Citation of papers across WoS/JCR subject categories

The citation analysis of papers in various subject categories showed that the average number of citations per paper varied significantly across categories, which is confirmation that biological disciplines demonstrate substantial differences in patterns of scientific communications. For instance, papers in the *microscopy* subject category on average received 16 times more citations than the papers in the *ornithology* subject category (Table 3). Papers in the most productive subject category, *biology*, obtained on average one of the lowest citation counts (1.9 citations per paper). It can be explained with heterogeneous subjects that are covered by the aforementioned subject category, which basically embraces all biological disciplines and sub-disciplines characterised with a great variety of citation dynamics. In our sample the result was significantly influenced by the papers published in *Periodicum*

TABLE 3

Average number of citations per paper across subject categories.

Subject categories	N of citations per paper
microscopy	28
virology	21
physiology	18.7
developmental biology	16.3
microbiology	13.9
cell biology	12.7
biochemistry and molecular biology	12.1
evolutionary biology	11.8
ecology	10.7
mathematical and computational biology	10.5
toxicology	10.2
genetics and heredity	10
environmental sciences	9.4
marine and freshwater biology	8.7
immunology	7.9
biodiversity conservation	7.5
biochemical research methods	6.5
plant sciences	6
zoology	5.3
entomology	2.1
biology	1.9
mycology	1.9
ornithology	1.7

biologorum, which received on average 0.7 citations per paper (Table 1). In fact, those papers comprise 79.1% of all papers classified in the *biology* subject category. Moed *et al.* (21) emphasize that ranking of publications from different fields, based on citation counts, can be affected seriously by differences between citation characteristics in those fields. One should expect high citation levels, for instance, in biochemistry and cell biology, medium citation levels are to be expected in plant physiology and low citation levels in taxonomy.

To get a more objective picture, we compared our results with the number of citations per paper for the similar categories, in the similar time frame, according to the Essential Science Indicators (ESI) database. We concluded that for Croatian papers, the average citation in ecology and environmental sciences was above the world average and the average citation in animal science, microbiology and plant science was approximately at the world average. Croatian papers in biochemistry are cited marginally below world average, whilst Croatian papers in molecular biology, genetics and immunology are faring worse, being cited significantly below the world average.

Citation of papers across years

The analysis of the average citation counts of papers published from 1991 to 2005 demonstrated that the both measures of central tendency (mean and median) showed decreasing trend (Figure 4). Average citation of papers published in 1993, 1994 and 1995 was noticeably above average, which in part was due to the fact that there were a substantial number of highly cited papers (over 50 citations) published in given years.

When we summed up citations of papers published in three 5-year periods, one-way ANOVA confirmed significance of differences in the trend of decline ($F(2,1)=75,924$; $p=0,000$) (Figure 5). *Post hoc* test showed that differences were statistically significant between all analysed periods.

In the interpretation of the obtained results, it is important to stress that there is a time lag before a published paper starts to receive citations. In citation analysis a citation window of three years (the year of publication and two years more) is often applied in studies of the impact of papers, while on the other hand this has been considered

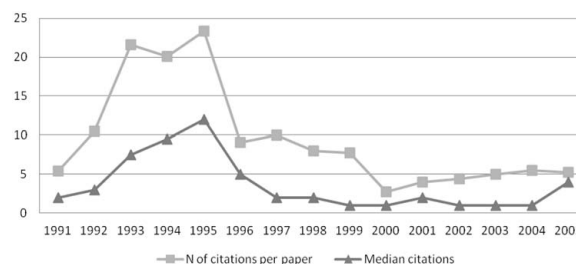


Figure 4. Average citation of Croatian biology papers published from 1991 to 2005 in WoS journals.

