Research Evaluation, volume 14, number 2, August 2005, pages 110–120, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Research performance

Bibliometric indicators at the micro-level: some results in the area of natural resources at the Spanish CSIC

Rodrigo Costas and María Bordons

This analysis is based on the international database Science Citation Index and the Spanish database ICYT combined. A total of 3,302 SCI and 1,183 ICYT publications were identified during 1994–2001 for the 333 permanent scientists analysed. The scientific performance of scientists was studied through different indicators related to: activity (SCI and ICYT productivity), expected impact (average impact of publications, percentage of documents in top journals), observed impact (number of citations per document, number of highly cited papers) and publication habits. Only 3% of the scientists did not show any publication in the period. An increase in international productivity is observed while national productivity tends to decrease over time. Research professors (the highest professional category at CSIC) show higher productivity and observed impact than the remaining categories. However, a collective of scientists from different professional categories with a selective publication strategy towards high-quality journals and rewarded with a high number of citations is identified. Main advantages and limitations in obtaining indicators at the micro-level are outlined.

Rodrigo Costas and María Bordons are at the Centro de Información y Documentación Científica (CINDOC), CSIC, Joaquín Costa 22, 28002 Madrid, Spain; emails: rodrigo.costas@cindoc.csic.es and mbordons@cindoc.csic.es

BIBLIOMETRIC INDICATORS constitute a useful tool for the study of research performance at very different levels of analysis (countries, regions, institutions and centres), as has been extensively described in the literature. However, the assessment of research performance of individual scientists (micro-level studies) is more controversial and less studied. It presents a special challenge, since different limitations and difficulties need to be surpassed. Problems include the low validity of statistical indicators applied to small units and the requirement of high levels of precision and completeness in the collection of data. Moreover, the use of procedures of individual research assessment based on productivity leads to the fostering of quantitative-oriented publication strategies and may prevent scientists from following more innovative and risky avenues of research.

Studies of the research performance of individual scientists can be based on different sources of data: curriculum vitae (Formann, 1992; Dietz *et al*, 2000; Gaughan and Bozeman, 2002), institutional reports (Carayol and Matt, 2004), surveys and questionnaires (Hemlin and Gustafsson, 1996; Prpic, 2000) and bibliographic databases (Davis and Wilson, 2001; Bordons *et al*, 2003; Turner and Mairesse, 2004) are some of them. All these sources provide information on productivity (with different degrees of reliability and comprehensiveness), but qualitative assessment requires other methodologies such as the opinion of experts (Nederhof and Van Raan, 1987) and/or impact-based indicators (Sonnert, 1995; So, 1998). Interestingly, bibliometric indicators have proved specially adequate for the identification and study of the most prominent scientists (Davis and Wilson, 2001), and for this type of author the best correlation was found between citation analysis and expert opinion (So, 1998). However, this correlation is not always found and bibliometric indicators can complement and assist peers in their judgements but do not replace them (Van Raan, 1996). Convergence between both methods support expert decisions, while divergences indicate the need for a more detailed and careful analysis.

In spite of their limitations, micro-level studies are increasingly requested by science policy managers at centres and institutions as a support tool for science management and tenure-track decisions. The possibility of assisting the process of personnel selection or promotion in a quite objective way by using weighted bibliometric indicators has been the objective of different studies (Formann, 1992; Nicolini *et al*, 1995).

However, the difficulties of the task were clearly pointed out by Vinkler (1995), who highlighted the importance of being rigorous and the difficulties in reaching an agreement about main indicators and corresponding weights. In the meantime, gaining in-depth knowledge about the main benefits and limitations of bibliometric indicators at the micro-level is essential to enhance their adequate application and avoid misuse.

This paper shows the main results of a study of the research performance of scientists working in natural resources at the Spanish Council for Scientific Research (CSIC). This study was requested by a steering scientific committee in charge of the development and follow-up of the area at CSIC. The objective of this paper is to analyse the usefulness of micro-level studies for the assessment of the area and as a science policy instrument.

Research in natural resources and environmental sciences includes a wide array of scientific subjects. It aims to gain in-depth knowledge on natural phenomena and achieve sustained development that respects nature. Different analyses have dealt with the study of natural resources through bibliometric indicators in different countries and with different approaches (Karki, 1990; Perez Alvarez-Ossorio *et al*, 1997; Katz and Plevin, 1998; Gatto *et al*, 1999; Steele and Stier; 2000; Godin *et al*, 2002), but as far as we know it has never been analysed from a micro-level perspective.

