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Bibliometrics as a tool for measuring gender-specific research performance: an example from South African invasion ecology

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Abstract Citations to published work are gaining increasing prominence in evaluations of the research performance of scientists. Considering the importance accorded to gender issues in South African science, it is surprising that (to our knowledge) no research has as yet ascertained the extent of sex differences in citations to the published work of scientists in this country. Our literature study shows that studies that have been conducted elsewhere tend to neglect in their analyses important gender-related and other factors, such as the sex composition of multi-authored papers and the extent of foreign co-authorship. Against this background, we illustrate the difficulties inherent in measuring the quality aspect of sex-specific research performance by means of an analysis of a dataset of articles ($n = 229$) that were published between 1990 and 2002 in the field of invasion ecology and in journals included in the Thomson Reuters Web of Science. Each article has at least one South African author address. The results indicate that foreign co-authorship is a better correlate of high citations than the sex of South African authors, and this is true irrespective of whether the annual citation rate or window period is used, whether or not self-citations are excluded, and whether or not the number of authors is controlled for by calculating fractional counts. The paper highlights these and other considerations that are relevant for future gender-focused bibliometric research, both in South Africa and beyond.

Keywords Bibliometrics · Gender · Research performance · Citations · Invasion ecology

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Introduction

Increasing women's participation in science and collecting sex-disaggregated data on the issue is considered a pressing need internationally (United Nations Educational, Scientific and Cultural Organization (UNESCO) 2007). Considering the central role that research performance and its measurement plays in assessing and rewarding the role performance of scientists, it may be argued that one cannot address the issue of women's participation in science without taking into account gender variations in research performance. This construct is commonly defined in terms of two dimensions: the number of papers individuals publish and the number of times they are cited. As noted by Ward and Grant (1996) and by Mcelhinny et al. (2003), the majority of studies that compare the research performance of women and men have focused on the former, without measuring gender difference in citations. Their almost universal finding, that women publish less than men, has been found to apply to South Africa as well (Prozesky 2006).

This focus on the quantitative dimension of research performance ignores the fact that output volume does not necessarily imply impact or recognition of the output by others (Cole and Zuckerman 1984; Helmreich et al. 1980), particularly when one considers the exponential growth in the volume of scientific publications globally. With regard to gender in particular, one cannot merely argue that, because women are known to publish less than men, they are cited less than men. There are indeed some indications that women as a group may tend to exhibit different publication behaviour or habits than men do—publishing less in terms of quantity but more in terms of quality, for example (Sonnert 1995; Sonnert and Holton 1995).

Against this background, it is important to note that citation-based measures have become increasingly important in determining rewards such as funding, hiring, promotion and tenure, and despite strong criticism against the use of citations to scientists' work to assess their research performance, this practice is "unlikely to be abandoned in the near future" (Leimu and Koricheva 2005, p. 31). From a gender perspective, the criterion of quantity may count more heavily for women than for men. For example, Persell (1983, p. 45) reports that, in the field of education, "[w]hen women hold their own in the quality of their research, they derive no benefit from it, while the quantity of publication (where men outperform women) counts more heavily for women than for men". Citations also represent the most common form of recognition within science, which encourages future publication (Ward and Grant 1996). From the perspective of the sociology of knowledge, sex differences in citations may indicate the extent to which a gender's ideas dominate and therefore shape a field. However, patterns in citations that reflect or even reproduce gender inequalities can be "subtle, not easily detectable without tally sheets and statistics; they can operate below the level of awareness" (Hutson 2002, p. 331). Quantifying them by means of citation analysis should therefore constitute an important dimension of any research aimed at assessing women's status, performance and contribution to science.

In South Africa, the National Advisory Council on Innovation (NACI) has recently advised the Minister of Science and Technology that, "public funds must be utilized to increase the volume and enhance the *quality of scientific output* performed by women" (National Advisory Council on Innovation (NACI) 2008, p. 11, italics added). What is implied is that South African women scientists fall short, relative to their male counterparts, in terms of *both* the quantitative and qualitative dimensions of research performance. However, this seems to be an untested assumption: to the author's knowledge, not a single study has been conducted in South Africa on sex differences in terms of the quality of scientific output.

This paper is aimed at investigating to what extent this may be attributed to challenges involved in applying bibliometrics as a tool for the valid measurement of sex-specific research performance. It reports on the findings of a dual research strategy, involving both a literature study and the analysis of primary data on citations to South African authored scientific journal contributions to the field of invasion ecology. The contribution of the paper is situated primarily in the methodological realm, by taking into account various potentially confounding variables, some of which, as the literature study shows, have not been taken into account in any previous research on sex differences in citations. These variables concern time since publication, the collaborative nature of both publications and citations (i.e., between sexes and between authors from different countries) and the tendency to self-cite. In order to determine whether and to what extent they have a distorting effect on bibliometric measures of gender-specific research performance, we compare results of two sets of analyses: one that does not control for these variables, and one that does. The paper concludes with a summary of the methodological considerations that should (or would not) be taken into account in future gender-focused bibliometric research, both in South Africa and beyond.

Literature study

In order to determine the extent to which potentially confounding variables have been taken into account in previous research on sex differences in citations (as generated by the Institute for Scientific Information [ISI]), a total of 49 such studies, with publication dates ranging from 1973 to 2011, were identified and reviewed (Table 1).

The following section reports on the data processing methods utilised in these studies, and highlights methodological issues we will be investigating in more detail through our own analysis of primary citation data.

Time-related controls

In the majority of studies reviewed, citations were collected over a continuous period that consists of a number of years, with only 5 studies[1] that recorded article and/or journal citation rates for only one year. A number of studies (7) do not fall into either category, as they involved recording citations received in a number of discrete (i.e., non-continuous) years.[2] Most of the researchers who collected citations for more than one year control for the fact that citations may increase over time since the publication of the cited article, and in the majority of cases this involves computing an annual citation rate by dividing the total number of citations that a cited article has received at a specific point in time (usually at the time of data collection) by the number of years that have lapsed since that article's year of publication. Three of the more recent studies,[3] that use regression models, included time as a variable in the equation in order to control for the fact that more recent articles have had less time to be cited. Another relatively rare approach among researchers who compare the sexes in terms of citations was followed by Stack (1994), Gonzalez-Brambila and Veloso (2007),

[1] Mauleón and Bordons (2006), Wennerås and Wold (1997), Toutkoushian (1994) and Trimble (1985, 1993).

[2] Lewison (2001), Davis and Astin (1987), Irvine and Martin (1986), Cole (1979), Cole and Cole (1973), Cole and Zuckerman (1984) and Reskin (1978).

[3] Walters (2006), Haslam et al. (2008) and Montpetit et al. (2008).

Table 1 A summary of studies that analysed ISI-data to compare men and women in terms of citations (1973–2011)

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Cole and Cole	1973	(1) SCI (1961, 1964, 1965, 1967, 1969, 1970)	(1) Mean citations per year (2) Citations per published paper	Unknown	Excluded	Chemistry, biology, and psychology
Reskin	1978	(1) SCI (1961–1971) (2) SCI (1961 and 1964, for early work)	(1) Average citations over an 11-year period (2) Number of citations listed in 1961 and 1964	Unknown	Unknown	Chemistry
Cole	1979	(1) SCI (1961, 1964, 1965, 1967, 1969 and 1970) (2) SCI (1961, 1965, 1967, 1970, and 1972 for a subset of cases) (3) SCI (1961, 1965, 1968, 1970 and 1972 for a subset of cases) (4) SSCI (1972–1974 for a subset of cases)	Mean and total number of citations for the various years	Unknown	Excluded	Biology, chemistry, psychology and sociology
Helmreich et al.	1980	(1) SSCI (1974, 1975, 1976) (2) SCI (for a subset of cases)	The average (mean and median) citations for the years 1973–1975	Straight count	Excluded	Psychology
Over and Moore	1980	(1) SSCI (1975, 1976 and 1977)	Mean citation rate between 1975 and 1977	Straight count	Excluded	Psychology
Persell	1983	SCI	A count and average (mean) number of citations scientists received over a two-year period (1970–1971) to articles they published in 1967 and 1968	Straight count	Unknown	Education
Cole and Zuckerman	1984	SCI	(1) No. of citations, year to year, to an author's cumulative publications over the first 12 years of his/her career (2) Citation counts aggregated for the 12-year period, the first 7 years and the later 5 (3) Average citations per paper for the 12-year period, the first 7 years and the later 5	Straight count	Excluded	Astronomy, biochemistry, chemistry, earth sciences, mathematics, physics

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Trimble	1985	SCI (1982)	Average (mean) citation rate in 1990, reported for 6 different chronological cohorts of scientists to normalise for the effect of scientific age	Straight count	Excluded	Astronomy
Irvine and Martin	1986	SCI	No. of citations to publications published in the 4-year period after registration for a PhD. The no. of citations was generally taken every two years over a six-year period, except where this was impossible, in particular for the very earliest students	Whole count	Unknown	Radio astronomy
Davis and Astin	1987	SSCI (1980 and 1982)	Total no. of citations during 2 years (1980 and 1982)	Unknown	Unknown	Social sciences
Long	1992	(1) SCI (various years) (2) JCR	(1) Average citations per year over the 3 years following a paper's publication, by career age (2) Average citations per article (mean no. of citations divided by the mean no. of publications), by career age	Fractional count	Unknown	Biochemistry
Ward et al.	1992	SSCI (1974–1989)	Citations to articles published during 1974–1983. Compared the average (mean) citation rates of men and women in various cohorts and subgroups	Straight count	Unknown	Sociology
Trimble	1993	SCI (1990)	Average (mean) citation rate in 1990, reported for 6 different chronological cohorts of scientists to normalise for the effect of scientific age	Straight count	Excluded	Astronomy

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Cronin and Overfelt	1994	(1) SCI (2) SSCI (3) A&HCI	A 10-year analysis. Time-in-field data were used to normalise raw citation scores	Straight count	Excluded, but included for distribution of citations across the A&HCI, SCI and SSCI	Library and Information Science
Stack	1994	SSCI (1982)	Average number of citations received per year by articles published in 1978	Unknown	Excluded	Sociology
Toutkoushian	1994	(1) SCI (2) SSCI (3) A&HCI	Number of times cited in 1985	Straight count	Excluded	All (Faculty at the University of Minnesota)
Davenport and Snyder	1995	JCR	Computed average number of 1985–1994 citations to a sample of 100 articles	Straight count	N/A	Sociology
Hammel et al.	1995	SSCI	Citations over the entirety of the period 1962–1987, but counted for an individual only for those articles that were published during the period of eligibility for the career transition under consideration	Unknown	Unknown	Anthropology
Sonnert	1995	JCR	Average annual rate of citations (sum of citations/career age)	Fractional count	N/A	Biology
Kolpin and Singell	1996	JCR (1986)	Measured at a point in a scientist's career, i.e., for a 2-year interval, the year of the sample (1974 and 1985) and the subsequent year (1975 and 1986)	Fractional count	N/A	Economics
Wennerås and Wold	1997	SCI	No. of times papers were cited during 1994	Unknown	Unknown	Medicine

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Flores et al.	1999	SSCI (1986–1996)	Citations across the 11-year time span to papers published 1969–1995	Straight count	Unknown	Psychology
Lewison	2001	(1) JCR (2) SCI	(1) Citation data for publications in 1988, 1990, 1992 and 1994. Papers prior to 1988 were classified using 1988 categories and post-1994 papers were classified using 1988 categories (2) Citation counts for a sub-sample of papers were determined over a 5-year period for papers published between 1988 and 1996	Fractional count	Unknown	All (Icelandic researchers)
Tregenza	2002	WoS index/es (unspecified)	Citation rate of papers published 3–4 years previously	Unknown	Unknown	Ecology and evolutionary biology
Bordons et al.	2003	JCR (1999)	Average impact factor of the publication journals of every author for the publication years 1994–1999	Unknown	N/A	Natural resources and chemistry
Leta and Lewison	2003	JCR	Citations from 1996 to 2000 to publications in 1996	Unknown	N/A	Astronomy, immunology and oceanography
Leimu and Koricheva	2005	(1) SCI (2) JCR	Annual citation rate (total citation count as of January 2004/no. of years since publication), standardised by the journal impact factor	Straight count	Unknown	Ecology
Kelly and Jennions	2006	WoS index/es (unspecified)	*h*-index: based on the assumption that papers accumulate citations at a fixed rate; m = h divided by scientific age	Unknown	Excluded for a sub-sample	Ecology and evolutionary biology
Mauleón and Bordons	2006	JCR (2001)	Average impact factor of journals in year 2000	Unknown	N/A	Materials science
Peñas and Willet	2006	WoS index/es (unspecified)	Unknown	Unknown	Unknown	Library and information science

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Symonds et al.	2006	Wos index/es (unspecified)	(1) Median no. of citations received until the end of 2005 per paper published by scientists of approx. the same scientific age (2) *h* index based on publications in the period 1996–2005 (thereby controlling for scientific age)	Unknown	Excluded for a sub-sample	Ecology and evolutionary biology
Trifunac	2006	Wos index/es (unspecified)	Average citation rate per cited article per year as of January 10, 2004 (= total no. of citations/ no. of cited papers) by career year	Whole count	Unknown	Soil dynamics and earthquake engineering
Walters	2006	SSCI	Citations to articles published in 2003, counted from the month the article was published to mid-October 2005. A time variable (the natural log of time in months between article publication and mid-October 2005) was added to the regression equation in order to control for length of exposure	Straight count	Included	Crime-psychology
Gonzalez-Brambila and Veloso	2007	(1) SCI (2) SSCI	Four-year citation window (number of citations in the 4 years subsequent to the publication year of papers published from 1991 to 1997)	Unknown	Unknown	All (Mexican researchers productive)
Leahey	2007	(1) SSCI (2) A&HCI	Cumulative number of citations: obtained citation rates for each article published by each samples faculty member and summed them to obtain the total number of citations received by each individual)	Unknown	Unknown	Sociology and linguistics
Haslam et al.	2008	WoS index/es (unspecified)	Citations accrued over 10 years by articles published over a one-year period, i.e., citations counted mid-July 2006 to articles published in 1996. Month of publication was recorded as a control variable in all regression analysis	Unknown	Included	Social and personality psychology

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
Housri et al.	2008	(1) JCR (2) WoS index/es (unspecified)	Average impact factor of journal in the year in which each paper was published (with the exception of articles published in 2006, for which the 2006 impact factor was used). Mean number of citations per article	Whole count	Unknown	Academic surgery
Krampen	2008	(1) SCI (2) SSCI	Average number of citations per publication year over the period 2000 to 2006.	Unknown	Excluded	Psychology
Mauleón et al.	2008	(1) JCR (2) SCI	(1) Average impact factor of journals in 2000 weighted according to the number of documents published in each journal (2) Number of citations received by documents published from 1996 to 2000, since their publication year to June 2005	Unknown	Unknown	Life sciences
Montpetit et al.	2008	(1) JCR (2) SCI	(1) Average impact score for the period 2001 to 2005 (2) The frequency whereby an article published during the period 1985–2005 is cited during the same period. A control variable, the difference between 2006 and the year of publication, is included in order to take into account the fact that more recent articles have had less time to be cited.	Combination	Unknown	Political science
Borsuk et al.	2009	WoS index/es (unspecified)	Data were collected from 1997 to 2004. Citation rates for each article were calculated as the sum of the citations received during the year of publication and two years following publication	Unknown	Unknown	Ecology

Table 1 continued

Author(s)	Pub. date	Data sourc(es) and year(s)	Time-related decisions and controls	Approach to multi-authored papers	Self-citations	Discipline(s)
García-Pérez	2009	WoS index/es (unspecified)	*h*-indices	Unknown	Included and excluded	Methodology of the Behavioural sciences
Powell et al.	2009	WoS index/es (unspecified)	Citations during a five-year period (2003–2007) to articles published in the year 2003	Unknown	Unknown	Construction
Sandström	2009	WoS index/es (unspecified)	Citations up until May 2007 to articles published during the period 1998–2004. An open citation window was applied	Unknown	Included	Medicine
Borrego et al.	2010	WoS (unspecified)	Median number of citations received up until 2006 per article published before and after completion of the Ph.D.	Unknown	Included and excluded	All, excluding humanities
Corley and Sabharwal	2010	(1) SSCI (2) JCR	(1) Total number of citations received by authors of articles that were catalogued in the SSCI index between 1973–2007 (2) For each author, the average impact factor was computed by taking the mean impact factor of all of the articles authored by that person during the study period	Unknown	Included	Public administration
Hunter and Leahey	2010	(1) SSCI (2) A&HCI	Cumulative citations and citations per publication per year	Unknown	Unknown	Sociology and linguistics
Reese-Evans	2010	SCI	The number of citations to each article published in all volumes of two journals, from inception to 2007	Straight count	Unknown	Library and Information Science
Aksnes et al.	2011	(1) SCI (2) SSCI (3) A&HCI	Cumulative citation counts. The period for which citations are taken into account varies from 2 to 5 years, depending on publication year	Whole counts	Unknown	All (Norwegian scientists)

Borsuk et al. (2009), and Powell et al. (2009), who used a fixed citation window, which involves limiting for each cited article the time period for which citations are counted to the same number of years after publication. This is in spite of the fact that the fixed citation window approach is considered the "standard method in bibliometric analysis, in order to give equal time spans for citation to articles published in different years" (Craig et al. 2007, p. 243, as cited in Bornmann 2010).

Controlling for multiple authorship

Counting citations without taking into account multiple authorship has been termed "one of the most serious errors in empirical judgement made in the sociology of science" (Lindsey 1980, p. 145). Already in 1980, Lindsey noted that, "[s]ince scientific publication is now characterized by extensive multiple authorship, this error has become critical" (p. 146). It has been found that multi-authored papers are more likely to be cited and to be more highly cited than single-authored papers (Beaver 1986, cited in Fox 1991; Rousseau 1992, cited in Cronin and Overfelt 1994; also see Lindsey 1980 for a review). More to the point of this review is evidence that women are more heavily represented as co-authors and men as sole authors of articles in (1) major sociology journals, which "might reflect young women scholars' avoidance of submission of solo-authored works to top-ranking journals" (Ward and Grant 1991, p. 213), and (2) education journals (Demetrulias 1986). However, neither Cole and Zuckerman (1984), nor Long (1992) found any evidence that women collaborate more or less often than men, while Over and Moore (1980) report that women academic psychologists published slightly more often than men as sole authors.

In 1981, Garfield proclaimed that "[t]here is as yet no agreed-upon method for assigning credit to each co-author" (p. 277). A decade later, Cronin and Overfelt (1994) summarised three different approaches to allocating credit in the case of multi-authored works: (1) straight counts (first author only receives credit); (2) whole counts[4] (each author receives full credit); and (3) fractional counts (fractions are awarded to each co-author, usually by dividing citation count by number of co-authors).[5] Of the 32 studies reviewed, more than a third (14) made *no reference* as to how credit was assigned in the case of multi-authored works. Of the remaining 18 studies, by far the majority (12) applied straight counts, 2 applied whole counts and only 4 applied a fractional count.

According to MacRoberts and MacRoberts (1987, p. 346, as cited in Cronin and Overfelt 1994), applying these three very different methods of credit allocation will "in all likelihood give widely different results". In response, Cronin and Overfelt (1994) compared results that were obtained by using all three of the above-mentioned approaches to allocating citation credit in the case of multi-authored works. Although they used *only* straight counts to test the relationship between citation level and gender, it is important to note that they found little difference in the overall rankings produced by the three approaches. They therefore conclude that "all three approaches could be used interchangeably without introducing *significant* distortions", but do acknowledge that this may not apply to other populations with, for example, different authorship patterns (p. 65).

Extending this point to sex differences in citations, possible sex differences not only in the tendency to co-author, but also in terms of authorship position, require taking into account the sex composition of an author set. Findings are not conclusive, however. On the

[4] Also referred to as "normal counts" (Trifunac 2006, p. 1070).

[5] Also referred to as "adjusted counts" (Cronin and Overfelt 1994, p. 61), or "per author counts" (Trifunac 2006, p. 1070).

one hand, there is a lack of evidence among biochemists (Long 1992, p. 170) that women are "relegated to the back of the author list", Cole and Zuckerman (1984) found that women scientists in various fields are first authors as often as men. Ferber (1986), cited in Davenport and Snyder 1995) reports that citation counts for mixed gender collaborative authors fall somewhere in between citation scores for each gender of single authors, and in the field of ecology Borsuk et al. (2009) found no significant differences in citation rates by first-author gender. On the other hand, the weight of evidence seems to indicate that women are more likely to be subsidiary or non-lead co-authors in major (prestigious and widely read) sociology journals (Ward and Grant 1991), education journals (Demetrulias 1986), as well as in the fields of business (Walters et al. 1990), academic psychology (Over and Moore 1980[6]; Teghtsoonian 1974), ecology (Borsuk et al. 2009), and construction (Powell et al. 2009).

In 1984, Cole and Zuckerman noted that the sex composition of sets of authors, particularly combinations of men and women, has not been taken into account in most research on sex differences in citation rates. In fact, at the time of writing, they knew of no study that had taken into account papers authored by men and women jointly, and it was "still not clear how best to count citations when the sex composition of collaborative groups varies" (p. 241). Our review, conducted more than two decades later, shows that only approximately 1 in 5 studies use whole or fractional counts, and could therefore (at least potentially) take into account papers authored by men and women jointly. One study (Montpetit et al. 2008) took the gender of such papers to be that of the majority of authors and, when there was a tie, reverted to a straight count (the gender of the lead author).

The tendency to use straight counts, and as a consequence defining female(male)-authored articles as those with female(male) solo or first authors, and neglecting the sex composition of author sets may be attributed to two main factors. The first of these is the convention followed during approximately the first two decades after the inception of Science Citation Index (SCI)[7] in 1961 to attribute all citations to a multi-authored paper to the first or solo author (Garfield 1981; Sonnert 1995). The lack of all-author data meant that citation counts were underestimated for the subset of authors who collaborate more than usual and whose names tend not to be the first in the author sets. Thus, sex differences in authorship practices mentioned above, "may produce artifactual differences in citation counts" (Cole and Zuckerman 1984, p. 220). Even though all-author data became available in the ISI indexes of the 1980s, our literature study shows that researchers who compare the sexes in terms of citations still tend to collect and link citations to first or solo authors only, rather than use whole or fractional counts.

The second possible reason why researchers have neglected the sex composition of author sets in their citation comparisons between the sexes, is that obtaining data on the sex of authors—and especially of all the authors in author sets that are ever-increasing in size—is very time-consuming, since most periodicals (and therefore the Thomson Reuters

[6] In the latter case, however, the sex differences were small enough to lead Over and Moore (1980, p. 415) to conclude that "[t]he men and women were […] equally likely to employ authorship patterns that enhance individual visibility".

[7] Already in the early 1980s, ISI recognised the need "to treat all authors in every article as though they were listed first" (Garfield 1981, p. 269) and started developing a system that would allow this. In 1978, Garfield (1981) was the first to use these so-called "all-author data". He does mention that "[d]eveloping all-author lists is considerably more complex than conducting first-author studies" (p. 269). However, his findings (the average author received 1,178 citations to papers on which he or she appeared as first author and 2,633 as co-author) clearly demonstrate "the importance of all-author data" (p. 275).

Web of Science [WoS] indexes based on them) only record the initials of authors.[8] Even if a study is limited to papers published in journals that generally publish authors' first names (e.g., Tregenza 2002), many papers may have authors with androgynous names that are not evidently male or female.

The last issue concerning multi-authored papers relates specifically to internationally co-authored articles. Leta and Lewison (2003) and Lewison (2001) cite several studies that have demonstrated that internationally co-authored papers tend to have higher impact than domestic ones. More importantly, the tendency to co-author papers internationally may relate to gender, as it may depend on the availability of travel grants to go to conferences abroad (Lewison 2001). Leta and Lewison (2003) and Lewison (2001) are the only researchers whose studies we reviewed, who determined whether females are as likely as males to co-author papers internationally. Leta and Lewison (2003) investigated the frequency of domestic and foreign publications according to the sex of a sample of Brazilian scientists, but found that female scientists tend to collaborate internationally as much as men do—a factor they suggest might have contributed to the similarity they found between men and women in terms of the potential impact of their publications. In his study of Icelandic scientists, Lewison (2001) divided his sample of papers between purely Icelandic papers and ones with a foreign co-author, and found a "relative paucity of female authorships" (p. 42) in the latter category of papers.

The tendency to self-cite

The final methodological issue considered in this review concerns the way in which self-citations are dealt with in studies that compare men and women in terms of citations. According to Creamer (1998, p. 35), the "rate of self-citation is high enough that it is fairly common practice to remove self-citations from total citation counts". Of the 43 studies that utilised WoS indexes, more than half (24) did not indicate explicitly whether self-citations were included or not. Of the remaining 19 studies, approximately half (10) excluded self-citations, while 5 did so for only a sub-sample, or part of the analysis, primarily because of the time-consuming process involved in identifying and excluding self-citations. In order to overcome this problem, two sets of researchers (Kelly and Jennions 2006; Symonds et al. 2006) analysed only a randomly selected sub-sample of scientists. The exclusion (or not) of self-citations is of particular relevance for this paper, as the likelihood to cite oneself seems to be related to gender, with women having been shown to be less likely to cite themselves than men (Lutz 1990; Helmreich et al. 1980; also see Creamer 1998 for a review). However, Hutson (2006), Borrego et al. (2010), and Symonds et al. (2006) found no evidence of gender differences in the rates of self-citation, and the latter conclude that their citation analysis is unlikely to be systematically biased by any gender differences in the rates of self-citation.

[8] In some countries, it is possible to differentiate between the sexes based on the surname alone. For instance, in Poland more than sixty percent of all surnames can be determined as belonging to a man (those which end with "-ski", "-cki" or "-owy") or a woman (those ending with "-ska", "-cka" or "-owa") (Webster 2001). In Iceland, women's surnames typically end in "dottir", whereas the names of men end in "son", which allowed Lewison (2001) to conduct one of the most extensive and detailed analyses of gender differences in citations thus far. Lewison (2001, p. 42) rightly comments that, "It would be very difficult to extend such a study to other countries unless there were a complete list of the country's researchers available with their sexes so that comparisons could be made".

Methodology

The subfield of invasion ecology in South Africa

Webster (2001) notes that bibliometric studies, particularly those focusing on gender differences in publication productivity, are usually concentrated on small samples, partly because sexing a relatively large sample of scientists is very time-consuming (as mentioned above), but also because citation characteristics are field-dependent, and therefore indirectly related to gender, as the sexes differ in terms of their participation in various fields.[9] The present study follows suit, by including only South African authors of articles on a subfield of ecology—invasion ecology—in the study population.

Richardson and Van Wilgen (2004, p. 47) define invasion ecology as "the study of the human-mediated introduction of organisms, especially introductions to areas outside the potential range of given organisms, as defined by their natural dispersal mechanisms and biogeographical barriers". According to these South African invasion ecologists, the field (sometimes also referred to as invasion biology) addresses all aspects relating to the introduction of organisms, their ability to establish, naturalize and invade in the target region, their interactions with resident organisms in their new location, and the consideration of costs and benefits of their presence and abundance with reference to human value systems. Fundamental research questions in invasion ecology include: (1) Why are some species more successful invaders than others? (2) Why are some systems more susceptible to invasions than others? and (3) How can the harmful impacts of invasions be prevented, reduced or mitigated? (Drake et al. 1989, and Williamson 1996, as cited in Richardson and Van Wilgen 2004).

From a global perspective, South Africa has been identified as one of only three regions outside the USA where researchers who produce highly cited articles in invasion ecology are well-represented (Pyšek et al. 2006), and the country alone accounts for two-thirds of research effort on the African continent (Pyšek et al. 2008). A recent bibliometric study of all biological invasions-related publications in the SCI from 1991 to 2007 ranked a South African[10] as the most productive author in the field over this period, ranked South Africa in the top 15 publication position, and found that South Africa had higher citation per publication (CPP) values compared to other world regions, including the US and Western Europe (Qiu and Chen 2009). South African researchers in this field therefore enjoy a high level of productivity and representation and effective international collaboration in the international invasions literature. It is therefore not surprising that one of only six highly prestigious DST-NRF[11] Centres of Excellence in South Africa, the Centre for Invasion Biology (CIB), focuses on invasion ecology. The first author's involvement as a core team member of this Centre provided her with background knowledge of the field of invasion ecology, which was especially useful to define the field of invasion ecology according to its outputs, and to identify its authors.

Data source

In compiling a dataset of relevant publications, all articles published in the field of invasion ecology between 1990 and 2002, with at least one South African author address and

[9] See Boshoff (2005) for South African statistics in this regard.

[10] Prof David Richardson, currently Deputy Director of the CIB and a Professor in the Department of Botany and Zoology at Stellenbosch University.

[11] The South African Department of Science and Technology (DST) and National Research Foundation (NRF)—the two bodies responsible for the funding and administration of the Centres of Excellence.

published in journals listed in the WoS, were extracted from SA Knowledgebase. The latter is a dynamic database of public science in South Africa, developed by the Centre for Research on Evaluation, Science and Technology (CREST) at Stellenbosch University. Only full-length articles were extracted, meaning that notes, letters, reviews, proceeding papers and editorial material were excluded. Articles were selected in terms of the presence of invasion ecology-related terms and their combinations or derivatives in article titles and abstracts, keywords, journal and institutional affiliation.[12] The help of scientists at the CIB was enlisted to assess the exhaustiveness of the key terms and the selected articles. A total of 246 articles were identified.

Determining the sex and national affiliation of authors

Although SA Knowledgebase provides some author-specific data on demographic variables, data on sex were available for less than 30% of the authors in the invasion ecology dataset. The next step was to fill in the missing data by examining, among others, the original articles and/or other publications by the same author, and web pages providing staff profiles of academic departments. This significantly reduced the number of authors with missing sexes. The procedure also helped in the identification of the national affiliation of authors (i.e. South Africa or foreign country address), in cases where SA Knowledgebase did not capture the national affiliation of authors in the invasion ecology dataset. The sex and national affiliation of authors could be fully identified for 229 of the 246 articles.

Calculating citations and applying time-related controls

As SA Knowledgebase does not contain any data on citations, the total number of citations for each article was obtained from the online WoS citation database. Specifically, the total number of citations per article since the year of publication until December 2008 was calculated. Only citing *articles* (as opposed to reviews, proceeding papers, etc.) were considered. The names of authors of the citing articles were also recorded and checked against those of the cited articles to identify self-citations. The latter enabled the calculation of a total citation count that excludes self-citing. For both sets of citation counts (i.e. self-citations respectively included and excluded) a time-related control was applied by dividing the total number of citations (at the end of 2008) by the number of years since publication of the cited article.

Apart from this annual citation rate, a second time-related control was introduced by limiting, for each cited article, the time window for which citations are counted to three years after the year of publication (the minimum duration, according to Bornmann 2010). For instance, if a cited article was published in 2001, citations up to 2004 were counted; similarly, citations until 2005 were included for an article that was published in 2002. This fixed citation window measure also had two variants: self-citations respectively included and excluded. Thus, in this study the annual citation rate and the fixed citation window are

[12] Examples include invasive/invasion (management); alien/plant invasions; naturalized/non-indigenous; indigenous; native; exotic; biological invasions, alien species, invasive alien species and invasion biology/ecology. In subsequent searches, the net was thrown wider, as broader terms and their derivatives (e.g., biological diversity and biological control) were used to identify papers that may have been overlooked by the more obvious key terms. In case of doubt, the contents of papers were scanned in order to decide whether they should be included or not.

treated as two separate approaches that provide different comparable perspectives in the measurement of citations.

Controlling for multiple authorship

Fractional counts were calculated to control for the number of authors per cited article. Practically this means that, for each cited article, the four sets of citation counts (two time-related controls, each with and without self-citations) were divided by the number of co-authors. Thus, an additional four sets of fractional counts were calculated. Together with the other four sets of (whole) citation counts, it implies a total of eight citation measures.

Results

The first set of results for the eight citation measures is based on authorships, as opposed to articles, as the unit of analysis. In an authorship dataset an author is counted for every article that he or she produces, which means that the total number of authorships will always exceed the total number of (non-duplicate) authors. The 229 articles are associated with 386 South African male authorships, 109 South African female authorships, 21 foreign male authorships and 6 foreign female authorships. The authorship analysis in Table 2 shows that the average number of citations received by foreign male authors is always higher than that received by either South African authors (male or female) or foreign female authors. This is the case irrespective of the measure of citation used. South African male authors, in turn, received higher citations than South African women on all eight measures.

The next step was to control for the effect of foreign male authors by splitting the authorship dataset in two: a subset of authorships where every underlying article is co-authored by at least one foreign male, and a subset where none of the underlying articles is co-authored by a foreign male (Table 3). The results of this procedure confirm the previous finding: the highest citations are associated with foreign male authorships and, when the influence of foreign men is systematically removed, the larger number of citations is associated with South African male authorships.

It is important to note that an analysis of authorships ignores the sex composition of sets of collaborating authors. For instance, it is not clear in Table 3, in subset 2, how many of the 107 South African female authorships are co-occurring with South African male authorships. A better solution is to consider the article as the unit of analysis and to categorise each article in terms of author sex and national affiliation. This was done in Table 4, which shows that the highest citation overall is associated with the 18 articles that are co-produced by South African men and foreign authors. This is true for seven of the eight citation measures. The exception is the window measure that uses fractional counts and includes self-citations. For this measure, articles that are authored by a single South African male solicited the highest citations. However, the calculation of fractional counts assigns a larger citation weight to single-authored articles, as these articles are divided by 1 and the others by a factor greater than 1, meaning that, for single-authored articles, the fractional count will always equal the whole count. Thus, where fractional counts are reported, the citation rate of single-authored articles will always exceed that of multi-authored papers in cases where both attract the same number of citations. Since the calculation of fractional citation counts is considered a fair control for papers with multiple

Table 2 Authorship dataset: interaction between citation measure and author sex and author national affiliation

National affiliation and sex of authors	Annual citation rate				Fixed time window, 3 years			
	Self-citations included		Self-citations excluded		Self-citations included		Self-citations excluded	
	Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count
SA men ($n = 386$) [participating in 206 articles]	1.33	0.51	1.02	0.39	2.67	1.01	1.51	0.58
SA women ($n = 109$) [participating in 94 articles]	0.89	0.36	0.66	0.27	1.67	0.68	0.96	0.40
Foreign men ($n = 21$) [participating in 18 articles]	2.99	1.24	2.52	1.07	3.86	1.53	2.29	0.92
Foreign women ($n = 6$) [participating in 3 articles]	1.31	0.44	0.89	0.29	1.17	0.33	1.17	0.33

Table 3 Authorship dataset: interaction between citation measure and author sex and author national affiliation, controlling for foreign male authors

Authorship subset	National affiliation and sex of authors	Annual citation rate				Fixed time window, 3 years			
		Self-citations included		Self-citations excluded		Self-citations included		Self-citations excluded	
		Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count
Subset 1: At least one foreign male co-author	Foreign men ($n = 21$) [participating in 18 articles]	2.99	1.24	2.52	1.07	3.86	1.53	2.29	0.92
	Foreign women ($n = 2$) [participating in 1 article]	2.59	0.65	1.82	0.46	3.00	0.75	3.00	0.75
	SA men ($n = 26$) [participating in 17 articles]	1.98	0.85	1.67	0.74	2.54	1.04	1.54	0.64
	SA women ($n = 2$) [participating in 2 articles]	0.29	0.14	0.29	0.14	0.50	0.25	0.50	0.25
Subset 2: No foreign male co-author	SA men ($n = 360$) [participating in 189 articles]	1.28	0.48	0.98	0.37	2.68	1.01	1.51	0.58
	SA women ($n = 107$) [participating in 92 articles]	0.91	0.37	0.67	0.27	1.69	0.69	0.97	0.41
	Foreign women ($n = 4$) [participating in 2 articles]	0.68	0.34	0.43	0.21	0.25	0.13	0.25	0.13

Table 4 Article dataset: interaction between citation measure and author sex and author national affiliation

National affiliation and sex of authors	Annual citation rate				Fixed time window, 3 years			
	Self-citations included		Self-citations excluded		Self-citations included		Self-citations excluded	
	Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count	Whole count	Fractional count
South African man/men & foreign author(s) ($n = 18$)	2.89	1.27	2.45	1.09	3.39	1.41	2.11	0.89
South African men only ($n = 81$)	1.40	0.57	1.10	0.45	2.80	1.10	1.62	0.66
South African women and men ($n = 70$)	1.01	0.37	0.75	0.27	1.96	0.73	1.11	0.41
South African women/woman & foreign author(s) ($n = 1$)	0.57	0.29	0.57	0.29	1.00	0.50	1.00	0.50
Single South African woman ($n = 18$)	0.52	0.52	0.38	0.38	0.83	0.83	0.61	0.61
Single South African man ($n = 36$)	0.48	0.48	0.33	0.33	1.56	1.56	0.83	0.83
South African women only ($n = 4$)	0.20	0.10	0.11	0.06	0.50	0.25	0.25	0.13
South African women and men & foreign author(s) ($n = 1$)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

authors, it could be argued that the use of whole citation counts for multi-authored papers will produce results that are inflated.

Table 4 reveals another instance where the results seem to differ according to citation measure: the comparison of articles produced by a single South African man versus those produced by a single South African woman. In terms of the annual citation rate, articles by a single South African woman attract, on average, more citations than articles by a single South African man. However, these differences are not statistically significant, based on a series of independent *t*-tests (self-citations included: $t = 0.194$, df $= 52$, $p = 0.847$; self-citations excluded: $t = 0.328$, df $= 52$, $p = 0.744$). Furthermore, when a fixed citation window is applied, the average citation counts appear highest for articles produced by a single South African man. These differences are also not statistically significant (self-citations included: $t = -1.754$, df $= 49.4$, $p = 0.086$; self-citations excluded: $t = -0.709$, df $= 52$, $p = 0.481$).

Overall the results indicate that foreign co-authorship is a better correlate of high citations than the sex of South African authors, and this is true irrespective of whether the annual citation rate or window period is used, whether or not self-citations are excluded, and whether or not the number of authors is controlled for by calculating fractional counts.

Conclusion

Since the publication in 1973 of the first study that compared men and women in terms of citations by analyzing data generated by the ISI, approximately 50 similar studies have been conducted in the past 3–4 decades. This is a small research effort, compared to the much larger body of empirical literature comparing men and women in terms of publication productivity, which most probably points towards the fact that comparing the sexes in terms of citation counts is much more complex and time-consuming than comparing them in terms of article counts.

On the basis of an analysis of this body of literature, we have highlighted some of the difficulties that are involved in the drawing of reliable and valid comparisons between men and women in terms of the citations their work attracts. At the core of the methodological complexities involved, lies the time-consuming process involved in sexing articles, especially those with a large number of joint authors of different sexes. Citation studies with a gender focus have as yet not managed to address these challenges well: sample sizes have been relatively small, which limits generalisability; credit tends to be allocated via straight counts, which does not take into account possible sex differences in authorship practices and as such may disadvantage women more than men; and the exclusion of self-citations tends to be neglected, which again may bias findings towards men. In addition, among researchers who compare the sexes in terms of citations, average annual rate of citations has been the preferred method for controlling for the fact that articles have different "ages", while the standard bibliometric method involving the use of fixed citation windows has been all but ignored.

These methodological considerations have all been taken into account in the analysis presented here. A foreign (male) author effect is evident, as the highest citations to South African (co-) authored articles in invasion ecology appear to be associated with this subgroup. If one controls for foreign male authors, a clear sex effect emerges, as the highest citations are then associated with South African men (compared to South African women). However, internationally co-authored articles dominate the citation profiles, even when controlling for both self-citations and number of co-authors (through the calculation

of fractional counts). This supports Van Raan's (1998) conclusion that the higher citations achieved by internationally co-authored papers is not because of a greater probability of self-citing (which, in turn, is possible because of a larger number of authors generally associated with international co-authorship), but because of a genuine "impact-strengthening" effect of international collaboration.

Lastly, within the South African science policy arena, calls are frequently made to address the status of women in science. The trend towards corporatism in the South African higher education sector (which produces by far the majority of the country's scientific output) means that this status increasingly depends on what are argued to be objective measures of research performance. Objective measures, for instance, must take into consideration that more than half of South Africa's total article output is produced by foreign authors (Sooryamoorthy 2009). The research presented here provides evidence that the use of citation counts to compare men and women in terms of the qualitative dimension of their research performance requires meeting a number of methodological challenges, which have thus far been neglected in the majority of studies that draw such a comparison. Descriptions of gender differences in citations should therefore be approached cautiously, and with particular sensitivity to the effect that gender differences in the tendency to co-author internationally may have on citation counts.

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