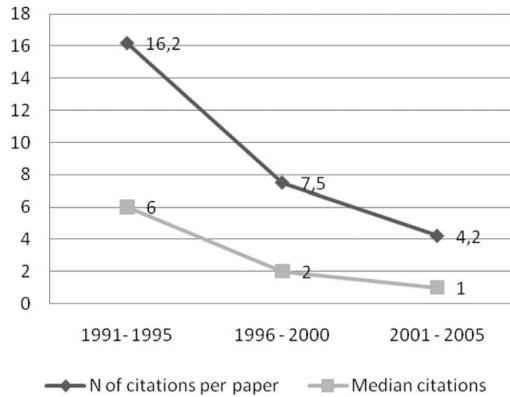


Figure 5. Average citation per paper in the 5-year periods.

as somewhat short (7). Although bibliometric studies mostly show that the recent papers are cited more often than the older ones, it is important to point out that the Figure 4 shows the data for the field of biology as a whole, and that the citation dynamics differ across biological disciplines. Rapidly developing disciplines, for instance biochemistry and molecular biology, are characterized with the faster aging of literature cited. Citations to papers in those fields peak in the second year after publication. On the other hand, in the disciplines such as botany or zoology citation counts accumulate at a slower rate, therefore a 5-year time frame is considered to be more appropriate for the citation analysis (year of publication plus four more years).

Although it is not possible to determine, using this study's methodology, if the decrease of average citation rate of papers in our research is the result of the lower number of received citations, or the result of the inappropriate time frame that prevents the valid citation analysis, one of the reasons for the decrease in average citation rate across years is definitely due to the fact that papers published at the start of the observed period accumulated more citations until the beginning of 2008, when we extracted data from WoS, in comparison to the papers published at the end of the observed period. Other studies covering publications in natural sciences showed as well that the total number of citations, as the most common measure of success of a scientific paper, is in favor of the older papers (22, 23).

Distribution of papers by the number of citations

With the purpose of the more accurate interpretation of the significance of the average citation counts, we analysed the share of uncited papers, as well as the share of highly cited papers in our sample. Namely, in scientometric analysis the distribution of citation counts is usually extremely skewed and only a small number of papers are cited approximately at the average rate.

In the analysed body of biological papers published from 1991 to 2005, we found that the percentage of papers that did not receive a single citation in the time period from 1991 to the beginning of 2008 was 34.7%

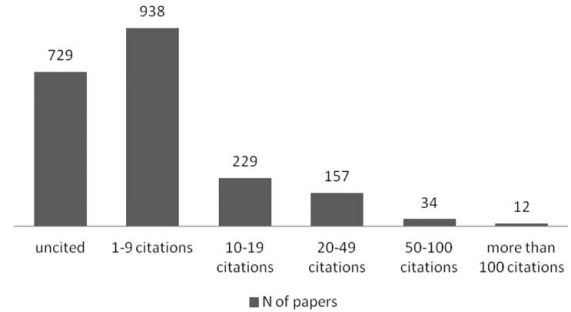


Figure 6. Distribution of papers based on the number of citations.

(Figure 6). A high share of these uncited papers, 46.5%, was published in *Periodicum biologorum*. The key reason for this outcome is the fact that the aforementioned journal covers the broad range of biological and related disciplines, which are characterized with heterogeneous citation dynamics. For this reason the journal is lacking specialization which in the end affects its recognition in the relevant environment. Additional reason for relatively low citation rate of its papers is that the journal has little support both by the Croatian scientist and by the national science policy.

The majority of papers in the cited corpus received less than 10 citations (68.5%). In total 46 (3.4%) papers received 50 or more citations (Figure 6). Highly cited research papers are considered as the indicators for identifying possible scientific excellence (24). Since citation rates vary by field, the selection procedure for highly cited papers should be suited to the specificities of various biological disciplines. So far, the studies showed that the highly cited papers are mostly multi-authored papers, often published in international co-authorship (25, 26). Those papers in our sample that received more than 100 citations (0.6% of papers) were mostly classified in *biochemistry and molecular biology* and *environmental sciences* subject categories. The majority of those papers, 91.6%, were published in international co-authorship. The highest citation rate (189 citations) was received by a paper published in the journal *Cell*, which belongs to the *biochemistry and molecular biology* subject category.

Citation of papers published in "top 10%" journals

It is likely that a paper published in a journal with a higher IF will receive more citations than a paper published in a journal with the lower IF (27). We discovered that the papers published in "top 10%" journals (161 papers) received in total 2,424 citations. The average number of citations per paper was 15.1 (median 7), with the range from 0 to 189 citations. The papers published in "top 10%" journals were cited up to twice as frequently as the papers from the total analysed body of papers (7.3 citations per paper, median 2). Mann-Whitney test confirmed that the papers published in "top 10%" journals are statistically significantly more cited than the rest of the papers from the total analysed body of papers ($Z = -7,100; p = 0,000$)

Previous researches imply that uncitedness is strongly related to the value of the IF of a journal, as the journals with higher IF values have lower share of uncited papers (28, 29). However, we established that no less than 23% of papers published in "top 10%" journals were uncited. χ^2 -test confirmed statistically significant difference in the number of cited papers among the papers published in the top 10% journals ($\chi^2(df=1)=10,732$; $p=0,001$).

Publishing in the most prestigious biology journals on average had an influence on the higher citation rate of papers, but in itself was not a guarantee that an individual paper in the journal would be cited. Individual paper citation rate determine the journal's IF and not *vice versa*. Since IF of a journal does not inform on the citation rate of an individual paper published in that journal, the use of IF as the indicator of the quality of papers is not justified.

Citation and co-authorship

In the observed corpus of Croatian papers published in biology journals, the number of co-authors was correlated with the higher citation count of a paper. Spearman's rank correlation coefficient (Spearman's rho) showed statistically significant and positive relationship between co-authorship and the number of citations received ($\rho=0,23$; $p<0,01$, $N=2099$).

Taking into account the papers that were published in co-authorship of up to ten authors (2,064 papers), we found out that those papers received on average 7.2 citations per paper (median 2). The average citation of the papers co-published in collaboration of more than ten authors (35 papers) was 14.2 citations per paper (median 8). Papers published in co-authorship of more than ten authors received approximately twice as much citations (Mann-Whitney test showed statistically significant difference $Z=-3,603$, $p=0,000$).

Citation of the internationally co-authored papers

International co-authorship, as a rule, results in publications with higher citation impact (19), which was confirmed in this research as well. Internationally co-authored papers with a Croatian address (676 papers) published in biology journals in WoS received in total 10,226 citations, or on average 15.1 citations per paper. They are cited approximately twice as frequently as the

papers from the total analysed body of papers (Figure 7). According to Persson (30), international collaboration is an important factor contributing to high impact of papers from small countries.

One of the reasons for higher citation rates of the internationally co-authored papers lies in the fact that those papers are with the greater frequency published in leading journals. We found that 105 of internationally co-authored papers with a Croatian address published in "top 10%" journals received in total 1,764 citations, which is the average of 16.8 citations per paper (Figure 7). It can be concluded that publishing internationally co-authored papers in "top 10%" journals had the biggest influence on the scientific impact of the Croatian biological papers in the international scientific environment.

CONCLUSION

The purpose of this research was to establish the state of scientific productivity and citation impact of Croatian scientists within the field of biology using scientometric analysis of scientific papers published in biology journals indexed in the WoS-SCI Expanded database from 1991 to 2005. 2,099 papers with a Croatian address were indexed in the aforementioned database in that period. The papers were published in 342 journals that, according to the WoS/JCR classification, belong to the field of biology. The obtained results speak of a steady trend of growth in the number of published papers; the number of papers quadrupled in the final year of the observed period (2005), compared to the first year (1991).

We have confirmed that various biology disciplines have specific patterns of scientific communication, so one can not expect all biologists to have the same productivity, or their papers to have the same impact measured in the number of received citations. The number of papers, as well as the average number of citations per paper, varied significantly in different WoS/JCR subject categories. The largest percentage of papers was published within the *biology* (31.9%) and *biochemistry and molecular biology* (20.9%) subject categories, and the smallest percentage within the *microscopy* and *ornithology* (0.1%) subject categories. On average, scientific papers in the *ornithology* (1.7 citations per paper) and *mycology* and *biology* (2 citations per paper) subject categories were the least cited, while scientific papers in the *virology* (21 citations per paper) and *microscopy* (28 citations per paper) subject categories were the most cited. *Ecology* (10.7 citations per paper) and *environmental sciences* (9.4 citations per paper) showed an above-average citation, in worldwide terms. When it comes to the total number of analysed papers, average citation was 7.3 citations per paper. The percentage of papers that did not receive a single citation was 34.7%, and the percentage of papers that received 50 or more citations was 3.4%. Although biological sciences are generally marked with a faster aging of literature, it was shown that the papers published in the 1990s on average received more citation than the papers published in the 2000s. The real reason

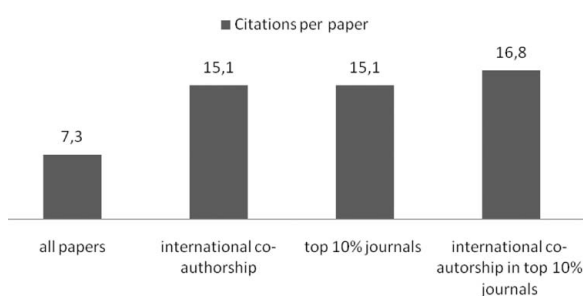


Figure 7. Average citation for four different sets of papers.

for this could be determined with in-depth citation analyses and qualitative methods.

Within the sample of journals with 20 and more published Croatian papers, it was determined that 41.9% of papers were published in journals indexed in the Current Contents database, and that 25% of papers were published in journals whose IF was above the median IF of the subject category.

Papers published in prestigious international journals are potentially more read which gives them the opportunity to be more cited, although citation should be seen as an indicator of relevance and the importance of the paper. Croatian scientists published 7.7% of their papers in 47 of the most prestigious ("top 10%") biology journals in the period from 1991 to 2005, with an average of 15.1 citations per paper. The trend of an increase in the average number of authors per paper in the observed 15-year span indicates an increase in collaboration and teamwork among the scientists that work in different aspects of the biological sciences. Most of the analysed papers were co-authored publications (90.1%). In the field of biology as a whole on average 4.1 authors per paper were observed. There were significant differences in the average number of authors per paper depending on biology disciplines. On average, the smallest number of authors was registered in the *ornithology* (1.7 authors per paper) and the *biodiversity conservation* (2 authors per paper) subject categories, and the largest number was registered in the *virology, genetics and heredity* (6 authors per paper) and *microscopy* (6.3 authors per paper) subject categories. A larger number of authors per paper was correlated with a larger citation count of the papers. Papers co-published by more than ten authors received approximately twice the citations than papers published in co-authorship of up to ten authors. International collaboration is an important factor in evaluating the scientific status of a country. The percentage of papers that were co-authored with a foreign institution in the total sample was 32.3% (65.2% in the "top 10%" journals). On average, internationally co-authored papers received 15.1 citations per paper. In general, internationally co-authored papers published in the "top 10%" journals obtained the largest average citation (16.8 citations per paper).

Based on the obtained results about the scientific activity in the field of biological sciences in Croatia, a conclusion can be made that there is a need to define a more acceptable system for the assessment of scientific performance than the existing one. A new model of evaluating scientific work should acknowledge specificities of scientific publishing and citation in different biology disciplines, which has not been the case so far.

Stimulation of the publishing of papers in journals with a high IF in the Croatian evaluation system of scientific work is basically positive, because it became evident that papers in journals with the highest IF are, on average, significantly more cited than papers in the total body of analysed papers, which should be an indicator of recognition in the relevant worldwide scientific commu-

nity. One should, however, take into account the fact that the IF is a tool in determining the quality of a journal, not in determining the quality of a single paper, or the quality of a single scientist. Publishing a paper in a journal with a high IF does not necessarily mean that the paper will have an impact in the scientific community, i.e. that it will be cited. In determining the status of a journal using the IF in the procedure of evaluating scientific performance of biologists, it would be more appropriate to take into account a 5-year IF. Biology is a broad field with a different citation dynamic, so a two-year period from the publishing of the paper, which is taken to calculate the standard, or the Garfield IF, is not an optimal period in all biology disciplines.

The problem on which the national science policy does not have a clear stand is Croatian journals, especially those that deal with the issues of natural sciences. Croatian natural scientists are not being stimulated to publish papers in national journals that in WoS, in general, do not fall within the category of prestigious journals according to their IF. However, one can not disregard the importance of domestic journals in the national scientific environment, especially if those journals deal with topics of national importance. We especially emphasize the problems of researching biodiversity and Croatian flora and fauna, which play an important role on a national level, and whose disregard could have serious long-term consequences.

By using the results of this research to define the condition and the trends in the field of biology in Croatia, as well as to suggest the improvement of the model of evaluation of scientific work, we indicate the need to introduce a systematic scientometric analysis into scientific evaluation processes, as well as into processes of planning and developing a national science policy.

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