Methodology

The Spanish Council for Scientific Research (CSIC) is the main institution in Spain devoted to research. The institutional scientific activity is carried out by more than 2,200 scientists working in more than 100 institutes distributed all over the country. The Spanish Council for Scientific Research is organised in eight scientific fields, natural resources being one of them.

Sources of data

A total of 333 permanent scientists were working at CSIC in the area of natural resources (NR) in 2002. Their names, centres, professional category and length of their professional career at CSIC were provided by the organisation. Their scientific publications were obtained from two different databases: the international database Science Citation Index, CD-ROM edition, and the Spanish ICYT (CD-ROM edition) during the years 1994–2001. No overlapping was found between the databases in the area under study and during the period analysed. All types of documents were downloaded. The ISI classification of journals in categories was considered for the subject analysis.

A careful strategy was designed to collect, exhaustively and with the highest precision, the scientific output of the scientists from the bibliographic databases. This strategy includes:

- downloading of CSIC publications identified by means of a search in the address field;
- codification and normalisation of the institutions included in the address field following a specific codification scheme developed at CINDOC (Fernandez *et al*, 1993);
- collection of NR scientists' production searching by author names. Each author name is considered linked to its institutional address to avoid confusion between different authors with the same name. Variants of scientists' names are identified. Different procedures were followed to verify the identity of doubtful authors: analysis of co-authors, subject topics and journals of publication; search for CV of scientists available in Internet, and check of data with experts.

Indicators of research performance

The activity of scientists has been described as multidimensional, since it includes research, but also other activities such as education, consultancy and administrative tasks. This paper focuses on the research dimension, which is studied from a quantitative point of view. The research performance of the scientists was analysed through the following indicators:

1. Activity indicators

- Number of international publications (ISI);
- Number of national publications (ICYT);
- Percentage of ISI publications as a measure of the international orientation of authors.

Full count, in which each document is fully assigned to each of the contributing authors, was applied. Fractional count, in which each author contributes to a fraction of the paper, is also obtained for ISI publications (for example, in a paper with five authors, one fifth was assigned to each of them). Results based on full and fractional counts were compared.

2. *Visibility indicators*, based on impact factor and citations, were obtained only for international publications.

a. Expected impact was studied through different indicators:
   - Average, minimum and maximum impact factor of publication journals, following the impact factor of journals in 2000 (Journal Citation Reports 2001). The maximum and minimum impact factor of their publication journals were recorded as a proxy of the most and least prestigious journal used by the authors. A limitation of these indicators is the well-known variation of impact factor by disciplines, so impact factor measures should be limited to intra-discipline comparisons.
   - Percentage of publications in high-impact factor journals. Considering the ranking of journals in descending order of impact factor by subject categories, those included in the first quartile of their category were described as high-impact factor journals (% documents in first quartile, %Q1). This indicator allows inter-discipline comparisons.

b. Real impact was analysed through different indicators based on the number of citations received by the documents. Citations in the period 1994–2000 to documents published in the same years were considered in the calculation of the following:
   - Number of citations per author;
   - Average number of citations per document;
   - Number of highly cited papers (HCP) per author (following Vinkler, 1995). The average number of citations per document can be misleading, since one citation per document can be obtained by author A with 50 documents each cited once, or by author B with 50 documents and 50 citations in just one paper. The number of highly cited papers per author enables us to distinguish between these situations. In this paper, highly cited papers are those documents which received more than 14 citations (5% of the most cited papers).

3. *Publication habits*: signing order of authors in the publications was studied in both databases. For every author, the percentage of documents as first, last and single-author were obtained.

For every researcher, the number of years working at CSIC as a scientist was considered as a proxy for the length of their professional career. A quite good correlation was found between age and 'years at CSIC', explained by the fact that most scientists develop their scientific career at CSIC starting from the lowest professional rank.

Results were checked by the scientific committee involved in the study, which included nine scientists with different specialisation profiles and from different centres within the institution.

The software SPSS, version 11.5, was used for the statistical analysis of data. Comparisons between means were made through tests for non parametric distributions (Kruskall–Wallis, Mann–Whitney and Wilcoxon tests). Factor analysis was used to explore the relationship among variables and, more specifically, to uncover the latent structure (dimensions) of the set of variables.

Results

A total of 3,302 documents (74%) were obtained from ISI databases and 1,183 documents (26%) from ICYT. Only 26 scientists (8%) had no ISI publications in the period under study while 84 (25%) had no ICYT publications, which indicates a high international orientation of scientists in the area. On average, each scientist published 14 documents in ISI and four in ICYT journals during the eight years studied.

Productivity

The international productivity showed a skewed distribution ranging from 0 to 114 (average = 15 documents, median = 12 documents) (Table 1 and Figure 1). A high correlation between full and fractional count was found (r=0.919), so the former was used in the rest of the document due to its easier calculation. The national productivity was also quite skewed, obtaining values from 1 to 63 documents per author in the whole period.

Significant differences were found between the ISI and ICYT distributions of scientists by productivity levels (Table 2). A higher productivity was observed in the international database. More than 60% of the scientists published at least nine documents in ISI, while this level of productivity accounted for only 17% of scientists in ICYT. More than half of the scientists had between one and eight documents in ICYT. Only 11 scientists (3%) did not show publications in any database. Around 4% of the scientists published only in ICYT, while 22%

Table 1. Scientific activity of scientists

	Average ±SD	Median	Range (Min–Max)	N
No. ISI documents				
Total count	15.00±12.75	12.00	1–114	307
Fractional count	4.76±4.08	3.73	0.10–35.59	307
No. ICYT documents				
Total count	5.77±6.37	4.00	1–63	249

Note: SD = standard deviation

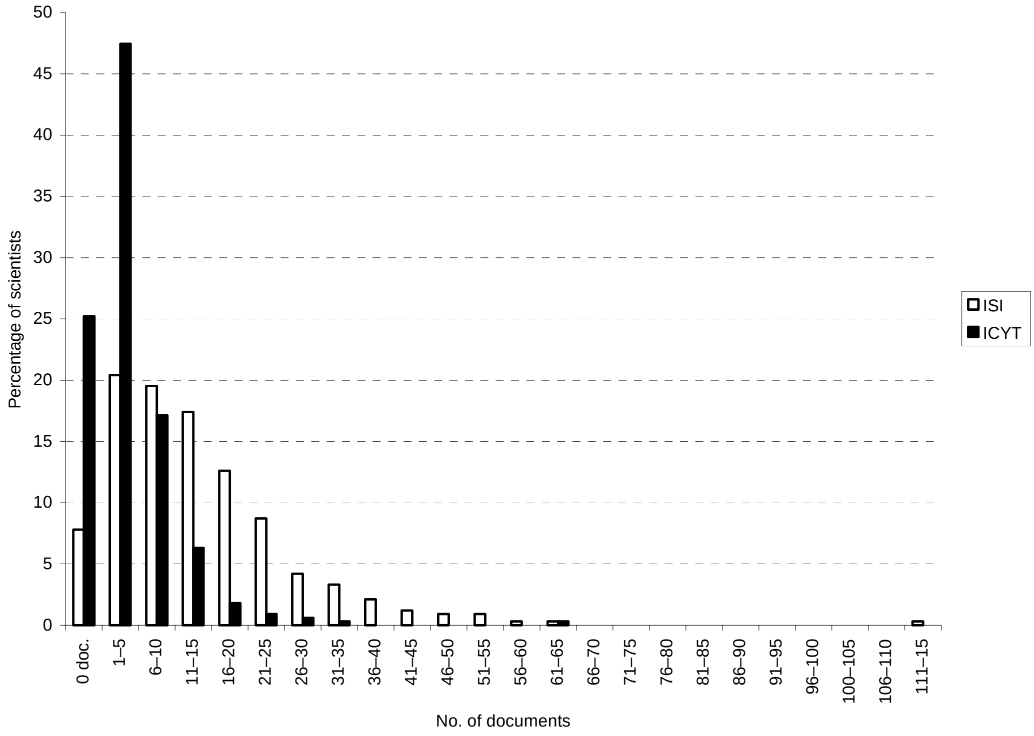

Figure 1. Productivity of scientists

published only in ISI, and 70% had publications in both databases.

Differences in productivity according to professional category were explored in both databases. ISI productivity tended to increase with professional category: from 12.17±8.85 for tenured scientists to 15.65±12.00 for research scientists and 26.16±20.13 for research professors. Significant differences were found between research professors and the other two categories ($p < 0.05$) (Figure 2). ICYT productivity was also higher in the upper category: 5.04±4.82 documents per tenured scientist, 4.11±5.72 per scientific researcher, and 8.00±10.83 per research professor; the differences between tenured scientists and research professors being significant ($p < 0.05$) (Figure 2).

International productivity tended to increase during the period from six documents per author in 1994–1997 to eight documents per author in 1998–2001. This increase was also confirmed within each professional category (Table 3). By contrast, productivity of scientists in national journals tended to decrease during the same period, especially for research scientists and research professors (Table 4).

Signing habits

Signing habits of scientists were quite similar in both databases: on average each author published 25% of their documents as first author and almost 30% as last author (Table 5). The main differences

Table 2. Distribution of scientists according to their productivity

	ISI		ICYT	
	No. scientists	**%**	**No. scientists**	**%**
0 doc.	26	7.81	84	25.23
1–8 doc.	105	31.53	193	57.96
9–16 doc.	99	29.73	45	13.51
17–24 doc.	54	16.22	7	2.10
25–32 doc.	23	6.91	2	0.60
>=33 doc.	26	7.81	2	0.60
Total	333	100.00	333	100.00

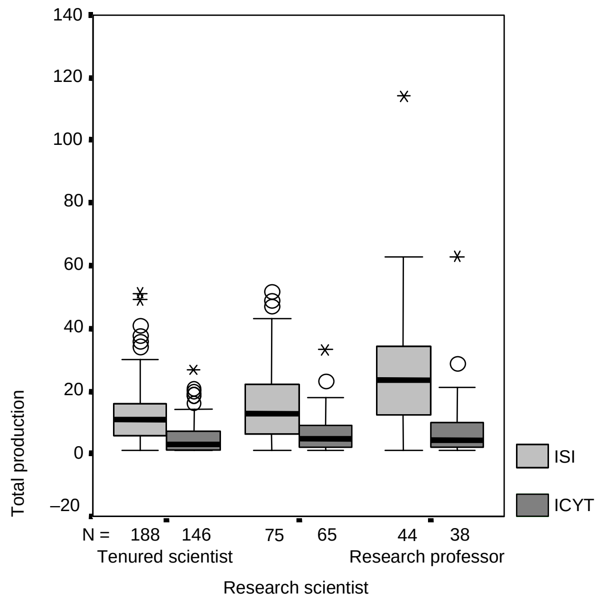

Figure 2. Productivity by professional category

Table 3. ISI productivity by professional category over time

ISI		1994–1997	1998–2001	N	Sig.
Tenured scientist	Average±SD	5.35±4.21	6.79±5.58	188	0.001
	Range (Min–Max)	0–26	0–31		
	Median	4	6		
Research scientist	Average±SD	7.07±6.06	8.55±6.77	75	0.001
	Range (Min–Max)	0–28	0–32		
	Median	7	7		
Research professor	Average±SD	11.30±9.40	14.86±11.92	44	0.001
	Range (Min–Max)	0–54	1–60		
	Median	9	12.5		
Total	Average±SD	6.63±6.03	8.38±7.59	307	0.001
	Range (Min–Max)	0–54	0–60		
	Median	5	7		

Note: significant differences calculated between periods within each category

in authorship patterns between the databases concern the percentage of single-authored documents, which was always very low but higher in the national database. Around 5% of an ISI author's production was single-authored versus 13% of their ICYT production. In ISI, 72% of the authors do not have any document signed alone. However, 80% of the authors have at least one ISI document signed as first author and 84% of the authors have signed as last author at least once. The high values of standard deviation indicate that there are large inter-author variations.

Since we know that the position in which authors sign a document can be related to their contribution to the research and their professional category, signing habits by category were calculated. Figure 3 shows there are signing habits according to professional category. Research professors tended to sign in the last position whereas tenured scientists appeared more frequently as first author of publications. This trend is especially clear in ISI: tenured scientists published as first author significantly more frequently than research professors (29% vs. 17%, $p < 0.05$), and appeared less frequently than the other two categories as last author of publications (25% for tenured scientists vs. 33% for researcher scientists and 39% for professors). Concerning ICYT, tenured scientists also signed more frequently than the remaining categories as first author (31% for tenured scientists vs. 19% for research scientists and 21% for professors), the differences between tenured scientists and research scientists being significant ($p < 0.05$). However, no significant differences were found in the national database in the trend of the three categories to sign as last author.

Table 4. ICYT productivity by professional category over time

ICYT		1994–1997	1998–2001	N	Sig.
Tenured scientist	Average±SD	2.63±2.69	2.41±2.86	146	N.S.
	Range	0–16	0–16		
	Median	2	1		
Research scientist	Average±SD	3.60±3.93	2.51±2.85	65	0.05
	Range	0–25	0–11		
	Median	2	1		
Research professor	Average±SD	5.11±6.00	2.89±5.39	38	0.001
	Range	0–35	0–28		
	Median	3.50	1		
Total	Average±SD	3.26±3.79	2.51±3.35	249	0.001
	Range	0–35	0–28		
	Median	2	1		

Note: significant differences calculated between periods within each professional category

Table 5. Signing habits of scientists in SCI and ICYT documents

Signing practices	Average±SD	Median	Min–Max	N
ISI				
% first author	25.52±21.57	21.95	0–100	307
% last author	29.00±24.00	25.00	0–100	307
% single author	4.66±12.40	0.00	0–100	307
ICYT				
% first author	26.33±31.12	20.00	0–100	249
% last author	27.48±28.13	23.08	0–100	249
% single author	13.26±25.94	0.00	0–100	249

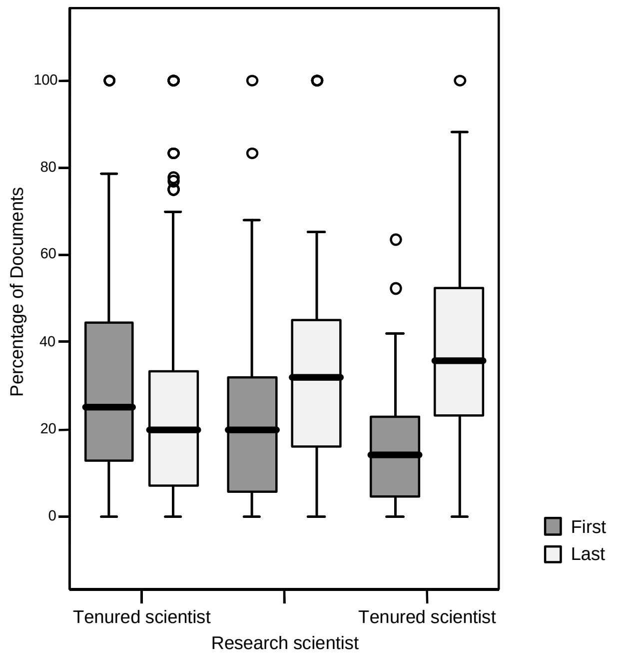

Figure 3. Signing practices by professional categories (ISI)

Impact

In relation to the visibility of publications, the average impact factor of publication journals was used as indicator of expected impact, and the number of citations received as indicator of observed impact (Table 6).

Scientists tended to prefer to publish their documents in journals in the first and second quartiles (42% and 34% respectively). The authors publish only 7% of their production in journals located in the fourth quartile. On average the scientific output of each scientist received four citations per document, but the distribution was very skewed, ranging from zero to 15 citations per document. Almost 6% of the scientists did not receive any citation and on average 35% of the documents of an author did not receive any citation in the period under study.

Research professors publish in more visible journals than the other two professional categories ($p < 0.05$), as far as impact factor is concerned. However, significant differences were not found between professional categories in the percentage of documents in journals in the first quartile (45% for research professors, 42% for research scientists and 41% for tenured scientists).

A higher observed impact was found for research professors as compared with the other professional categories. First, they obtained a higher number of citations per document (5.20±2.56 citations/documents) than the other two categories (3.73±3.02 for tenured scientists; 3.47±2.68 for research scientists, $p < 0.05$) (Figure 4), but also the lowest percentage of non-cited documents (30.07±19.00 for research professors vs. 39.35±24.14 for research scientists, $p < 0.005$) (Figure 5) and the highest number of highly cited papers.

A total of 18 authors (6%) did not receive any citation in the period under analysis. These scientists were 10 tenured scientists (5% of tenured scientists), six research scientists (8% of research scientists) and two professors (4% of research professors), the differences between categories being not significant.

A total of 119 scientists (39% of the scientists with international publications) had at least one highly cited paper. A relationship was observed between professional category and highly cited papers. Lack of highly cited papers is quite frequent among tenured scientists and research scientists, while the contrary is true for research professors: 72% of research professors do have highly cited papers vs. around 35% of scientists in the other two categories (Table 7).

Table 6. Impact indicators for natural resources scientists

Impact	Average±SD	Median	Min–Max	N
Impact factor	1.64±1.23	1.34	0.22–9.06	305
% Q1 doc.	41.76±26.25	42.86	0–100	305
No. citations	58.15±76.56	35.00	0–899	305
No. citations/doc.	3.88±2.92	3.21	0–15.44	305
% Non–cited doc.	35.27±24.36	30.77	0–100	305

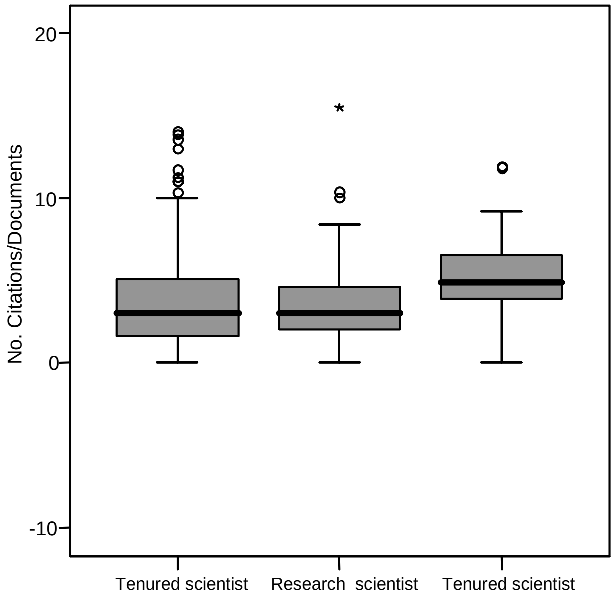

Figure 4. Citations per document by professional category

Relationship between variables

The relationship between the different indicators used was studied through factor analysis. The purpose of factor analysis is to discover simple patterns in the relationships among the variables. In particular, it seeks to discover if the observed variables can be explained largely or entirely in terms of a much smaller number of variables called *factors*. In our study we have obtained five factors, which

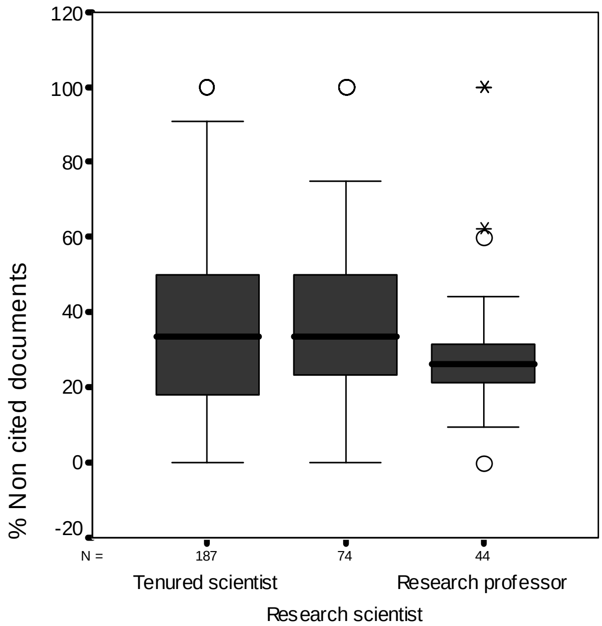

Figure 5. Percentage of non-cited documents by professional category

Table 7. Distribution of highly cited papers by professional category

	No. authors without HCP	% by categ.	No. authors with HCP	% by categ.	Total
Tenured scientist	128	68.45	59	31.55	187
Research scientist	46	62.16	28	37.84	74
Research professor	12	27.27	32	72.73	44
Total	186	60.98	119	39.02	305

accounted for 64% of the explained variance (Table 8: only factors with eigenvalues higher than 1.0 are retained). Table 8 shows the solution before and after rotation. The varimax rotation was used, since it improves the interpretability of the factors. The total percentage of variance explained is the same before and after rotation, but the eigenvalues for each of the extracted factors change. That is, after rotation each extracted factor accounts for a different percentage of variance explained, even though the total variance explained is the same.

Factor analysis generates a table (component matrix) in which the rows are the observed raw indicator variables and the columns are the factors or latent variables which explain as much of the variance in these variables as possible. The cells in this table are factor loadings, which are the correlation coefficients between the variables (rows) and factors (columns). The squared factor loading is the percentage of variance in that variable explained by the factor. Looking at Table 9, loadings above 0.6 can be considered ‘high’ and those below 0.4 are ‘low’. A minimum cut-off of 0.3–0.35 is usually required to consider a variable as a defining part of a factor. The meaning of the factors can be inferred from seeing which variables are most heavily loaded on which factors.

The first factor in Table 9 has high loadings from two variables: number of citations per document and percentage of non-cited documents, which show an inverse relationship. Moreover, the percentage of international documents, percentage of documents in the first quartile and number of highly cited papers also have moderate loadings and the number of ISI documents shows a low influence on this factor. The influence of the remaining variables on this factor is very low. This factor shows a publication strategy towards high-quality journals (first quartile), which is associated with high production, especially in international journals, and is rewarded with a high number of citations per document and highly cited papers. This strategy is not only independent of professional

Table 9. Exploring relationship among variables: rotated component matrix

	Factors				
	1	2	3	4	5
No. cit/doc.	0.791	0.277			
% Non-cited doc.	–0.784				
% International doc.	0.575			0.353	
% Doc. 1st quartile	0.537	0.399		–0.233	
HCP	0.505	0.440		0.385	
IF (max)		0.858			
IF (mean)		0.855			
Years at CSIC	–0.295		0.724		
% Doc. 1st author			–0.713		
% Doc. last author			0.668		
Category		0.422	0.650	0.266	
IF (min)	0.287			–0.767	
No. ISI doc.	0.363	0.328		0.738	
Sex					0.869
% Doc. single author	–0.251	0.254			0.538

Notes: Varimax rotation with Kaiser; only coefficients above 2.5 are reported.
HCP = highly cited papers; IF (max) = maximum impact factor of the publication journals of the authors; IF (min) = minimum impact factor of the publication journals of the authors; IF (mean) = average impact factor of the publication journals weighted by the number of documents; Sex = 1 women, 2 men; Category = 1 tenured scientists, 2 research scientists, 3 research professors.

Table 8. Variance explained

Factors	Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.52	23.50	23.50	2.55	16.97	16.97
2	2.04	13.61	37.11	2.32	15.44	32.42
3	1.56	10.37	47.47	2.04	13.57	45.99
4	1.50	10.03	57.51	1.65	10.97	56.96
5	1.03	6.87	64.38	1.11	7.42	64.38

Obtaining bibliometric indicators at the individual level is a complex endeavour due to different methodological problems but it provides an interesting overview of the research performance of scientists in a given area

category (which does not contribute to this factor), but also seems to be negatively related with years at CSIC. It seems that this strategy is more frequent among newcomers. So, we could call this factor 'Internationally oriented strategy of newcomers'.

Average and maximum impact factor values are strongly associated with the second factor, while number of highly cited papers and professional category appear moderately associated. The percentage of documents in the first quartile and the number of ISI documents show low factor loadings. In summary, this factor shows behaviour linked to category: as category increases, so ISI productivity, impact factor of journals and number of highly cited papers is higher. This factor can be called 'Publication strategy linked to professional promotion': production and visibility increases with category. It seems that HCP is more influential than number of citations per document, maybe because it is more difficult to obtain a high number of citations per document with large productivity values.

The third factor is associated with category, percentage of documents as last author and number of years at CSIC (positive loadings) as well as with percentage of documents as first author (negative loading). It can be labelled 'Signing habits'. The higher the number of years at the institution, the higher the professional category and the trend to sign as last author.

The fourth factor is strongly associated with number of ISI documents and minimum impact factor (IF min), which are inversely related. The rest of the variables show very low factor loadings. As ISI productivity increases, the minimum impact factor decreases; that is, very productive authors are less selective in their journals for publication, and they do not publish only in highly prestigious journals. This behaviour is slightly related to category.

The fifth factor is strongly associated with sex and moderately associated with percentage of single-authored documents. There is a positive relationship which indicates that men (scored as '2', compared to women scored as '1') sign less often as single author.

In summary, although professors showed the best results by means of productivity and impact measures, a collective of scientists from different professional categories with a selective publication strategy towards high-quality journals and attaining high number of citations was identified. They not only obtain HCP, but also a high number of citations per document, which is more difficult to obtain with high levels of production.

Discussion

Micro-level studies are increasingly demanded by science managers with different objectives such as monitoring research over time, making inter-area comparisons, identifying outstanding authors, grouping scientists with a similar specialisation profile, and exploring the relationship between variables in the activity of scientists. Our study indicates that obtaining bibliometric indicators at the individual level is a complex endeavour due to different methodological problems but, once it is achieved, it provides an interesting overview of the research performance of scientists in a given area. The research performance of scientists can be studied via different univariate features, such as productivity, expected impact or observed citations, but all these variables can also be considered globally through multivariate techniques. In this study both approaches — uni and multivariate — are used to describe the behaviour of scientists in the area of natural resources. The application of factor analysis enables us to unravel the hidden structure of data and to identify the relationships among activity, impact and publication habits of scientists.

Productivity

The distribution of NR scientist productivity is very skewed (is exponential), as has been previously described in different disciplines (Lotka, 1926; Huber, 2001). Most authors produce publications at a very low rate, few produce at the average rate and very few are highly productive. This study allows us to identify non-publishing scientists, detect highly productive ones, describe the national–international orientation of scientists and analyse the relationship between productivity and other performance measures.

The percentage of NR scientists without publications is very low. Only 3% of researchers had no publications over the studied period. This could be related to the fact that teaching is not compulsory among CSIC scientists, so their activity is highly oriented towards research. Moreover, it should be pointed out that this study focuses on journal articles. Therefore, other scientific output such as books or reports or even patents are not considered.

The degree of international orientation of scientists in the area, as measured through the percentage of ISI publications, is an interesting issue. Are all scientists equally involved in national publications? Can we limit our bibliometric studies to international publications, as very often occurs? Our data show that international publications predominate in the area (74%). On average each scientist publishes 70% of their production in international journals, but there is a large inter-individual variation. Moreover, there is no correlation between ISI and ICYT output per author, so the most productive scientists differ in each database, and a group of scientists that prefer to publish in national journals is identified. The publication strategy towards Spanish journals has been linked in other studies to specific research topics of special relevance for our country and not to the poor quality of their research (Rey and Martin, 1999). In fact, many of these authors are located in specific centres such as the Museo de Ciencias Naturales or Real Jardín Botánico, where some nationally oriented research lines are developed. It is clear that bibliometric studies based only on international publications will underestimate the activity of these scientists.

Our study shows that international individual productivity increases over the years, while the contrary trend is observed for national scientific output. This could indicate an increasing international orientation of research in the area, but it has been also associated with the criteria set in the 1990s in Spain for the evaluation of research activity of scientists, which give priority to international publications assuming their higher diffusion, impact and quality as compared with national ones (Jimenez *et al*, 2003). These criteria were successful in obtaining a higher visibility of Spanish scientists in the international scene, but have been criticised repeatedly due to their negative consequences on national journals, which are less and less attractive for scientists and their very survival becomes difficult. Moreover, these criteria may lead researchers to prefer internationally oriented research topics. The adequate assessment of nationally oriented scientists by experts in the field is especially needed in areas such as NR (the most nationally oriented of all CSIC natural and life sciences areas), in which local publications play an important role, and usual bibliometric indicators offer poor data.

Signing habits

The order in which the scientists appear in the byline of the papers follows different conventions depending on the fields (Cronin, 2001). In some areas the scientists appear in alphabetical order, but more frequently the position of the authors responds to the specific role played by the scientist in the development of the research (Trenchard, 1992; