Network Analysis of Peer Review Literature

Vladimir Batagelj
Institute of Mathematics, Physics and Mechanics,
Department of Theoretical Computer Science,
Jadranska 19, 1 000 Ljubljana, Slovenia
and
University of Primorska, Andrej Marušič Institute,
Muzejski trg 2, Koper, Slovenia
e-mail: `vladimir.batagelj@uni-lj.si`

Anuška Ferligoj
Faculty of Social Sciences, University of Ljubljana,
Kardeljeva pl. 5, 1 000 Ljubljana, Slovenia
e-mail: `anuska.ferligoj@fdv.uni-lj.si`

July 24, 2016; 03 : 23

Abstract

In the paper several analyses of peer review literature are provided. From the bibliographic data on "peer review" obtained from the Web of Science the citation network and some additional two-mode networks (works $\times$ authors, works $\times$ keywords, works $\times$ journals) were constructed. First, lists of the most productive authors, the most cited publications in the field of peer review, main journals publishing papers on peer review, and the groups of researchers that collaborated the most with their topics are given. The most influential publications in the field of peer review were identified from the citation network by main path procedures and by the islands method. All these approaches used CPS weights on citation arcs. The 47 publications from the main path are contained in all other obtained lists of the most influential publications. These publications are segmented into three phases defined by three time periods: before 1982 with the publications mostly published in the social sciences journals; from 1983 to 2002 with the publications published almost exclusively in the biomedical journals; and from 2002 on with the publications published in specialized journals on science studies. The obtained typology nicely shows the evolution of the peer review field. The collaboration network and the citation network among authors were also computed and analyzed.

The analyses were performed using **`Pajek`** – a program for analysis and visualization of large networks.

Keywords: peer review, large network, acyclic, citation network, arc weight, algorithm, main path, CPM path, islands, collaboration.

1 Introduction

The goal of the paper is to study publications on 'peer review' included in Web of Science till March 2016. Peer review is the evaluation of a work by one or more people of similar competence (peers) to the producers of the work. It constitutes a form of self-regulation by qualified members of a profession within the relevant field. Peer review methods are employed to maintain standards of quality, improve performance, and provide credibility (Wikipedia, 2016). There is a lot of criticisms of peer review. Nevertheless, it is still the only widely accepted method for research evaluation. There is also a lot of discussion and research how to improve it.

In the paper we present analyses of the bibliography on "peer review" as recorded in the Web of Science (WoS). The questions to be answered are:

- Which publications and which authors are the most cited?
- Which are the main journals publishing papers on 'peer review'?
- Which are the main topics in the works on 'peer review'?
- Which are the most influential publications in the field of 'peer review'?
- Which are the groups of researchers that collaborate the most, what are their topics?
- Which were the main phases in the evolution of the 'peer review' field?

For answering these questions several social network analysis approaches are applied on large citation and collaboration networks obtained from WoS. The most useful ones are the 'main path' analysis and the 'islands' procedure.

2 Data

2.1 Collecting the data

To the Web of Science (WoS) we put the query `"peer review*"`. In May and June 2015 we got (from Web of Science Core Collection) 17053 hits, and additional 2867 hits for the query `refereeing`. An example of a WoS paper's description is presented in Figure 1.

Using the program **`WoS2Pajek`** (Batagelj, 2007) we transformed the WoS data into a collection of networks: the citation network $\mathbf{Cite}$ (from the field CR), the authorship network $\mathbf{WA}$ (from the field AU), the journalship network $\mathbf{WJ}$ (from the field CR or J9), and the keywordship network $\mathbf{WK}$ (from the field ID or DE or TI). An important property of all these networks is that they have as the first node set the same set – the set of works (papers, reports, books, etc.) W. A citation network $\mathbf{Cite}$ is based on the citing relation $\mathbf{Ci}$

$$w\,\mathbf{Ci}\,z \equiv \text{work } w \text{ cites work } z$$

Works that appear in descriptions are of two types:

- hits – works with a WoS description;

```
PT J
AU Stensrud, DJ
   Brooks, HE
AF Stensrud, DJ
   Brooks, HE
TI The future of peer review?
SO WEATHER AND FORECASTING
LA English
DT Editorial Material
CR Tregenza T, 2002, TRENDS ECOL EVOL, V17, P349
   Wenneras C, 1997, NATURE, V387, P341, DOI 10.1038/387341a0
NR 2
TC 3
Z9 3
PU AMER METEOROLOGICAL SOC
PI BOSTON
PA 45 BEACON ST, BOSTON, MA 02108-3693 USA
SN 0882-8156
J9 WEATHER FORECAST
JI Weather Forecast.
PD DEC
PY 2005
VL 20
IS 6
BP 825
EP 826
DI 10.1175/WAF9010.1
PG 2
WC Meteorology & Atmospheric Sciences
SC Meteorology & Atmospheric Sciences
GA 001AU
UT WOS:000234505500001
ER
```

Figure 1: Record from Web of Science

- cited only works (listed in CR fields of descriptions, but not contained in the hits).

The information about the work's type is stored in a partition DC: $DC[w] = 1$ iff a work w has a WoS description; and $DC[w] = 0$ otherwise. Another partition $year$ contains the work publication year from the field PY or CR. We get also a vector NP: $NP[w] =$ number of pages of a work w. A CSV file `titles` with basic data about works with $DC = 1$ is also produced to be used in listing of results.

The usual *ISI name* of a work as used in the CR field, e.g.,

```
Tregenza T, 2002, TRENDS ECOL EVOL, V17, P349
```

has the following structure

AU_1 + `', '` + PY + `', '` + SO[:20] + `', V'` + VL + `', P'` + BP

where AU_1 is the first author's name and SO[:20] is the string of the initial (up to) 20 characters in the SO field.

In WoS records the same work can have different ISI names. To improve the precission the program **`WoS2Pajek`** supports also *short names* (similar to the names used in HISTCITE output (Garfield et al., 2003)). They have the format:

LastNm[:8] + `'_'` + FirstNm[0] + `'('` + PY + `')'` + VL + `':'` + BP

For example: `TREGENZA_T(2002)17:349`. From the last names with prefixes `VAN`, `DE`, etc. the space is deleted. Unusual names start with character $\star$ or `$`. The name `[ANONYMOUS]` is used for anonymous authors.

This construction of names of works provides a very good balance between the synonymy problem (different names designating the same work) and the homonymy problem (a name designating different works). We treat the remaining synomyms and homonyms in the network data as a noise. If their effect surfaces into final results we either correct our copy of WoS data and repeat the analysis, or, if the correction would require too much work, simply report the problem. A typical such case is the author name `[ANONYMOUS]` or combinations with some very frequent last names – in MathSciNet there are 85 mathematicians corresponding to the short name `SMITH_R` and 1792 mathematicians corresponding to the short name `WANG_Y`.

The composed keywords were decomposed to single words. For example, 'peer review' into 'peer' and 'review'. On keywords obtained from titles of works we apply the lemmatization (using Monty Lingua library). The name $*****$ denotes a missing journal name.

In March 2016 we updated the data by adding hits for the years 2015 and 2016 and manually prepared short descriptions for the most cited works (fields: AU, PU, TI, PY, PG, KW; but without CR data). We assigned them the value $DC = 2$.

The first analysis in 2015 revealed many papers without WoS descriptions having large indegrees in the citation network. We manually searched in WoS for each of them (with indegree larger or equal to 20) and, if found, we added them into the data set. Important earlier papers often did not use the now established terminology and were therefore overlooked by our queries.

After some iterations, we finally constructed the data set used in this paper. The final run of the program **`WoS2Pajek`** produced networks with sets of the following sizes: works $|W| = 721547$, authors $|A| = 295849$, journals $|J| = 39988$, and keywords $|K| = 36279$. In both phases 22981 records were collected. There were 887 duplicates (considered only once).

We removed multiple links and loops (resulting from homonyms) from the networks. The cleaned citation network **CiteAll** has $n = 721547$ nodes and $m = 869821$ arcs.

In Figure 2 a schematic structure of citation network is presented. Circular nodes correspond to query hits. Works cited in hits are presented with triangular nodes. Some of them are in the following phase (search for often cited works) converted into squares (found in WoS in the secondary search). They introduce new cited only nodes represented as diamonds. Since a work is usually citing an older work a citation network is (almost) acyclic.

In the following section we look at some statistical properties of obtained networks.

3 Distributions

In the left part of Figure 3 the distribution of the number of papers from WoS ($DC > 0$) by year is presented. We observe an intensive growth of the interest for the field of peer review, especially after the year 1990. This should be considered while determining time intervals and interpreting temporal analyses.

In the right part of Figure 3 we display the distribution of number of all (hits + cited only) works by year. It can be fitted by log normal distribution (Batagelj et al., 2014, p. 119–121):

$$dlnorm(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

Using the R's nonlinear least squares function `nls`

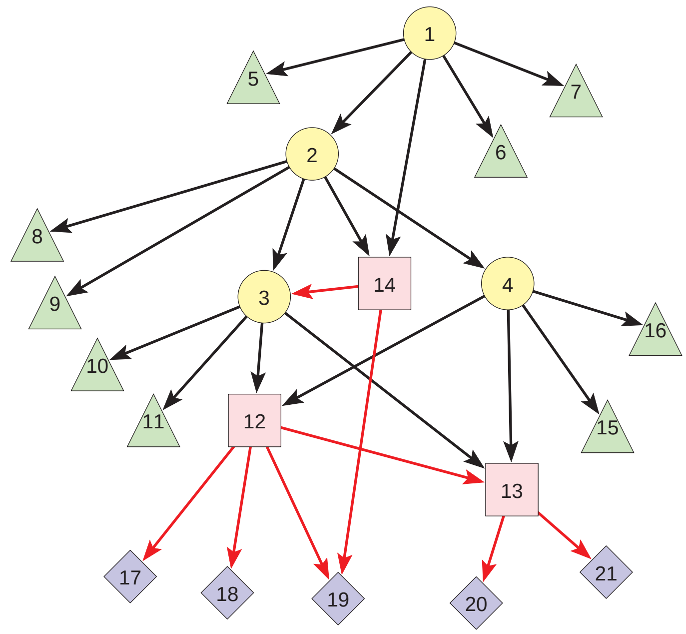

Figure 2: Citation network structure: $DC = 0$ – circle, square; $DC = 1$ – triangle, diamond.

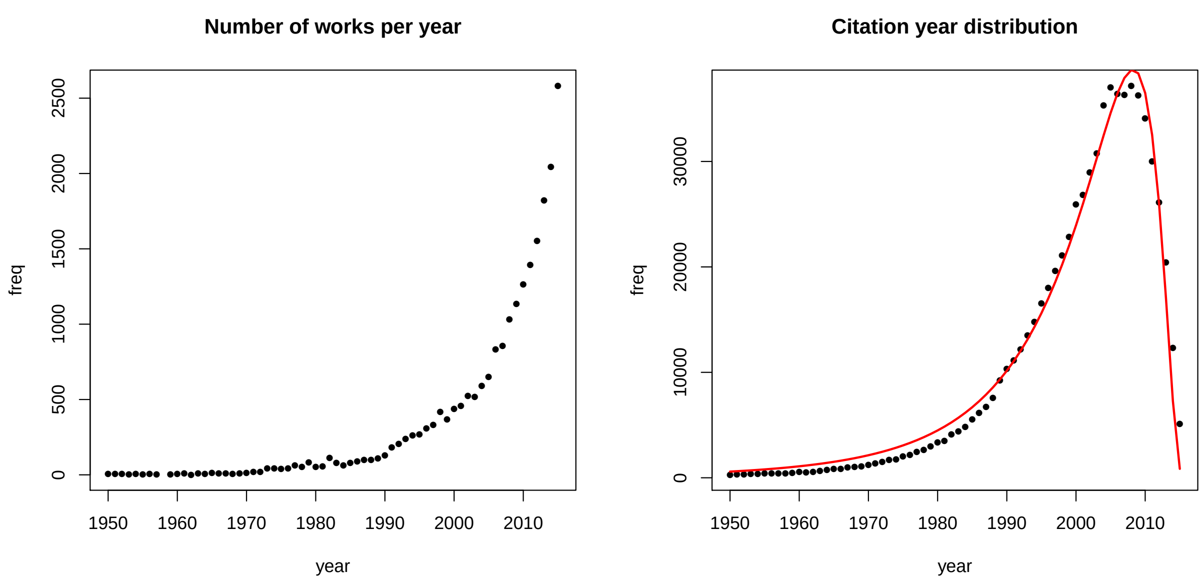

Figure 3: Growth of the number of works and citation year distribution

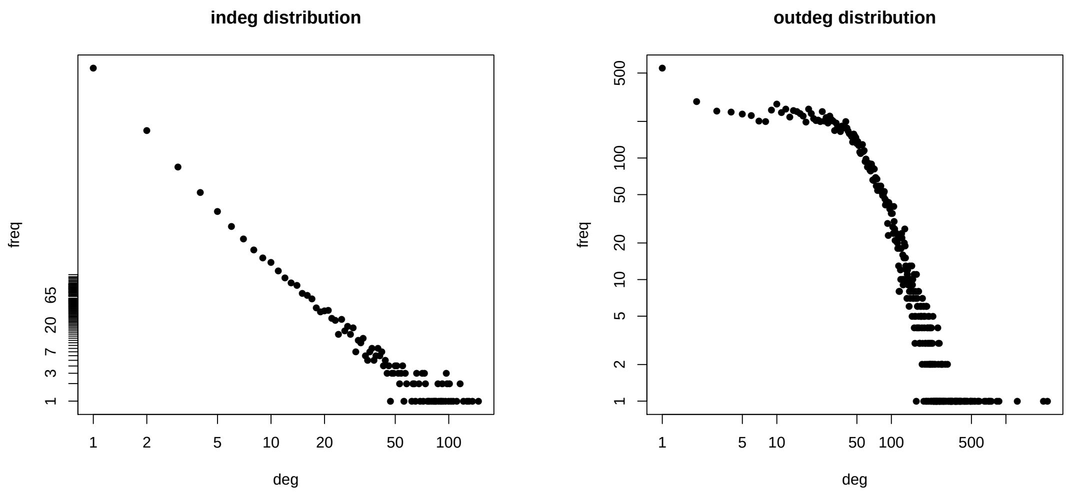

Figure 4: Degree distributions in citation network

```
y <- 1950:2015
model <- nls(freq~c*dlnorm(2016-y,a,b),start=list(c=350000,a=2,b=0.7))
```

we get $c = 731700$, $\mu = a = 2.595$, and $\sigma = b = 0.7404$.

Figure 4 presents indegree and outdegree distributions in the citation network **CiteAll** in double logarithmic scales. We see that indegrees exhibit a scale-free like behavior. It is also interesting that frequencies for outdegrees in the range $[3, 42]$ have almost a constant value – they are in the range [215,328]. The works with the largest indegrees are the most cited works.

In Table 1 31 the most cited works are listed. Among them there are seven publications on statistics. As expected, most of the top cited works are of older dates, only eight of them were published after 2000. We also searched for the most cited books. There are 15 books cited (number in parentheses) more than 50 times: (52) Kuhn, T: *The Structure of Scientific Revolutions*, 1962; (57) Glaser, BG, Strauss, AI: *The Discovery of Grounded Theory*, 1967; (67) Merton, RK: *The Sociology of Science*, 1973; (97) Lock, S: *A Difficult Balance*, 1985; (72) Hedges, LV, Olkin, I: *Statistical methods for meta-analysis*, 1985; (173) Cohen, J: *Statistical power analysis*, 1988; (87) Chubin, D, Hackett, EJ: *Peerless Science*, 1990; (60) Boyer, EL: *Scholarship reconsidered*, 1990; (51) Daniel, H-D: *Guardians of Science*, 1993; (55) Miles, MB, Huberman, AM: *Qualitative data analysis*, 1994; (64) Gold, MR, et al.: *Cost-Effectiveness in Health and Medicine*, 1996; (53) Lipsey, MW, Wilson, DB: *Practical Meta-Analysis*, 2001; (58) Weller, AC: *Editorial Peer Review*, 2001; (69) Higgins, JPT, Green, S: *Systematic reviews of interventions*, 2008; (130) Higgins, JPT, Green, S: *Systematic reviews of interventions*, 2011.

Works with the largest outdegree are the most citing works – usually overview papers. Three works with the largest number of citations (in parentheses) are: (2306) Goldstein, RJ: Heat transfer–A review of 2004 literature. Int J Heat Mass Tran, 2010; (2127) Goldstein, RJ: Heat transfer–A review of 2005 literature. Int J Heat Mass Tran, 2010; and (1259) Hillis, LD: 2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery. J Am Coll Cardiol, 2011. These works were mostly published recently (in the last ten years). Among the first 50 most citing papers only two were published before the year 2000 – one in 1998 and another in 1990.

Table 1: Most cited works

n	freq	first author	title
1	173	Cohen, J	Statistical Power Analysis for the Behavioral Sciences. Routledge,1988
2	164	Peters, DP	Peer-review practices of psychological journals - the fate of … Behav Brain Sci, 1982
3	151	Egger, M	Bias in meta-analysis detected by a simple, graphical test. Brit Med J, 1997
4	150	Stroup, DF	Meta-analysis of observational studies in epidemiology - A proposal for reporting. JAMA, 2000
5	135	Dersimonian, R	Metaanalysis in clinical-trials. Control Clin Trials, 1986
6	130	Zuckerma.H	Patterns of evaluation in science - institutionalisation, structure and functions of referee system. Minerva, 1971
7	130	Higgins, JPT	Cochrane Handbook for Systematic Reviews of Interventions. Cochrane, 2011
8	126	Moher, D	Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Plos Med, 2009
9	125	Higgins, JPT	Measuring inconsistency in meta-analyses. Brit Med J, 2003
10	121	Cicchetti, DV	The reliability of peer-review for manuscript and grant submissions - … Behav Brain Sci, 1991
11	119	Hirsch, JE	An index to quantify an individual's scientific research output. P Natl Acad Sci Usa, 2005
12	114	Mahoney, M	Publication prejudices: An experimental study of confirmatory bias … Cognitive Therapy and Research, 1977
13	114	van Rooyen, S	Effect of open peer review on quality of reviews and on reviewers' recommendations: … Brit Med J, 1999
14	114	Easterbrook, PJ	Publication bias in clinical research. Lancet, 1991
15	110	Landis, JR	Measurement Of Observer Agreement For Categorical Data. Biometrics, 1977
16	109	Godlee, F	Effect on the quality of peer review of blinding reviewers and asking them to sign their reports - … JAMA, 1998
17	108	Horrobin, DF	The philosophical basis of peer-review and the suppression of innovation. JAMA, 1990
18	107	Moher, D	Preferred Reporting Items for Systematic Reviews and Meta-Analyses: PRISMA. Ann Intern Med, 2009
19	107	Jadad, AR	Assessing the quality of reports of randomized clinical trials: Is blinding necessary? Control Clin Trials, 1996
20	105	Mcnutt, RA	The effects of blinding on the quality of peer-review - a randomized trial. JAMA, 1990
21	104	Cole, S	Chance and consensus in peer-review. Science, 1981
22	103	Moher, D	Improving the quality of reports of meta-analyses of randomised controlled trials: QUOROM. Lancet, 1999
23	98	Justice, AC	Does masking author identity improve peer review quality? - A randomized controlled trial. JAMA, 1998
24	97	Lock, S	A Difficult Balance: Editorial Peer Review in Medicine. Nuffield Trust, 1985
25	95	van Rooyen, S	Effect of blinding and unmasking on the quality of peer review - A randomized trial. JAMA, 1998
26	92	Black, N	What makes a good reviewer and a good review for a general medical journal? JAMA, 1998
27	91	Scherer, RW	Full publication of results initially presented in abstracts - a metaanalysis. JAMA, 1994
28	90	Higgins, JPT	Quantifying heterogeneity in a meta-analysis. Stat Med, 2002
29	90	Smith, R	Peer review: a flawed process at the heart of science and journals. J Roy Soc Med, 2006
30	87	Goodman, SN	Manuscript quality before and after peer-review and editing at annals of internal-medicine. Ann Intern Med, 1994
31	87	Chubin, D	Peerless Science: Peer Review and U.S. Science Policy. SUNY Press, 1990

None among these overviews is on the topic of peer review.

Considering the indegree distribution in citation network **CiteAll** we noticed that most of the works were referenced only once. We decided to remove all 'cited only' nodes with indegree smaller than 3 ($DC = 0$ and $indeg < 3$) – the boundary problem (Batagelj et al., 2014). We also removed all cited only nodes starting with strings `"[ANONYM"`, `"WORLD_"`, `"INSTITUT_"`, `"U_S"`, `"*US"`, `"WHO_"`, `"*WHO"`, `"WHO(".` `"AMERICAN_"`, `"DEPARTME_"`, `"*DEP"`, `"NATIONAL_"`, `"UNITED_"`, `"CENTERS_"`, `"INTERNAT_"`, `"EUROPEAN_"`. The final 'bounded' set of works W_B contains 45917 works.

Restricting two-mode networks **WA**, **WJ** and **WK** to the set W_B and removing from their second sets nodes with indegree 0 we obtain networks $\mathbf{WA}_B$, $\mathbf{WJ}_B$ and $\mathbf{WK}_B$ with reduced sets with the following sizes $|A_B| = 62106$, $|K_B| = 36275$, $|J_B| = 6716$.

Some information (co-authors, keywords) is available only for works with WoS description. In these cases we have to limit our analysis to the set of works with a description

$$W_D = \{w \in W_B : DC[w] > 0\}$$

Its size is $|W_D| = 22104$. By restricting basic networks to the set W_D we obtained subnetworks $\mathbf{WA}_D$, $\mathbf{WK}_D$ and $\mathbf{WJ}_D$.

A *temporal network* $\mathcal{N}$ is obtained if the *time* $\mathcal{T}$ is attached to an ordinary network. $\mathcal{T}$ is a set of *time points* $t \in \mathcal{T}$. In a temporal network nodes $v \in \mathcal{V}$ and links $l \in \mathcal{L}$ are not necessarily present or active in all time points. The node activity sets $T(v)$ and link activity sets $T(l)$ are usually described as a sequence of time intervals. If a link $l(u, v)$ is active in a time point t then also its endnodes u and v should be active in the time point t. The time $\mathcal{T}$ is usually either a subset of integers, $\mathcal{T} \subseteq \mathbb{Z}$, or a subset of reals, $\mathcal{T} \subseteq \mathbb{R}$.

We denote a network consisting of links and nodes active in time, $t \in \mathcal{T}$, by $\mathcal{N}(t)$ and call it the (network) *time slice* or *footprint* of t. Let $\mathcal{T}' \subset \mathcal{T}$ (for example, a time interval). The notion of a time slice is extended to $\mathcal{T}'$ by: a time slice $\mathcal{N}(\mathcal{T}')$ for $\mathcal{T}'$ is a network consisting of links and nodes of $\mathcal{N}$ active at some time point $t \in \mathcal{T}'$.

To get time slices in **Pajek** the relevant command is:

```
Network/Temporal Network/Generate in time
```

The generating in time operation creates a sequence of temporal network slices for subsequent study.

In the following we present a simple analysis of changes of sets of main authors, main journals and main keywords through time (Tables 2–6 and Figure 5). Analyses are based on temporal versions of subnetworks $\mathbf{WA}_D$, $\mathbf{WK}_D$ and $\mathbf{WJ}_D$ – the activity times are determined by the publication year of corresponding works.

Because of an increasing growth of the interest (see the left part of Figure 3) for the peer review topic we decided to split the time line into intervals $[1900, 1970]$, $[1971, 1980]$, $[1981, 1990]$, $[1991, 2000]$, $[2001, 2005]$, $[2006, 2010]$, $[2011, 2015]$.

4 Most cited works, main works, journals and keywords

In Table 2 the authors with the largest number of co-authored works ($\mathbf{WA}_D$ indegree) is presented and in Table 3 the list of authors with the largest fractional contribution of works (weighted

Table 2: Authors with the largest number of works ($\mathbf{WA}_D$ indeg)

n	works	author	n	works	author
1	282	[ANONYMO_	24	27	CASTAGNA_C
2	61	BORNMANN_L	25	25	COHEN_J
3	59	ALTMAN_D	26	25	HELSEN_W
4	55	SMITH_R	27	24	MAZEROLL_S
5	55	LEE_J	28	24	LEE_M
6	50	MOHER_D	29	24	ADAMS_J
7	48	DANIEL_H	30	23	CHENG_J
8	46	SMITH_J	31	23	LI_Y
9	38	CURTIS_K	32	22	JONES_A
10	36	BROWN_D	33	22	WANG_H
11	36	RENNIE_D	34	22	BROWN_R
12	35	LEE_S	35	22	ANDERSON_P
13	32	WANG_J	36	21	CALLAHAM_M
14	32	WILLIAMS_J	37	21	WILSON_D
15	31	THOENNES_M	38	20	MARSHALL_E
16	29	JOHNSON_C	39	20	LI_J
17	29	JOHNSON_J	40	20	YANG_Y
18	29	REYES_H	41	20	JOHNSON_D
19	28	ZHANG_Y	42	20	JONES_R
20	28	WANG_Y	43	20	BROWN_C
21	27	ZHANG_L	44	20	ZHANG_X
22	27	SMITH_M	45	20	BJORK_B
23	27	WILLIAMS_A	46	19	ANDERSON_M

indegree in the normalized $\mathbf{WA}_D$) is presented. It can be noticed that by comparing the authors from Table 3 with the list of the most cited works in Table 1, the two rankings are very different. Only four out of 46 authors with the largest number of works wrote publication that are on the list of 31 the most cited works. These are J. Cohen, D. Moher with two publications, D.V. Cicchetti, and R. Smith. This result is in line with the rather old study done by Cole and Cole (1973) in which they analyzed several aspects of the communication process in science. They used bibliometric data and survey data of university physicists to study the conditions making for high visibility od scientist's work. They found four determinants of visibility: the quality of work measured by citations, the honorific awards received for their work, the prestige of their departments and specialty. Quantity of the output had no effect on visibility.

We didn't check the listed author's names for homonymity. Obviously the name `[ANONYMO_` represents different authors.

In computing the author's contribution in Table 3 we use the so called *fractional approach* (Gauffriau et al., 2007) based on the normalized authorship network $\mathbf{N} = [n_{pv}]$ where

$$n_{pv} = \frac{wa_{pv}}{\text{outdeg}(p)}$$

Table 3: Authors with the largest contribution to the field (weighted indegree in normalized $\mathbf{WA}_D$)

n	value	author	n	value	author
1	282.0000	[ANONYMO_	23	10.2952	JONES_R
2	29.1167	BORNMANN_L	24	10.2198	MOHER_D
3	21.7833	DANIEL_H	25	10.0000	BEREZIN_A
4	18.2453	SMITH_R	26	10.0000	ROY_R
5	18.0105	ALTMAN_D	27	10.0000	HARNAD_S
6	17.7255	MARSHALL_E	28	9.8183	CURTIS_K
7	17.0000	GARFIELD_E	29	9.5333	ROUKIS_T
8	15.3788	SMITH_J	30	9.4851	ANDERSON_M
9	15.1737	RENNIE_D	31	9.0000	KOSTOFF_R
10	14.6538	SQUIRES_B	32	9.0000	LIESEGAN_T
11	14.5636	CHENG_J	33	8.9542	WILLIAMS_A
12	13.8833	THOENNES_M	34	8.8510	JOHNSON_J
13	13.7957	COHEN_J	35	8.8333	CHUBIN_D
14	13.2898	JOHNSON_C	36	8.6429	FONTANAR_P
15	13.2857	REYES_H	37	8.4959	WILLIAMS_J
16	12.9779	LEE_J	38	8.4909	JONES_A
17	12.6667	WELLER_A	39	8.3673	LEE_S
18	11.9167	BJORK_B	40	8.3333	CICCHETT_D
19	11.1648	BROWN_D	41	8.3333	DONOVAN_S
20	10.9091	BROWN_C	42	8.3133	WANG_J
21	10.5000	MERVIS_J	43	8.0000	REINDOLL_W
22	10.3762	CALLAHAM_M	44	7.9992	ADAMS_J

A contribution of each paper p is equal to $\sum_v n_{pv} = 1$. Then the contribution of an author v to the field is equal to its weighted indegree

$$\text{windeg}(v) = \sum_p n_{pv}$$

In Table 3 authors with the largest contribution to the field of "peer review" are listed. Comparing Table 2 and Table 3 we see, for example, that the author L. Bornmann contributed $0.477 = 29.1167/61$ to the papers he co-authored as he is collaborating with other researchers in the field. While E. Marshall and E. Garfield wrote most of their papers as single authors and are therefore moved up in Table 3.

The top authors in each time interval can be easily seen from the first rows of Table 4. They are: G.R. Clark (–1970), P. Weinstein, P. Milgrom, P. Ratener, K. Morrison and H. Zuckerman (1971–1980), B.P. Squires (1981–1990), D. Rennie (1991–2000), M.S. Benninger and R. Smith (2001–2005), L. Bornmann (2006–2010), and J. Lee (2011–2015). Let's look to the authors that remained in the leading group for at least two time periods. The sequence starts with R. Merton (–1980) and E. Garfield (–1990), followed by D. Chubin and T. Chalmers (1971–1990), B.

Table 4: Main authors through time

		-1970		1971-1980		1981-1990		1991-2000		2001-2005		2006-2010		2011-2015
1	13	CLARK_G	6	WEINSTEI_P	13	SQUIRES_B	19	RENNIE_D	13	BENNINGE_M	34	BORNMANN_L	36	LEE_J
2	12	FISHER_H	6	MILGROM_P	8	CHALMERS_T	16	SMITH_R	13	SMITH_R	30	DANIEL_H	31	BROWN_D
3	9	MILSTEAD_K	6	RATENER_P	8	COHEN_L	12	REYES_H	12	ALTMAN_D	26	ALTMAN_D	25	ZHANG_L
4	9	SMITH_J	6	MORRISON_K	7	CHUBIN_D	11	MARSHALL_E	12	JOHNSON_J	20	HELSEN_W	25	LEE_S
5	8	WILEY_F	6	ZUCKERMA_H	5	GARFIELD_E	9	LUNDBERG_G	11	CASTAGNA_C	18	ANDERSON_P	24	WANG_J
6	8	REINDOLL_W	5	HULKA_B	5	LOCK_S	9	KOSTOFF_R	10	RUBEN_R	17	RESNICK_D	24	CURTIS_K
7	8	GRIFFIN_E	5	READ_W	5	HARGENS_L	9	JOHNSON_D	10	KENNEDY_D	17	MOHER_D	23	BORNMANN_L
8	8	ROBERTSO_A	5	GARFIELD_E	5	RENNIE_D	8	BERO_L	9	YOUNG_E	17	KAISER_M	23	MAZEROLL_S
9	7	ALFEND_S	4	MERTON_R	5	MARSHALL_E	8	COHEN_J	9	WEBER_P		-----	23	WANG_Y
10	7	SALE_J	4	WALSH_J	5	SMITH_H	8	FLETCHER_R	9	JACKLER_R	12	CURTIS_K	19	THOENNES_M
11	7	MARSHALL_C		-----		-----	8	HAYNES_R	9	JOHNS_M	11	THOENNES_M	19	WANG_H
12	6	HALVORSO_H	2	CHUBIN_D	3	LUNDBERG_G	8	RUBIN_H	9	SATALOFF_R	10	LEE_J	19	MOHER_D
13	6	CAROL_J	2	CHALMERS_T			8	FLETCHER_S	8	D'OTTAVI_S	9	CASTAGNA_C		-----
14		-----					8	KHUDER_S	8	MOHER_D	9	SMITH_R	13	ALTMAN_D
15	4	GARFIELD_F						-----	8	WEBER_R			13	SMITH_R
16	2	MERTON_R					7	ALTMAN_D		-----				
17							6	SQUIRES_B	5	DANIEL_H				
18							5	MOHER_D	5	REYES_H				
19									4	BORNMANN_L				
20									4	RENNIE_D				

Table 5: Main journals ($\mathbf{WJ}_D$ indeg)

n	number	journal	n	number	journal
1	515	BMJ OPEN	21	66	ANN PHARMACOTHER
2	288	JAMA-J AM MED ASSOC	22	64	NEW ENGL J MED
3	177	PLOS ONE	23	62	CUTIS
4	175	NATURE	24	59	ANN ALLERG ASTHMA IM
5	174	SCIENTOMETRICS	25	59	BEHAV BRAIN SCI
6	174	BRIT MED J	26	59	PEDIATRICS
7	165	SCIENCE	27	57	CHEM ENG NEWS
8	127	*****	28	57	MED J AUSTRALIA
9	102	ACAD MED	29	54	J GEN INTERN MED
10	98	LANCET	30	53	MATER TODAY-PROC
11	92	SCIENTIST	31	53	J SCHOLARLY PUBL
12	91	LEARN PUBL	32	53	J NANOSCI NANOTECHNO
13	81	J AM COLL RADIOL	33	53	AM J PREV MED
14	80	PHYS TODAY	34	52	BMC PUBLIC HEALTH
15	78	ARCH PATHOL LAB MED	35	50	J SEX MED
16	78	J UROLOGY	36	50	J SPORT SCI
17	75	J ASSOC OFF AGR CHEM	37	50	MED EDUC
18	73	CAN MED ASSOC J	38	48	RES EVALUAT
19	71	ANN INTERN MED	39	48	BRIT J SPORT MED
20	67	ABSTR PAP AM CHEM S	40	47	PROCEDIA ENGINEER

Squires, E. Marshall and G. Lundberg (1981–2000), and D. Rennie (1981–2005) and H. Reyes (1991–2005). D. Altman, R. Smith and D. Moher remained in the leading group for four periods (1991-2015). C. Castagna and H. Daniel were very active in the period (2001–2010). In the last periods the leading authors are L. Bornmann (2001–2015), M. Thoennessen, J. Lee, and K. Curtis (2006–2015).

The short names ambiguity problem started to emerge with the growth of number of different authors in the period 1991–2000 with Smith_R (R, RD, RA, RC) and Johnson_D (DM, DAW, DR, DL). In the period 2006–2015 we can notice an 'invasion' of Chinese (or Korean) authors: Lee_J, Zhang_L, Lee_S, Wang_J, Wang_Y, and Wang_H. Because of the "three Zhang, four Li" effect (100 most common Chinese family names are shared by 85% of population, Wikipedia (2016)) all these names represent groups of authors. For example: Lee_J (Jaegab, Jaemu, Jae Hwa, Janette, Jeong Soon, Jin-Chuan, Ji-hoon, Jong-Kwon, Joong, Joseph, Joshua,Joy L, Ju, Juliet, etc.) and Zhang_L (L X, Lanying, Lei, Li, Lifeng, Lihui, Lin, Lina, Lixiang, Lujun).

Much attention to the process of peer review was given in the field of medicine. This can be seen as 23 journals out of 47 top journals publishing topics on peer review are from medicine (see Table 5). Among these top journals are also Nature, Science, Scientist, but also the specialized journal on science studies Scientometrics. The third on the list is a rather new (from 2006) open access scientific journal PLOS (Public Library of Science).

Table 6: Main journals through time

	-1970
75	J ASSOC OFF AGR CHEM
21	LANCET
15	BRIT MED J
9	PHYS TODAY
7	SCIENCE
6	J ASSOC OFF ANA CHEM
4	J AM OIL CHEM SOC
4	YALE LAW J
3	NATURE
3	BRIT J SURG
3	AM SOCIOL

	1971-1980
24	SCIENCE
20	MED J AUSTRALIA
18	NEW ENGL J MED
16	AM J PSYCHIAT
15	PHYS TODAY
11	JAMA-J AM MED ASSOC
10	HOSP COMMUNITY PSYCH
10	FED PROC
10	BRIT MED J
9	NATURE
9	AM SOCIOL
7	NEW YORK STATE J MED
7	MED CARE

	1981-1990
46	JAMA-J AM MED ASSOC
42	SCIENCE
33	BEHAV BRAIN SCI
32	PHYS TODAY
29	NATURE
27	NEW ENGL J MED
27	SCIENTIST
25	BRIT MED J
19	CAN MED ASSOC J
16	PROF PSYCHOL
13	SCI TECHNOL HUM VAL
13	S AFR MED J
12	HOSPITALS

9	LANCET
6	SCIENTOMETRICS

	1991-2000
126	JAMA-J AM MED ASSOC
71	NATURE
66	BRIT MED J
45	SCIENCE
39	ANN INTERN MED
38	LANCET
29	CAN MED ASSOC J
28	SCIENTIST
26	BEHAV BRAIN SCI
25	SCIENTOMETRICS
23	ACAD MED
23	J ECON LIT

12	PHYS TODAY
9	NEW ENGL J MED

	2001-2005
49	JAMA-J AM MED ASSOC
40	CUTIS
32	BRIT MED J
28	LEARN PUBL
26	NATURE
24	ABSTR PAP AM CHEM S
23	ACAD MED
22	J PROSTHET DENT
22	ANN ALLERG ASTHMA IM
18	SCIENTOMETRICS
16	J UROLOGY
16	MED EDUC

14	LANCET
13	SCIENCE
12	SCIENTIST

	2006-2010
44	SCIENTOMETRICS
33	JAMA-J AM MED ASSOC
31	J SEX MED
27	PLOS ONE
27	J NANOSCI NANOTECHNO
27	ACAD MED
25	SCIENTIST
25	J UROLOGY
23	LEARN PUBL
23	J SPORT SCI
23	ARCH PATHOL LAB MED
21	NATURE

19	CUTIS
19	MED EDUC
19	SCIENCE
16	BRIT MED J

	2011-2015
489	BMJ OPEN
146	PLOS ONE
78	SCIENTOMETRICS
73	J AM COLL RADIOL
53	MATER TODAY-PROC
47	PROCEDIA ENGINEER
47	PROCEDIA COMPUT SCI
43	ARCH PATHOL LAB MED
41	BMC PUBLIC HEALTH
30	BMC HEALTH SERV RES
30	J ATHL TRAINING
30	AM J PREV MED
29	ACAD MED

24	LEARN PUBL
23	JAMA-J AM MED ASSOC
19	BMJ-BRIT MED J

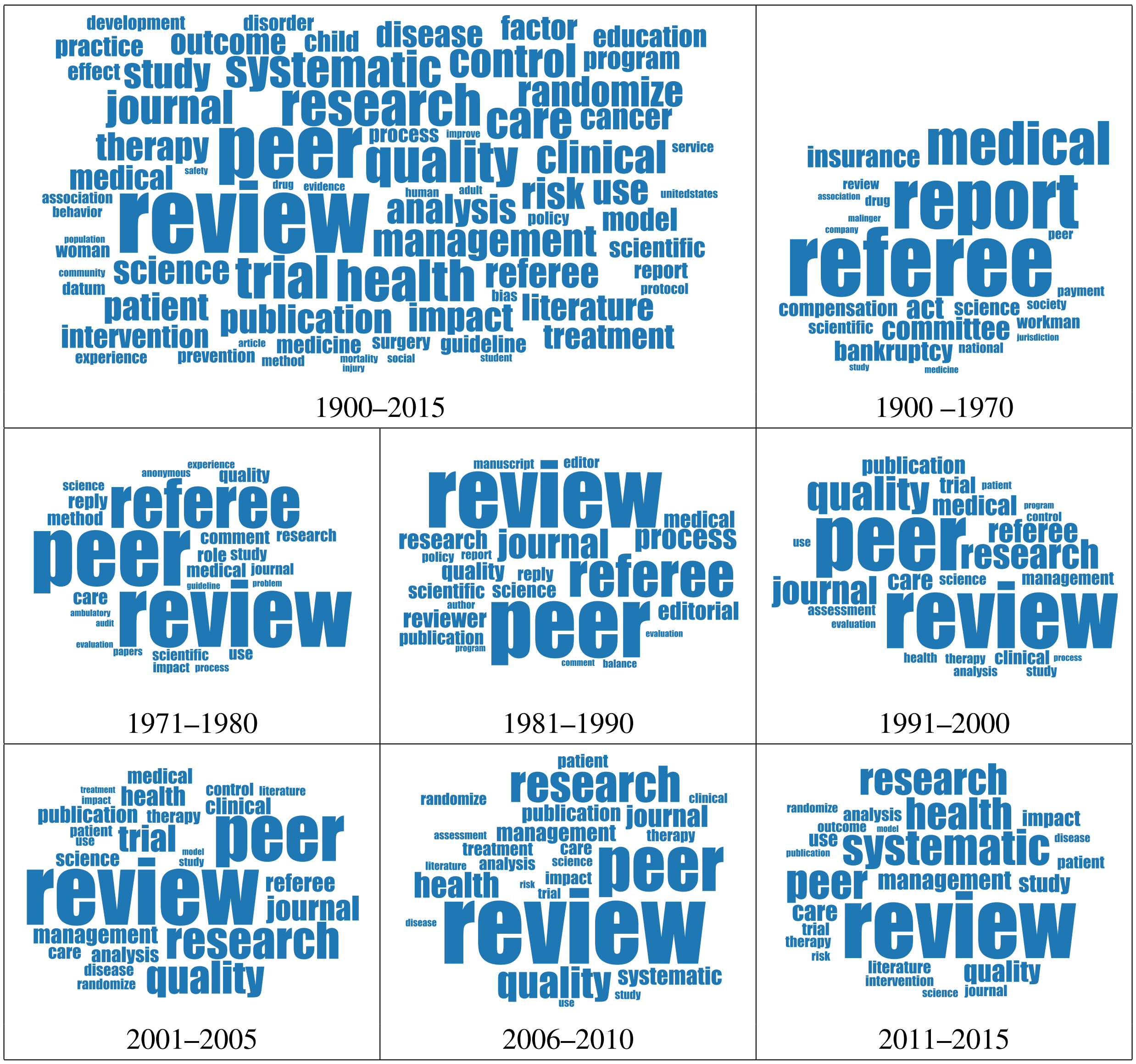

Figure 5: Keywords

From Table 6 it can be seen that the first papers on the "peer review" were published in journals on chemistry, physics, medicine, sociology and general science. Some of them remained among leading journals on "peer review" also in the following periods: Phys Today (–2000), Lancet (–2005), Science, Nature (–2010), and Brit Med J (–2015). In the period (1971–1980) two medical journals New Eng J Med (1971–2000) and JAMA (1971–2015) joined the leading group. JAMA was in the period (1981–2005) the main journal. In this period most of the leading journals were on medicine. In the period (1981–1990) two specialized journals Scientometrics (1981–2015) and Scientist (1981–2010) entered to the leading group. In the period (2006–2010) Scientometrics was the main journal. Next two journals to join the leading group were Acad Med (1991–2015) and Learn Pub (2001–2015). In the period (2006–2010) the open access journal Plos One entered to the leading group, joined in the period (2011–2015) by BMJ open. They occupied the two top positions, followed by Scientometrics. In the period (2011–2015) Science, Nature, JAMA, BMJ and Learn Pub disapeared from the strict leading group.

We also analyzed the main keywords (given keywords in the papers and words from the titles of the works) of the considered works (see upper left part of Figure 5). Of course the keywords 'review' nad 'peer' are on the top of the list, but also here we can find many medical terms (e.g., medical, health, medicine, care, patient, therapy, clinical, disease, cancer, surgery). As many works deal with the analysis of the peer review process there are also terms on the top of the list as trial, research, quality, systematic, journal, study and analysis.

From the changes in main keywords in each picture in the rest of Figure 5 we noticed that initially instead of peer review the term refereeing was prevailing. Besides the terms review and peer also terms science, study, quality, care, research and journal are in the leading group for (almost) all time periods (1971–2015). Terms referee and medical left the group after the year 2005. The following terms joined the leading group and remained in it: publication (1981–2015), trial, management, therapy, analysis, health, use, patient (1991–2015), disease, randomize, literature, impact (2001–2015), risk and systematic (2006–2015). For a shorter time the following terms were members of the group: scientific (–1990), process, evaluation (1971–2000), program (1981-2000), control (1991–2005), clinical (1991–2010), and treatment (2001–2010).

Looking at the extreme elements in distributions we can identify individually most important elements (with respect to a selected property). In the following sections we will use appropriate network analysis methods to identify important subnetworks.

5 Citations

A citation network is usually (almost) acyclic. In the case of small strong components (cyclic parts) it can be transformed into a corresponding acyclic network using the *preprint transformation*. In it we can determine the importance of arcs (citations) and nodes (works) using SPC (Search Path Count) weights (Batagelj et al., 2014, p. 83).

We first restricted the original citation network $\mathbf{Cite}$ to its 'boundary' (45917 nodes). This network, $\mathbf{CiteB}$, has one large weak component (39533 nodes), 155 small components (the largest of sizes 191, 46, 32, 31, 18), and 5589 isolated nodes. The isolated nodes correspond to the papers with WoS description, not connected to the rest of the network, and citing only works that are cited at most twice – and therefore removed from the network $\mathbf{CiteB}$.

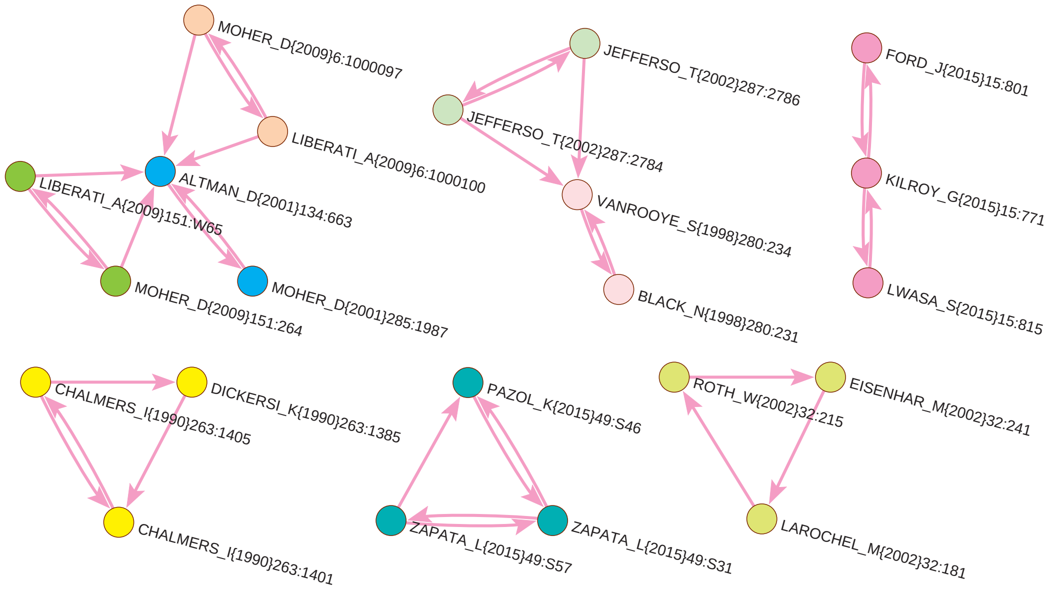

Figure 6: Selected strong components

The network **CiteB** contains also 22 small strong components (4 of size 3 and 18 of size 2). Selected strong components are presented in Figure 6. The SPC method, used in its analysis, requires that the citation network is acyclic. We transform it into an acyclic network, **CiteAcy**, using the preprint transformation. To make it connected we add to it a common source node s and a common sink node t (see Figure 7). The network **CiteAcy** has $n = 45965$ nodes and $m = 132601$ arcs.

5.1 Search path count method (SPC)

The *search path count* (SPC) method is a way to determine the *importance* of links (and also nodes) in an acyclic network based on their position. It computes counters $n(u, v)$ that count the number of different paths from some initial node (or the source s) to some terminal node (or the sink t) through the arc (u, v). It can be proved that all sums of SPC counters over a minimal arc cut-set give the same value F – the flow through the network. Dividing SPC counters with F we get *normalized* weights

$$w(u, v) = \frac{n(u, v)}{F}$$

that can be interpreted as the probability that a random s-t path passes through the arc (u, v).

A very efficient algorithm for computing SPC weights is given by Batagelj (2003) and Batagelj et al. (2014, p. 75-81) and is available in the program **`Pajek`**.

The *main path* starts in a link with the largest SPC weight and expands in both directions following the adjacent new link with the largest SPC weight. The *CPM path* is determined using the Critical Path Method from Operations Research (the sum of SPC weights on a path is maximal).

In July 2015 a new option was added to program **`Pajek`**:

```
Network/Acyclic Network/Create (Sub)Network/Main Paths
```

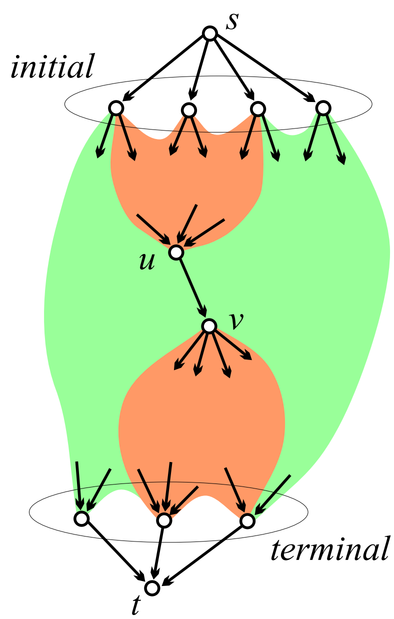

Figure 7: Search path count method (SPC)

with several suboptions for computing local and global main paths and for searching for Key-Route main path in acyclic networks (Liu and Lu, 2012). Here the procedure begins with a set of selected arcs and expands them in both directions as in the main path or CPM path procedure.

In the network **CiteAcy** we computed normalized SPC weights and on their basis determined the main path, the CPM path, main paths for 100 arcs with the largest SPC weights, and link islands [20 200].

Both main path and CPM procedure gave the same main path network presented in Figure 8. In Figure 9 main paths for 100 largest SPC weights are presented. The main path is included in this subnetwork and there are additional 47 works in parallel paths. Many of these aditional works are from the authors of the main path (e.g., Rennie, Cicchetti, Altman, Bornmann, Opthof). It is interesting that Moher's publications appear on main paths four times. He is also among the most cited authors and among authors that have the highest number of publications, but he is not on the main path.

5.2 Typology of the main path publications

There are 48 publications on the main path. After reading all these publications we classified them into three main groups of publications determined by the following time periods:

- before 1982: publications published mostly in the social science journals and books in the field of the philosophy and the social sciences;
- from 1983 to 2002: publications published almost exclusively in the biomedical journals;

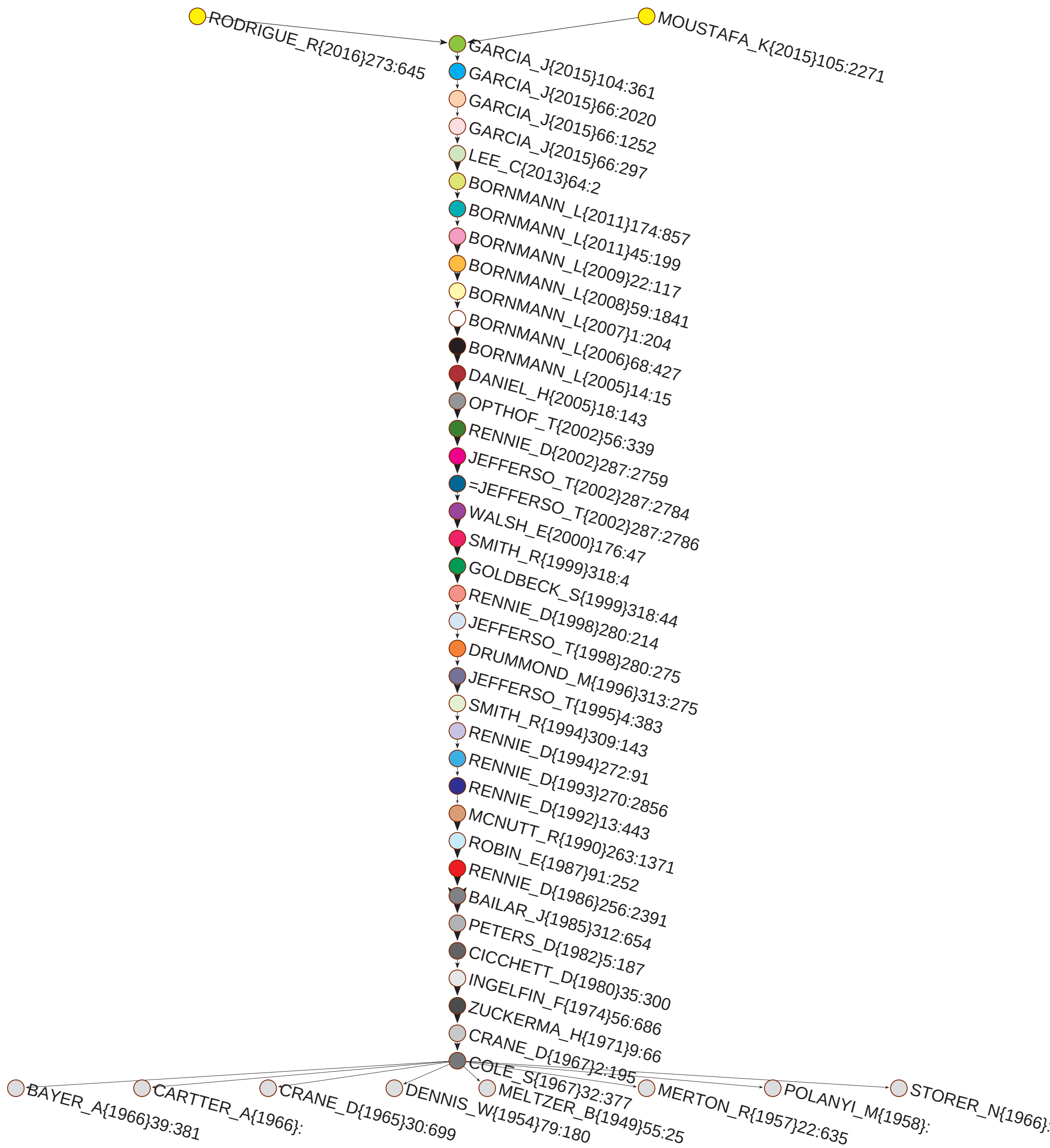

Figure 8: Main path.

- from 2003: publications published in specialized journals on science studies.

The main path publications till 1982

Journals: social science journals (e.g. American Journal of Sociology, American Sociologist, American Psychologist, Sociology of Education) and three books.

The most **influential authors:** Meltzer (1949), Dennis (1954), Merton (1957), Polany (1958), Crane (1965, 1967), Bayer and Folger (1966), Storer (1966), Cartter (1966), Cole and Cole (1967), Zuckerman and Merton (1971), Ingelfinger (1974), Cicchetti (1980), and Peters and Ceci (1982).

Topics: scientific productivity, bibliographies, knowledge, citation measures as measures of scientific accomplishement, scientific output and recognition, evaluation in science, referee system, journal evaluation, peer-evaluation system, review process, peer review practices.

The main path publications from 1983 to 2002

Journals: biomedical journals, mainly JAMA. From 1986 the International Congress on Peer Review and Biomedical Publication is organized every four years.

The most **influential authors:** Rennie (1986, 1992, 1993, 1994, 2002), Smith (1994, 1999), and Jefferson with his collaborators Demicheli, Drummond, Smith, Yee, Pratt, Gale, Alderson, Wager and Davidoff (1995, 1998, 2002).

Topics: the effects of blinding on review quality, research into peer review, guidelines for peer reviewing, monitoring the peer review performance, open peer review, bias in peer review system, measuring the quality of editorial peer review; development of meta-analysis and systematic reviews approaches.

The main path publications from 2003

Journals: specialized journals on science studies: Scientometrics, Research Evaluation, Journal of Informetrics, JASIST.

The most **influential authors:** Bornmann and Daniel (2005, 2006, 2007, 2008, 2009, 2011) and Garcia, Rodriguez-Sanchez and Fdez-Valdivia (4 papers in 2015, 2016). Others are Lee et al. (2013) and Moustafa (2015).

Topics: Bornmann and Daniel studied the validity of commitee peer review process for awarding long-term fellowship to post-graduate researchers, the use of h-index and pre-screening of applications at Boehringer Ingelheim Fonds. They also analysed citations of accepted and rejected papers at a prime chemistry journal (Angewandte Chemie Internationa Edition - AC-IE), the effect of exchanging reviews, the peer review process in this journal, the validity of its editorial decisions. The other papers study bias in peer review, selection of reviewers, and modelling the process of the author-editor communication.

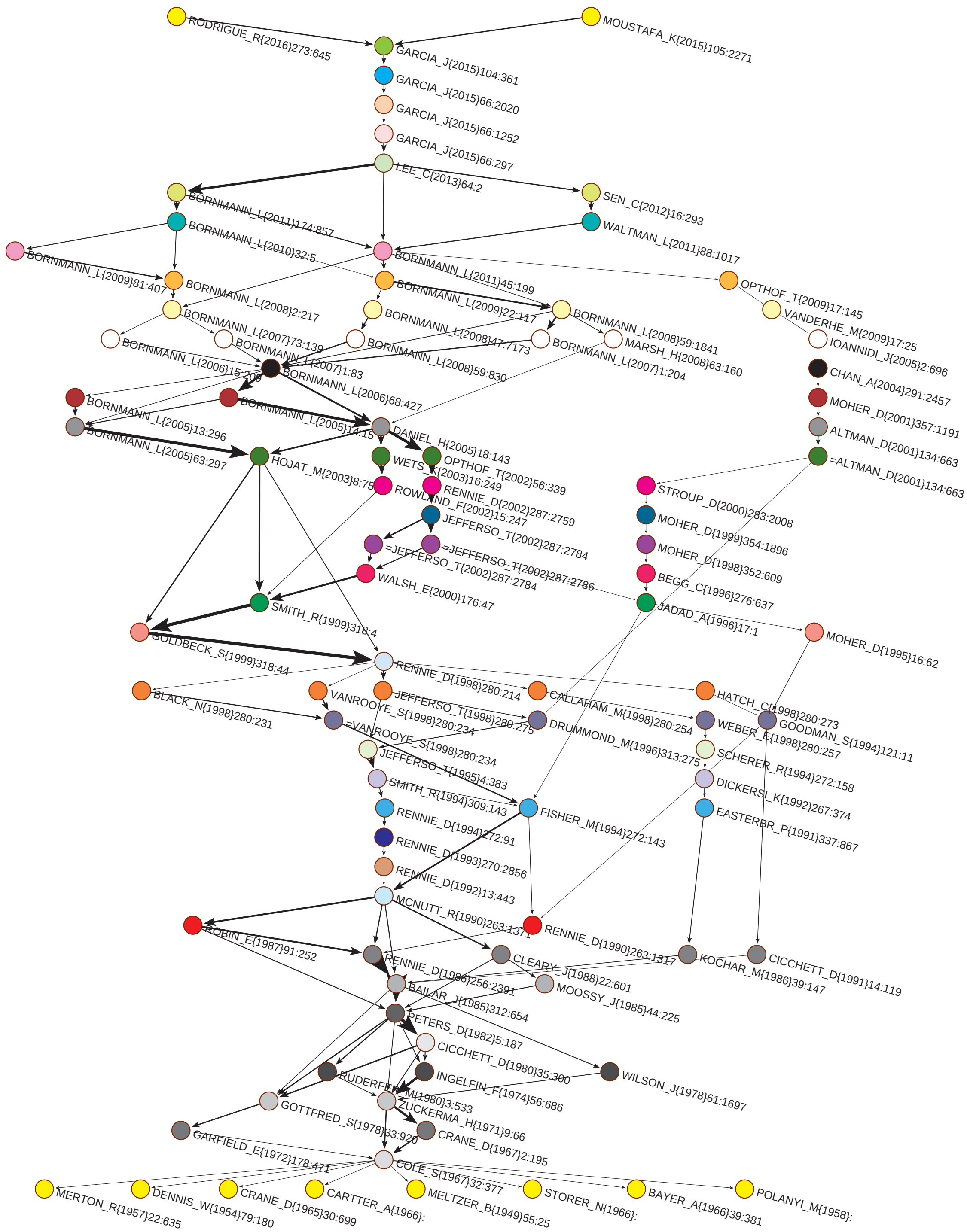

Figure 9: Main paths for 100 largest weights .

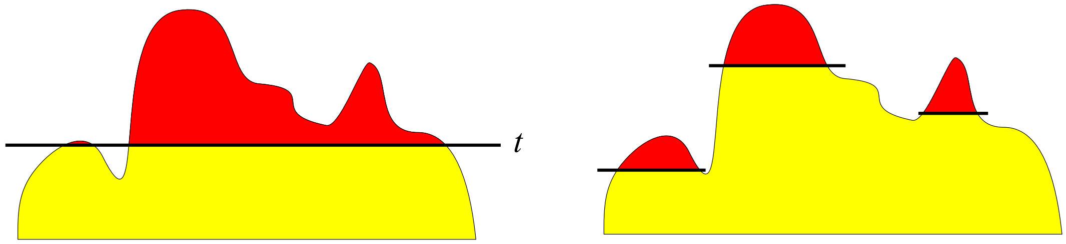

Figure 10: Cuts and islands.

5.3 Cuts and islands

Cuts and islands are two approaches to identify important groups in a network. The importance is expressed as a selected property of nodes or links.

If we represent a given or computed property of nodes / links as a height of nodes / links and we immerse the network into a water up to a selected property threshold level we get a *cut* (see the left picture in Figure 10). Varying the level we get different *islands* – maximal connected subnetwork such that values of selected property inside island are larger than the values on island's neighbors and the size (number of island's nodes) is in a given range $[k, K]$ (see the right picture in Figure 10). An island is *simple* iff it has a single peak. For details see Batagelj et al. (2014, p. 54-61).

Zaveršnik and Batagelj (2004) developed very efficient algorithms to determine the islands hierarchy and to list all the islands of selected sizes. They are available in program **Pajek**.

When searching for SPC link islands for the number of nodes between 20 and 200 (and between 20 and 100) we obtained 26 link islands (see Figure 11). We see that many of obtained islands have very short longest path, often a star-like structure (a node with its neighbors). Such islands are not very interesting. We visually identified "interesting" islands for detailed inspection. In the following list we present basic information for each of selected island: number of nodes for the selection of 20–200 nodes (and 20–100), the maximal SPC weight in the island and a short description of the island:

Island 1. $n = 191(99)$, 0.297. Peer-review.
Island 2. $n = 191(96)$, 0.211×10^{-8}. Discovery of different isotopes.
Island 3. $n = 178$, 0.165×10^{-8}. Biomass.
Island 7. $n = 42$, 0.425×10^{-8} . Athletic trainers.
Island 8. $n = 36$, 0.191×10^{-4} Sport refereeing and decision-making.
Island 9. $n = 32$, 0.793×10^{-10}. Environment pollution.
Island 13. $n = 29$, 0.451×10^{-10}. Toxicity testing.
Island 23. $n = 22$, 0.344×10^{-8}. Peer-review in psycho sciences.
Island 24. $n = 21$, 0.487×10^{-10}. Molecular interaction.

Only island 1 and island 23 deal with peer review. Other islands represent collateral stories. The Island 1 on peer-review is the most important because it has at least 10.000 times higher maximal SPC weight than the next one Island 8 on sport refereeing.

Because of a readability problem we extracted from Island 1 a subisland of size in range $[20, 100]$ and display it in Figure 12. It contains the main path and strongly overlaps with the main paths from Figure 9. The list of all publications from the main path (coded with 1), main paths (coded with 2) and SPC link island (20–100) (coded with 3) is given in Table 9 in Appendix. There are 105 publications in the joint list. Only 9 publications are only on main paths and only 10 publications are only in the SPC link island. The typology into three groups of publications holds also for the list of all 105 publications.

SPC line islands I_8 (Sport refereeing and decision-making) and I_{23} (Peer-review in psycho sciences) are presented in Figure 13.

Papers from the island I_8 span the years 2003–2015. Most of the journals are sport journals: J Sport Sci, J Sport Exercise Psy, J Sci Med Sport, Sports Med, etc. The main authors are Mallo, J, Catteeuw, P and Bizzini, M. The main topic in years 2003–2007 was a soccer refereeing performance, in 2008 two papers discuss the use of yellow card, three 2009 papers are about injuries in soccer, followed by the (offside) decision making in 2010–2014. Papers published in 2015 extend decision making performance to baskett and rugby.

Papers from the island I_{23} span the years 1974–2005. Most of the journals are psycho journals: Aust Nz J Psychiat, Prof Psychol, Am J Psychiat, etc. The main authors are Beatson, J, Cohen, LH and Luft, LL. Most of the papers deal with the peer review of psychotherapeutic treatments.The last four papers deal with the group peer review.

6 Collaboration

Multiplying the network $\mathbf{WA}$ from left with its reverse we get the *co-authorship* or *collaboration* network $\mathbf{Co} = \mathbf{WA}^T * \mathbf{WA}$ that describes a collaboration among authors. The value $co(u, v)$ of a link (u, v) is equal to the number of works co-authored by authors u and v.

To neutralize the over-representation of works with many co-authors in the resulting collaboration network we used the normalized authorship network, $\mathbf{N} = \text{diag}(\frac{1}{\max(1,\text{outdeg}(w))}) \cdot \mathbf{WA}$, in the computation of a collaboration network (Batagelj and Cerinšek, 2013). In a network $\mathbf{N}$ the values of links from a work to all of its co-authors are equal and they sum up in 1. In Batagelj and Cerinšek (2013) we calculated the normalized network $\mathbf{Ct} = \mathbf{N}^T * \mathbf{N}$ to get the contributions of authors to their works. For the analysis of ZB data (Cerinšek and Batagelj, 2015) we used a slightly modified normalized collaboration network $\mathbf{Ct}' = \mathbf{N}^T * \mathbf{N}'$, where is $\mathbf{N}' = \text{diag}(\frac{1}{\max(1,\text{outdeg}(w)-1)}) \cdot \mathbf{WA}$. Because all arcs in $\mathbf{Ct}'$ are bidirected with the same weights in both directions, we replaced them with edges (undirected links) with doubled weights. In this way we neutralize works with many co-authors: a k-clique of authors (of the same work) would bring in the weight of $\frac{k \cdot (k-1)}{2}$ and this is neutralized in $\mathbf{Ct}'$. We also set the diagonal values to 0. In Table 7 pairs of the most collaborating authors are presented.

It is not surprising that the pair Bornmann and Daniel is on the top of the list. Also D'Angelo and Abramo were publishing several research papers on peer review. Only the pair Fry and Thoennessen did not publish in the field of peer review, they published in physics. Flecher and Ferris published the paper on *Conflict of Interest in Peer-Reviewed Medical Journals: The World Association of Medical Editors' Position on a Challenging Problem* in several medical and biomedical journals whose editors were members of WAME. Saper and Maunsell were co-chairs of the Neuroscience Peer Review Consortium (NPRC), 33 journals on neuroscience belonged to the Consortium in 2008. They wrote the report of their work in the first year of NPRC with the title *The Neuroscience Peer Review Consortium* which was published in 14

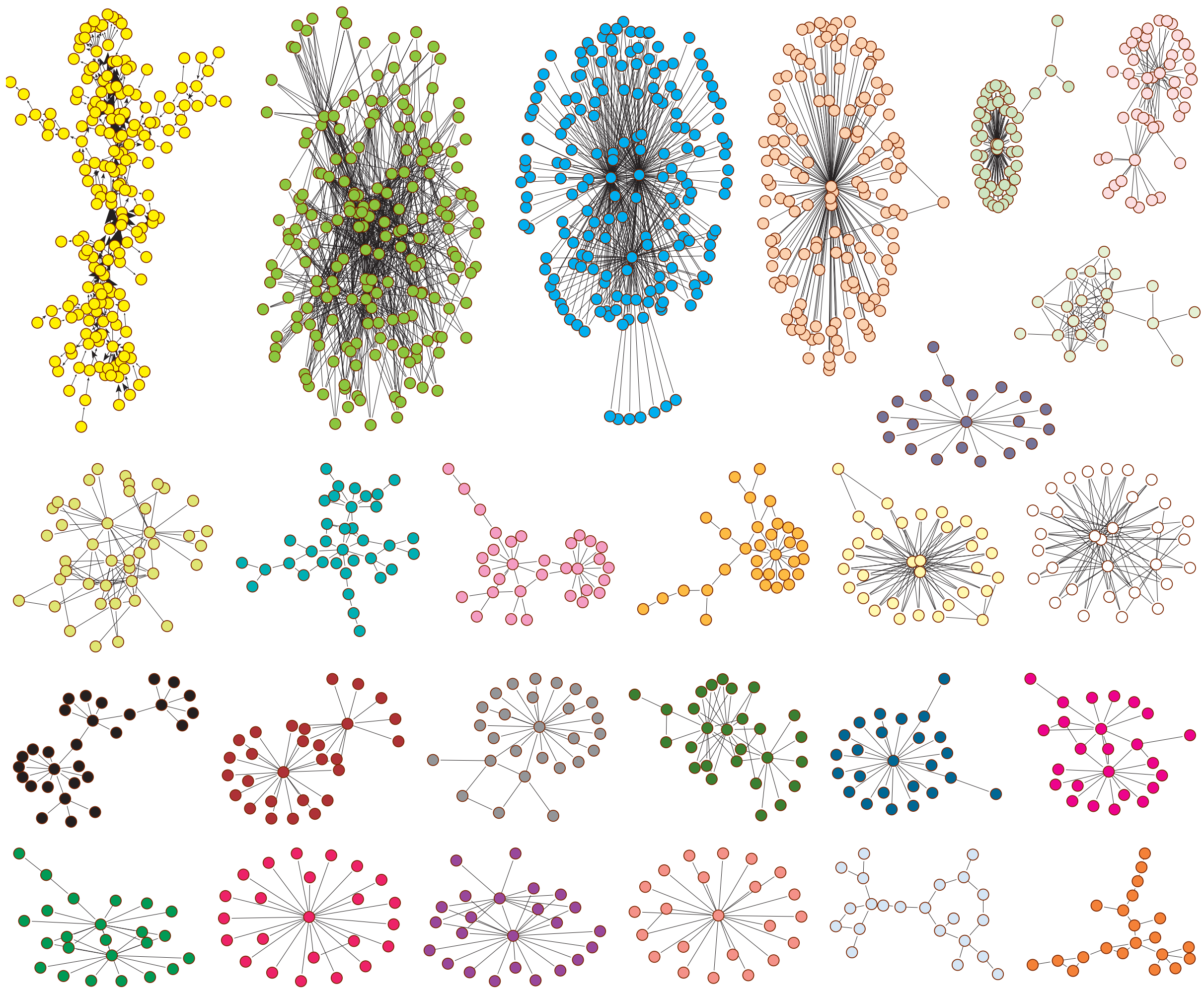

Figure 11: SPC islands [20 200].

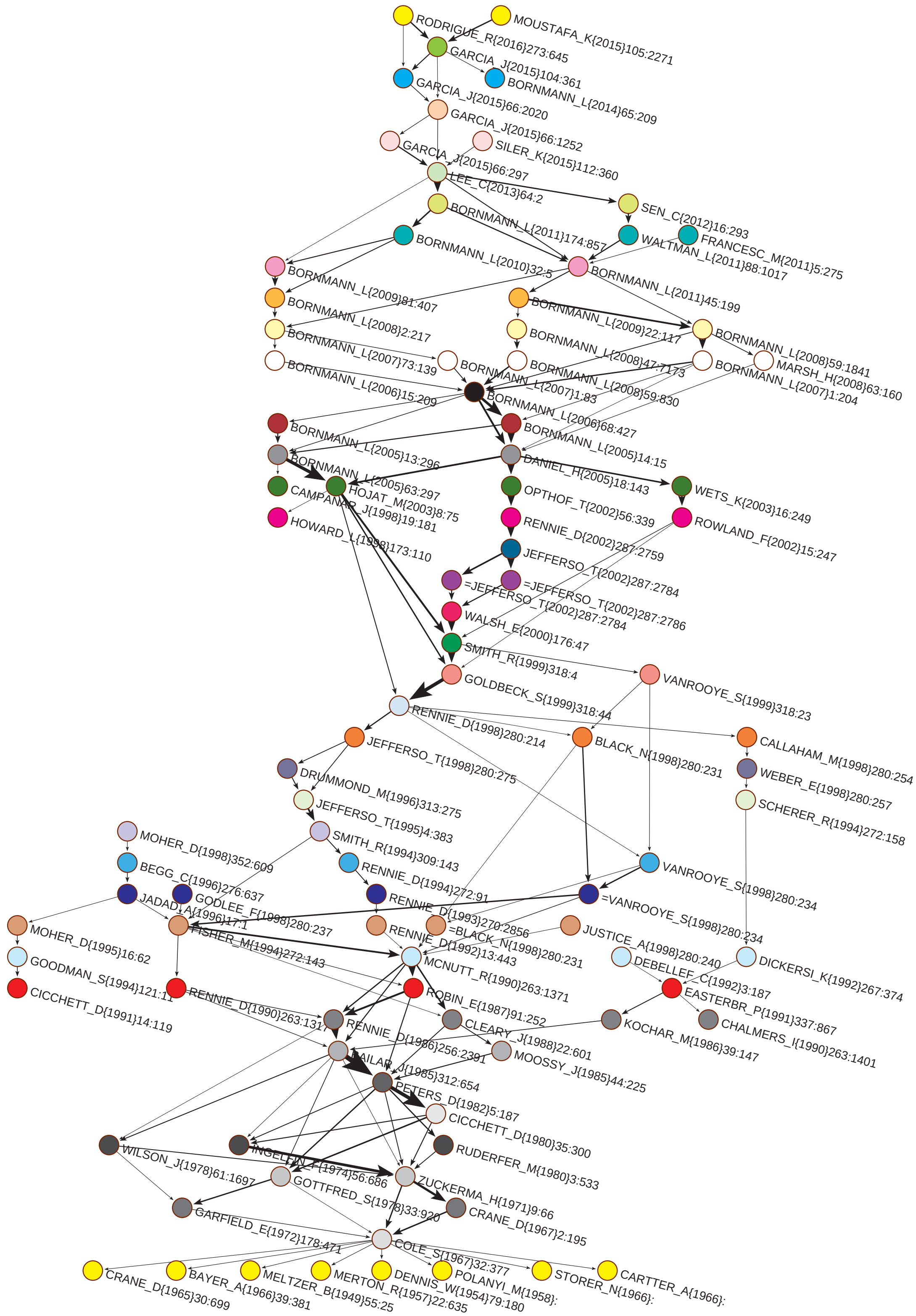

Figure 12: SPC Link Island 1 [100].

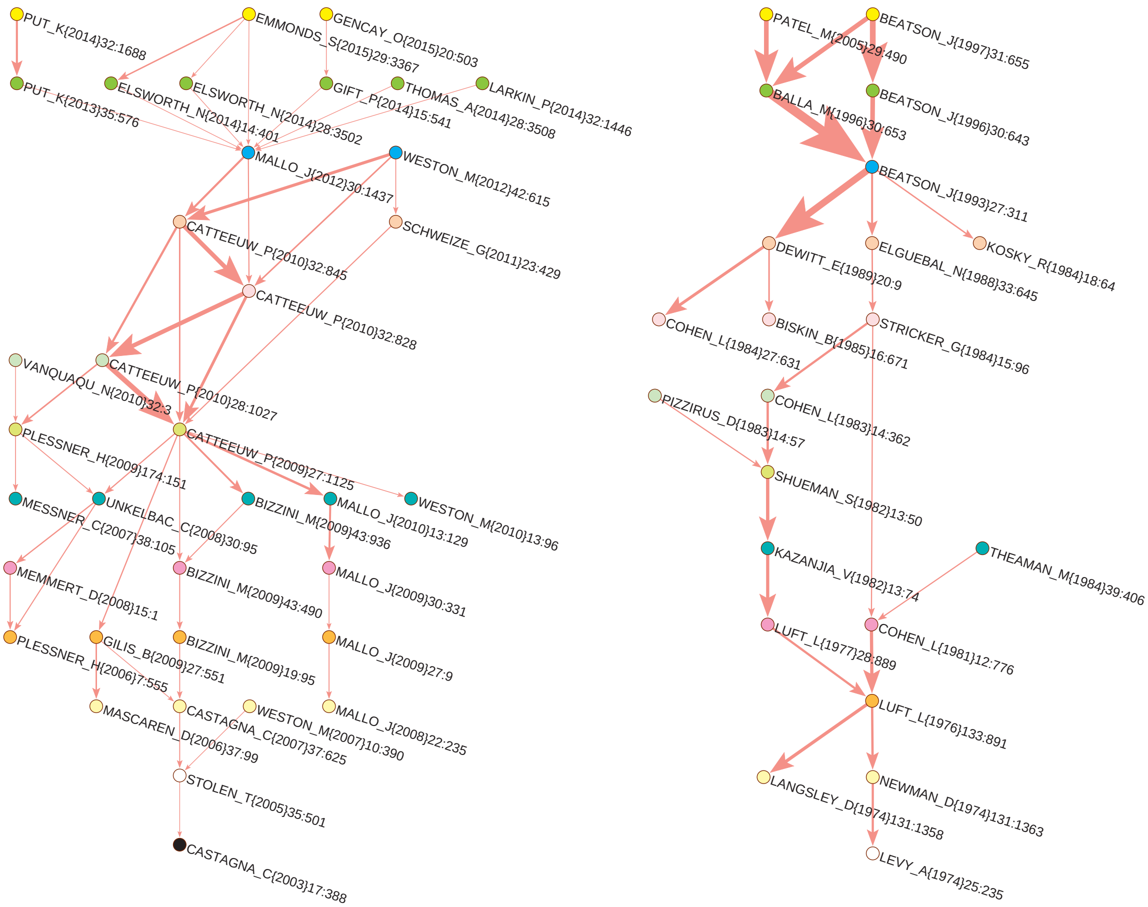

Figure 13: SPC Link Island 8 – Sport refereeing and decision-making; Link Island 23 – Peer-review in psycho sciences

Table 7: Most collaborating pairs

first author	second author	weight
Bornmann L	Daniel H	25.822
Brown D	Raff H	11.000
Saper CB	Maunsell JHR	10.338
DeAngelis CD	Fontanarosa PB	9.333
D'Angelo CA	Abramo G	6.333
Reyes H	Andresen M	5.500
Fry C	Thoennessen M	5.333
Kravitz RL	Feldman MD	5.067
Fletcher RH	Ferris LE	5.000

journals. Raff (the chair of the Publications Committee of the American Physiological Society – APS) and Brown (the Editor-in-Chief of Physiological Reviews) published the paper with the title *Civil, sensible, and constructive peer review in APS journals* in 11 journals on physiology in 2013. They discussed why eliminating prepublication peer review which has been questioned repeatedly over the past few decades is not a good option and they argued why prepublication peer review is worth the effort and cost and is critical to maintaining the scientific integrity of the publications. All other pairs were co-editors of a journal. DeAngelis and Fontanarosa were editors of JAMA (The Journal of the American Medical Association); Reyes and Andresen were editors of the Revista Medica de Chile; and Kravitz and Feldman were editors of the Journal of General Internal Medicine. They all wrote editors' notes in these journals mentioning also the journal's peer review process.

A *p_S-core* at level t in a collaboration nework is such a subnetwork in which each author's contribution (the sum of weights on links to other members of the core) is at least t (see Batagelj and Zaveršnik (2011) and Batagelj et al. (2014, p. 58–61)).

To identify the groups of most collaborating authors in the network $\mathbf{Ct}'$ we determined the p_S-core at level 2.5 – each author from the core collaborated with other authors from the core for at least 2.5 paper. The obtained core has 47 components, 7 of size at least 4 (see Figure 14).

From the list of all papers co-authored by authors of the largest component of the p_S-core (upper left subnetwork in Figure 14) we get the following its characterization: Papers span the years 1945–2016. Main journals are: JAMA, Atom Data Nucl Data, BMJ, Can Med Assoc J, J Am Coll Radiol, J Neurosurg-Spine, J Assoc Off Agr Chem, PLOS One, Ann Intern Med, BMC Med. The main authors (largest p_S-values) are: Raff_H, 11.0; Brown_D, 11.0; Fontanar_P, 9.3; Deangeli_C, 9.3; Thoennes_M, 5.3; Fry_C, 5.3; Ferris_L, 5.0; Fletcher_R, 5.0; Rennie_D, 4.8; Flanagin_A, 4.8; Squires_B, 4.0; Elmslie_T, 4.0; Moher_D, 3.9; Altman_D, 3.9; etc. The component contains also four of the most collaborating pairs from Table 7. Members of the component are involved in the main-stream biomedical peer review research. Some additional observations: Griffin, EL, Marshall, CV, Halvorson, HA, and Smith, JB are co-authors of *Report of subcommittee a on recommendations of referees* published in J Assoc Off Agr Chem in years 1945, 1947–1954, 1956, 1963–1966. The clique in the bottom right part of the component (Holly, L, Anderson, P, Kaiser, M, Matz, P, etc.) is formed by a group of co-authors from

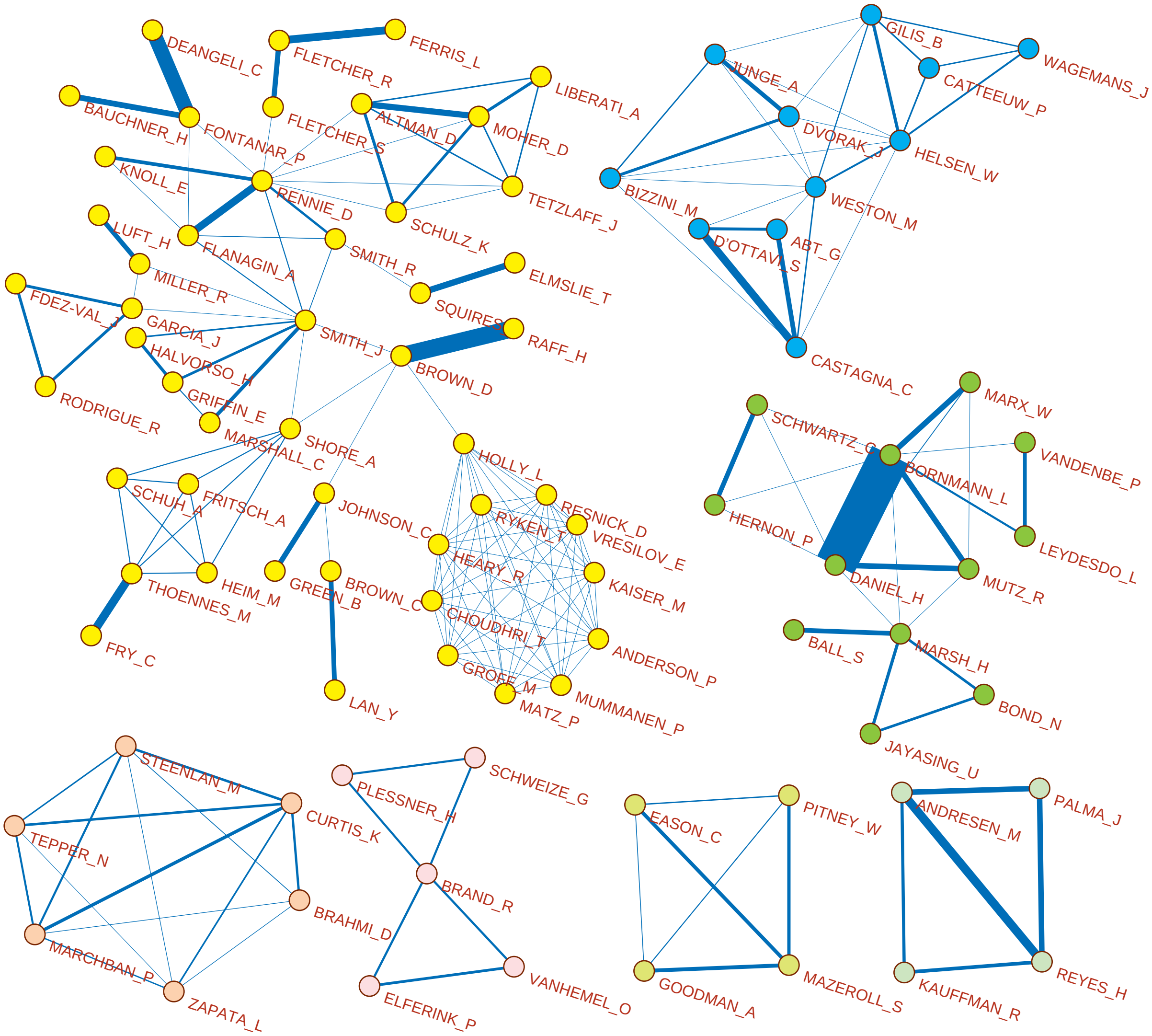

Figure 14: Normalized collaboration – p_S-core at level 2.5 components with at least 4 nodes

different institutions that published 17 joint papers all in Journal of Neurosurgery – Spine in August 2009. "Peer review" appears in their abstracts as a validation method. Altman, D and Moher, D co-authored 8 papers on reporting medical research (CONSORT, SPIRIT, PRISMA statements). Rennie, D and Flanagin, A published 13 joint papers all, except two, on the international congress on peer review and biomedical publication.

7 Author citations

Using the network multiplication we can produce other derived networks. The network

$$\mathbf{ACi} = \mathbf{WA}^T * \mathbf{Ci} * \mathbf{WA}$$

is a network of citations among authors (in Section 5 we analyzed citations among works). Its entry $aci[u, v]$ = number of works co-authored by the author u that are citing a work co-

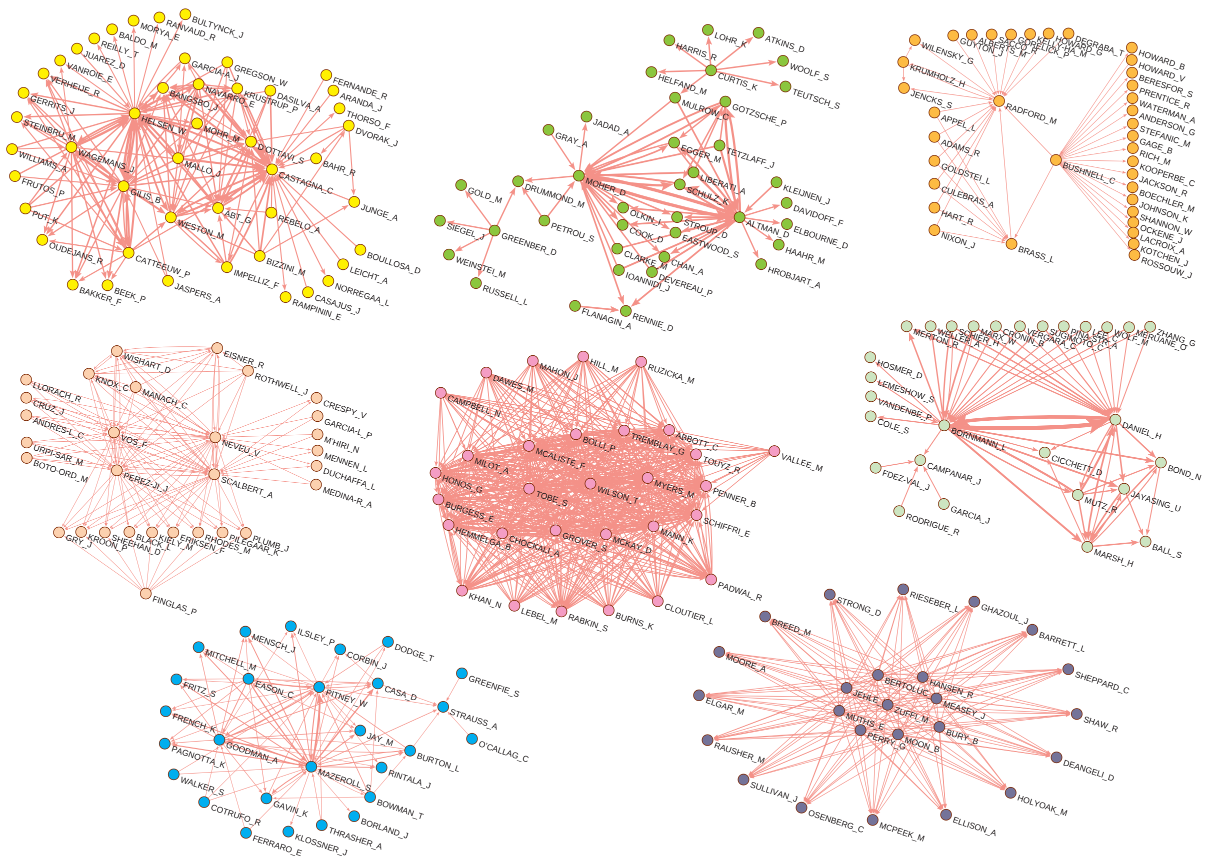

Figure 15: Author citation / Islands [20,50]

authored by the author v.

Groups of authors linked by stronger citations weights correspond to researchers working on similar topics. We computed the network $\mathbf{ACi}$ over the set W_D. To identify groups of citing authors we applied to it simple link islands of sizes $[20, 50]$. There are 8 such islands presented in Figure 15.

To get an insight in their background we determined the keywords characteristic for the members of a selected island I. We compute a restriction of the network $\mathbf{AK}$ to the island I

$$\mathbf{A}[I]\mathbf{K} = \mathbf{N}_D^T[A/I] * \mathbf{WK}_D$$

and for it the weighted indegrees – for a given keyword k the corresponding weighted indegree is equal to the fractional use of keyword k in all works authored by authors from the island I.

In a similar way a restriction of the network $\mathbf{AJ}$ to the island I

$$\mathbf{A}[I]\mathbf{J} = \mathbf{N}_D^T[A/I] * \mathbf{WJ}_D$$

can be used to identify journals in which authors from the island I are publishing.

For an illustration we selected in Figure 15 three islands: I_2 (Altman, Moher, ...), I_5 (Wilson, Burns, ...), and I_6 (Bornmann, Daniel, ...). The characteristic keywords and journals for them are given in Figure 16 and Table 8. From main keywords and main journals for each of selected island we get the following characterizations:

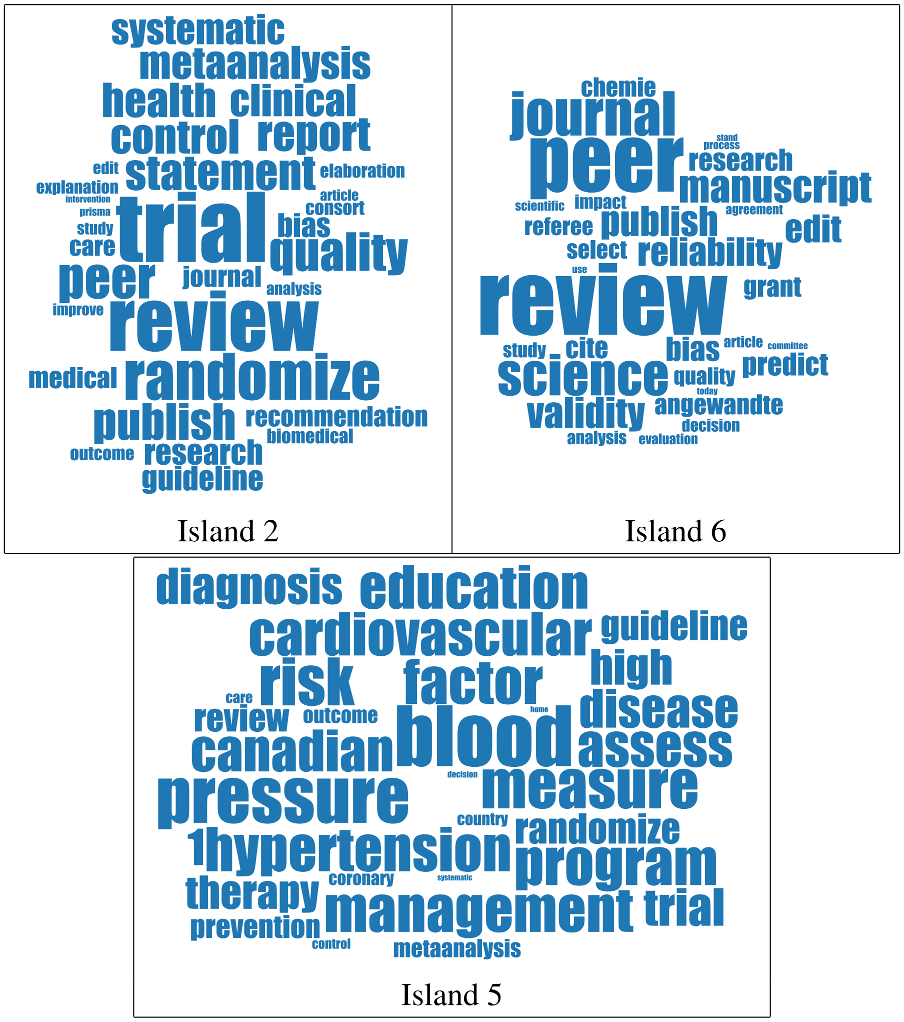

Figure 16: Keywords for islands 2, 6 and 5

- Island I_2: evaluation of biomedical research;
- Island I_5: (canadian) cardiovascular research;
- Island I_6: peer review (in chemistry).

Islands of **ACi** are directed graphs. An interesting information is the interplay between a hierarchy and equivalence (strong connectivity) in their structure. By the theorem 3.6 from Harary et al. (1965, p. 63), if we shrink strong components into single nodes the obtained reduced graph (condensation) is acyclic (a hierarchy). Acyclic graphs can be drawn in layers. Therefore for a given directed network we first determine its condensation, draw it in layers and finally expand back its strong components. This leads to a more infomative visualization of islands as shown for the island I_2 in Figure 17.

In the island I_2 there is a single nontrivial strong component (yellow nodes: Altman, Gotzsche, Moher, Egger, and Schulz). Most of the remaining nodes are either initial (green: indeg

Table 8: Journals in islands

		I_2		I_6		I_5
1	24.2240	JAMA-J AM MED ASSOC	18.7833	SCIENTOMETRICS	6.1839	CAN J CARDIOL
2	11.4278	*****	12.6667	J INFORMETR	1.0000	FIELD CROP RES
3	9.3834	ANN INTERN MED	7.0000	BEHAV BRAIN SCI	0.6667	CAN MED ASSOC J
4	8.0465	BRIT MED J	7.0000	J AM SOC INF SCI TEC	0.5000	ACAD MED
5	7.6500	CONTRACEPTION	6.8333	*****	0.5000	INDIAN J PHARMACOL
6	4.6746	PLOS MED	6.0000	J ASSOC INF SCI TECH	0.5000	AUST NZ J OBSTET GYN
7	4.5750	LANCET	5.6333	RES EVALUAT	0.5000	NURS OUTLOOK
8	4.3764	BMJ-BRIT MED J	4.4167	PLOS ONE	0.5000	TEACH HIGH EDUC
9	3.1500	TRIALS	3.0000	ANGEW CHEM INT EDIT	0.4286	CAN J APPL PHYSIOL
10	3.0667	BMC MED	3.0000	J AM SOC INFORM SCI	0.3333	J ADOLESCENT HEALTH
11	3.0000	STAT MED	3.0000	LEARN PUBL	0.3333	CAN RESPIR J
12	2.1714	PHARMACOECONOMICS	3.0000	J DOC	0.3333	PROCEDIA COMPUT SCI
13	2.1429	J CLIN EPIDEMIOL	2.3333	J CLIN EXP NEUROPSYC	0.3333	J UROLOGY
14	2.0671	AM J PREV MED	2.2000	LIBR INFORM SCI RES	0.2500	NUTRITION
15	2.0000	MED CLIN-BARCELONA	2.0000	B MED LIBR ASSOC	0.2500	AFR ENTOMOL
16	1.6226	PLOS ONE	2.0000	PHILOS SCI	0.2000	EUR J HEART FAIL
17	1.5000	OBSTET GYNECOL	2.0000	SCI COMMUN	0.2000	DIS MANAG HEALTH OUT
18	1.4762	CONTROL CLIN TRIALS	2.0000	JAMA-J AM MED ASSOC	0.2000	ENVIRON MODELL SOFTW
19	1.3333	PEDIATRICS	2.0000	AM PSYCHOL	0.2000	INT J TECHNOL ASSESS
20	1.1167	MED DECIS MAKING	1.6667	SCIENCE	0.2000	CRIT CARE MED
21	1.0000	ADDICTION	1.5000	AM SOCIOL REV	0.2000	AD HOC NETW
22	1.0000	J AM COLL NUTR	1.3333	MINERVA	0.2000	CLIN INVEST MED
23	1.0000	EMU	1.0000	SOC SCI INFORM STUD	0.2000	SCAND J WORK ENV HEA
24	1.0000	ARCH INTERN MED	1.0000	CHIMIA	0.1465	EUR UROL
25	1.0000	VALUE HEALTH	1.0000	J INFORM SCI	0.1250	COCHRANE DB SYST REV
26	1.0000	INT J SURG	1.0000	SCIENTIST	0.0667	BMJ OPEN

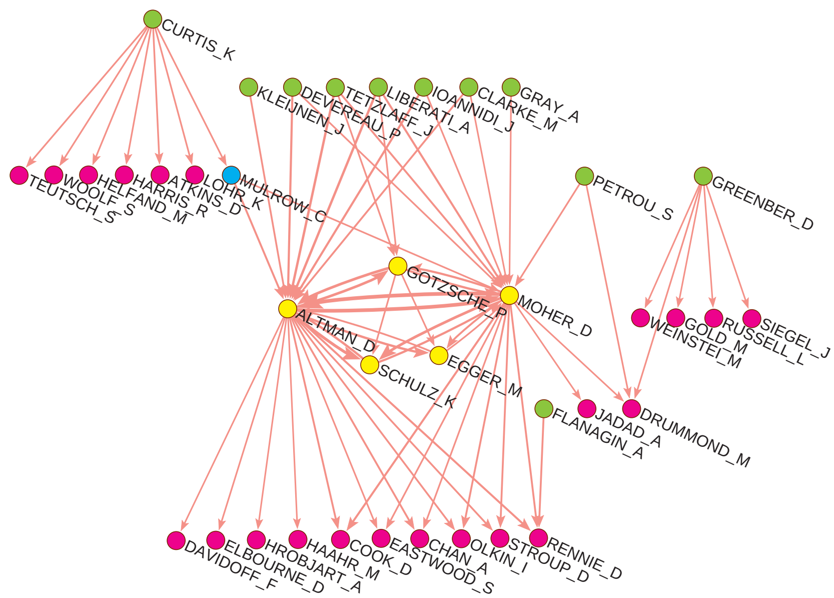

Figure 17: Island 2

$= 0$) or terminal (magenta: outdeg $= 0$). There is a single internal "acyclic" node (cyan: Mulrow).

8 Conclusions

The paper presents several analyses of peer review literature. Network analysis methods were used to analyze the bibliographic data on peer review obtained from the Web of Science. The obtained dataset was quite large with 721.547 publications. The results were obtained on several constructed one-mode networks (co-authorhip network, citation network) and on two-mode networks. All analyses were done using the program **Pajek**, a program for the analysis and visualization of large networks. As mentioned in Section 2.1 the data that we used in this paper were obtained using the query `"peer review*"` and `refereeing` to the Web of Science. Of course in the dataset are many nonrelevant (noisy) publication that have nothing to do with peer review field. As an example of such a noise we noticed when reading some abstracts from the dataset that they ended by ' Published by Elsevier Ltd. Selection and/or peer review under responsibility of' and were therefore selected into the dataset. This is only one example of non relevant publications in the selected dataset. There are two options what to do with such noisy data: (1) to clean the dataset or (2) to analyse the dataset that we obtained and to use appropriate methods to filter out important publications. Because the first option requires a prohibitive amount of work we selected the second approach. By using main path and island metod we very successfully identified the most important publications on peer review field.

Another, some times crucial, problem is the ambiguity of names of the authors, as we saw in Table 4. We could partially solve it by developing automatic disambiguation procedures, but the right solution is to resolve this problem while entering the data into bibliographic data bases; or even earlier by adoption by publishers standards such as ResearcherID, ORCID, DOI, etc. As a short term solution we need to include into the program **`WoS2Pajek`** additional options for creating short author names that will allow manual correction of names of critical authors.

There are many interesting results presented in the paper. The most productive authors and the most cited publications in the field of peer review were given. The main journals publishing papers on peer review, the main topics and groups of authors that collaborate the most were identified. All these were also studied in time.

The most influential publications in the field of peer review were identifiedusing main path procedures and the islands method. All these approaches used CPS weights on citation arcs. The 47 publications from the main path are included in all other obtained lists of the most influential publications. These publications are segmented into three phases defined by three time periods: before 1982 with the publications published in the social sciences journals (sociological, psychological, educational, etc.); from 1983 to 2002 with the publications published almost exclusively in the biomedical journals, mainly JAMA; and after 2003 with the publications published in specialized journals on science studies (e.g., Scientometrics, Research Evaluation, Journal of Informetrics). The obtained typology nicely shows the evolution of the peer review field.

Acknowledgments

This work is supported in part by the Slovenian Research Agency (research program P1-0294 and research projects J1-5433 and J5-5537) and is also based upon work from COST Action TD1306 "New frontiers of peer review" – PEERE, supported by COST (European Cooperation in Science and Technology).

References

Batagelj, V.: WoS2Pajek. 2007. Manual for version 1.4, July 2016.
`http://vladowiki.fmf.uni-lj.si/doku.php?id=pajek:wos2pajek`

Batagelj, V.: Efficient Algorithms for Citation Network Analysis, 2003.
`http://arxiv.org/abs/cs/0309023`

Batagelj, V., Doreian, P., Ferligoj, A. and Kejžar, N.: Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution. Wiley Series in Computational and Quantitative Social Science. Wiley, October 2014.

Batagelj, V., Cerinšek, M. (2013). On bibliographic networks. Scientometrics, 96(3), 845–864. doi: 10.1007/s11192-012-0940-1

Batagelj, V., Zaveršnik, M.: *Fast algorithms for determining (generalized) core groups in social networks.* Advances in Data Analysis and Classification 5 (2) (2011), 129-145.

Cerinšek, M., Batagelj, V. (2015). Network analysis of Zentralblatt MATH data. Scientometrics, 102(2015)1, 977-1001.

Cole, S., and Cole, J.R.: Visibility and the structural bases of awareness of scientific research. American Sociological Review 33(1973): 397-413.

De Nooy, W., Mrvar, A., and Batagelj, V.: Exploratory Social Network Analysis with Pajek; Revised and Expanded Second Edition. Structural Analysis in the Social Sciences, Cambridge University Press, September 2011.

Gauffriau, M., Larsen, P.O., Maye, I., Roulin-Perriard, A., von Ins, M.: Publication, cooperation and productivity measures in scientific research, Scientometrics, 73(2007)2, 175-214.

Harary, F., Norman, R.Z., and Cartwright, D.: *Structural models - an introduction to the theory of directed graphs*. Wiley, New York, 1965.

Liu, J.S. and Lu, L.Y.Y.: An integrated approach for main path analysis: Development of the Hirsch index as an example. Journal of the American Society for Information Science and Technology, 63 (2012),528-542

Garfield, E., Pudovkin, A.I., Istomin, V.S.: Why do we need algorithmic historiography? Journal of the American Society for Information Science and Technology, 54 (2003) 5, 400–412.

Garfield E., Pudovkin A.I., Istomin, V.S.: ***Histcomp*** – (*comp*iled *Hist*oriography program) http://garfield.library.upenn.edu/histcomp/guide.html http://www.garfield.library.upenn.edu/histcomp/index.html

Wikipedia: Peer review. http://en.wikipedia.org/wiki/Peer_review

Wikipedia: Histcite. https://en.wikipedia.org/wiki/Histcite

Wikipedia: Chinese surname. https://en.wikipedia.org/wiki/Chinese_surname

Zaveršnik, M., Batagelj, V.: Islands. XXIV. International Sunbelt Social Network Conference, Portorož, May 12–16, 2004. http://vlado.fmf.uni-lj.si/pub/networks/doc/sunbelt/islands.pdf

9 Appendix

In Tables 9, 10 and 11 a list of works on main path (1), main paths (2) and island (3) is presented. Only the first authors are listed.

Table 9: List of works on main path (1), main paths (2) and island (3) – part 1

year	code	first author	title	journal
1949	123	Meltzer, BN	The productivity of social scientists	AM J SOCIOL
1954	123	Dennis, W	Bibliographies of eminent scientists	SCIENTIFIC M
1957	123	Merton, RK	Priorities in scientific discovery - a chapter in the sociology of science	AM SOCIOL REV
1958	123	Polanyi, M	Personal Knowledge: Towards a Post-Critical Philosophy	UP Chicago
1965	123	Crane, D	Scientists at major and minor universities	AM SOCIOL REV
1966	123	Bayer, AE	Some correlates of citation measure of productivity in science	SOCIOL EDUC
1966	123	Storer, NW	The Social System of Science	HRW
1966	123	Cartter, A	An Assessment of Quality in Graduate Education	ACE
1967	123	Crane, D	Gatekeepers of science - some factors affecting selection of articles …	AM SOCIOL
1967	123	Cole, S	Scientific output and recognition - study in operation of reward system …	AM SOCIOL REV
1971	123	Zuckerma.H	Patterns of evaluation in science - … of referee system	MINERVA
1972	23	Garfield, E	Citation analysis as a tool in journal evaluation - journals can be ranked …	SCIENCE
1974	123	Ingelfin.FJ	Peer review in biomedical publication	AM J MED
1978	23	Wilson, JD	70th annual-meeting of american-society-for-clinical-investigation, …	J CLIN INVEST
1978	23	Gottfredson, SD	Evaluating psychological-research reports - … of quality judgments	AM PSYCHOL
1980	23	Ruderfer, M	The Fallacy Of Peer-Review - Judgment Without Science And A Case-History	SPECULAT SCI TECHNOL
1980	123	Cicchetti, DV	Reliability of reviews for the american-psychologist …	AM PSYCHOL
1982	123	Peters, DP	Peer-review practices of psychological journals - the fate …	BEHAV BRAIN SCI
1985	123	Bailar, JC	Journal peer-review - the need for a research agenda	NEW ENGL J MED
1985	23	Moossy, J	Anonymous authors, anonymous referees - an editorial exploration	J NEUROPATH EXP NEUR
1986	123	Rennie, D	Guarding the guardians - a conference on editorial peer-review	JAMA
1986	23	Kochar, MS	The peer-review of manuscripts in need for improvement	J CHRON DIS
1987	123	Robin, ED	Peer-review in medical journals	CHEST
1988	23	Cleary, JD	Blind versus nonblind review - survey of selected medical journals	DRUG INTEL CLIN PHAR
1990	123	Mcnutt, RA	The effects of blinding on the quality of peer-review - a randomized trial	JAMA
1990	23	Rennie, D	Editorial peer-review in biomedical publication - the 1st-international-congress	JAMA
1990	3	Chalmers, I	A cohort study of summary reports of controlled trials	JAMA
1991	23	Cicchetti, DV	The reliability of peer-review for manuscript and grant submissions …	BEHAV BRAIN SCI
1991	23	Easterbrook, PJ	Publication bias in clinical research	LANCET
1992	3	Debellefeuille, C	The fate of abstracts submitted to a cancer meeting …	ANN ONCOL
1992	123	Rennie, D	Suspended judgment - editorial peer-review - let us put it on trial	CONTROL CLIN TRIALS
1992	23	Dickersin, K	Factors influencing publication of research results - follow-up of …	JAMA
1993	123	Rennie, D	More peering into editorial peer-review	JAMA
1994	23	Scherer, RW	Full publication of results initially presented in abstracts - a metaanalysis	JAMA
1994	23	Goodman, SN	Manuscript quality before and after peer-review and editing at Annals …	ANN INTERN MED

Table 10: List of works on main path (1), main paths (2) and island (3) – part 2

year	code	first author	title	journal
1994	23	Fisher, M	The effects of blinding on acceptance of research papers by peer-review	JAMA
1994	123	Rennie, D	The 2nd international-congress on peer-review in biomedical publication	JAMA
1994	123	Smith, R	Promoting research into peer-review	BRIT MED J
1995	123	Jefferson, T	Are guidelines for peer-reviewing economic evaluations necessary …	HEALTH ECON
1995	23	Moher, D	Assessing the quality of randomized controlled trials …	CONTROL CLIN TRIALS
1996	23	Jadad, AR	Assessing the quality of reports of randomized clinical trials …	CONTROL CLIN TRIALS
1996	123	Drummond, MF	Guidelines for authors and peer reviewers of economic submissions to the BMJ	BRIT MED J
1996	23	Begg, C	Improving the quality of reporting of randomized controlled trials - The CONSORT statement	JAMA
1998	3	Godlee, F	Effect on the quality of peer review of blinding reviewers and …	JAMA
1998	3	Justice, AC	Does masking author identity improve peer review quality? - A randomized controlled trial	JAMA
1998	23	Weber, EJ	Unpublished research from a medical specialty meeting - Why investigators fail to publish	JAMA
1998	23	van Rooyen, S	Effect of blinding and unmasking on the quality of peer review - A randomized trial	JAMA
1998	23	Black, N	What makes a good reviewer and a good review for a general medical journal?	JAMA
1998	3	Campanario, JM	Peer review for journals as it stands today - Part 1	SCI COMMUN
1998	123	Jefferson, T	Evaluating the BMJ guidelines for economic submissions …	JAMA
1998	3	Howard, L	Peer review and editorial decision-making	BRIT J PSYCHIAT
1998	123	Rennie, D	Peer review in Prague	JAMA
1998	2	Hatch, CL	Perceived value of providing peer reviewers with abstracts and preprints …	JAMA
1998	23	Moher, D	Does quality of reports of randomised trials affect estimates of intervention efficacy …	LANCET
1998	23	Callaham, ML	Positive-outcome bias and other limitations in the outcome of research abstracts …	JAMA
1999	3	van Rooyen, S	Effect of open peer review on quality of reviews and on reviewers' recommendations …	BRIT MED J
1999	123	Smith, R	Opening up BMJ peer review - A beginning that should lead to complete transparency	BRIT MED J
1999	123	Goldbeck-Wood, S	Evidence on peer review - scientific quality control or smokescreen?	BRIT MED J
1999	2	Moher, D	Improving the quality of reports of meta-analyses of randomised controlled trials: QUOROM	LANCET
2000	123	Walsh, E	Open peer review: a randomised controlled trial	BRIT J PSYCHIAT
2000	2	Stroup, DF	Meta-analysis of observational studies in epidemiology - A proposal for reporting	JAMA
2001	2	Altman, DG	The revised CONSORT statement for reporting randomized trials …	ANN INTERN MED
2001	2	Moher, D	The CONSORT statement: revised recommendations for improving the quality of reports …	LANCET
2002	123	Jefferson, T	Effects of editorial peer review - A systematic review	JAMA
2002	123	Jefferson, T	Measuring the quality of editorial peer review	JAMA
2002	123	Rennie, D	Fourth International Congress on Peer Review in Biomedical Publication	JAMA
2002	23	Rowland, F	The peer-review process	LEARN PUBL
2002	123	Opthof, T	The significance of the peer review process against the background of bias …	CARDIOVASC RES
2003	23	Hojat, M	Impartial judgment by the "gatekeepers" of science: …	ADV HEALTH SCI EDUC
2003	23	Wets, K	Post-publication filtering and evaluation: Faculty of 1000	LEARN PUBL

Table 11: List of works on main path (1), main paths (2) and island (3) – part 3

year	code	first author	title	journal
2004	2	Chan, AW	Empirical evidence for selective reporting of outcomes in randomized trials …	JAMA
2005	23	Bornmann, L	Selection of research fellowship recipients by committee peer review …	SCIENTOMETRICS
2005	123	Daniel, HD	Publications as a measure of scientific advancement and of scientists' productivity	LEARN PUBL
2005	123	Bornmann, L	Committee peer review at an international research foundation: …	RES EVALUAT
2005	23	Bornmann, L	Criteria used by a peer review committee for selection of research fellows …	INT J SELECT ASSESS
2005	2	Ioannidis, JPA	Why most published research findings are false	PLOS MED
2006	123	Bornmann, L	Selecting scientific excellence through committee peer review - A citation analysis …	SCIENTOMETRICS
2006	23	Bornmann, L	Potential sources of bias in research fellowship assessments: …	RES EVALUAT
2007	123	Bornmann, L	Convergent validation of peer review decisions using the h index …	J INFORMETR
2007	23	Bornmann, L	Gatekeepers of science - Effects of external reviewers' attributes …	J INFORMETR
2007	23	Bornmann, L	Row-column (RC) association model applied to grant peer review	SCIENTOMETRICS
2008	23	Marsh, HW	Improving the peer-review process for grant applications …	AM PSYCHOL
2008	123	Bornmann, L	Selecting manuscripts for a high-impact journal through peer review …	J AM SOC INF SCI TEC
2008	23	Bornmann, L	The effectiveness of the peer review process: Inter-referee agreement …	ANGEW CHEM INT EDIT
2008	23	Bornmann, L	Latent Markov modeling applied to grant peer review	J INFORMETR
2008	23	Bornmann, L	Are there better indices for evaluation purposes than the h index? …	J AM SOC INF SCI TEC
2009	123	Bornmann, L	The luck of the referee draw: the effect of exchanging reviews	LEARN PUBL
2009	2	Opthof, T	The Hirsch-index: a simple, new tool for the assessment of scientific output …	NETH HEART J
2009	2	van der Heyden, MAG	Fraud and misconduct in science: the stem cell seduction	NETH HEART J
2009	23	Bornmann, L	The influence of the applicants' gender on the modeling of a peer review …	SCIENTOMETRICS
2010	23	Bornmann, L	The manuscript reviewing process: Empirical research on review …	LIBR INFORM SCI RES
2011	123	Bornmann, L	Scientific Peer Review	ANNU REV INFORM SCI
2011	123	Bornmann, L	A multilevel modelling approach to investigating the … of editorial decisions: …	J R STAT SOC A STAT
2011	3	Franceschet, M	The first Italian research assessment exercise: A bibliometric perspective	J INFORMETR
2011	23	Waltman, L	On the correlation between bibliometric indicators and peer review: …	SCIENTOMETRICS
2012	23	Sen, CK	Rebound Peer Review: A Viable Recourse for Aggrieved Authors?	ANTIOXID REDOX SIGN
2013	123	Lee, CJ	Bias in peer review	J AM SOC INF SCI TEC
2014	3	Bornmann, L	Do we still need peer review? An argument for change	J ASSOC INF SCI TECH
2015	3	Siler, K	Measuring the effectiveness of scientific gatekeeping	P NATL ACAD SCI USA
2015	123	Garcia, JA	The Principal-Agent Problem in Peer Review	J ASSOC INF SCI TECH
2015	123	Garcia, JA	Adverse selection of reviewers	J ASSOC INF SCI TECH
2015	123	Moustafa, K	Don't infer anything from unavailable data	SCIENTOMETRICS
2015	123	Garcia, JA	Bias and effort in peer review	J ASSOC INF SCI TECH
2015	123	Garcia, JA	The author-editor game	SCIENTOMETRICS
2016	123	Rodriguez-Sanchez, R	Evolutionary games between authors and their editors	APPL MATH COMPUT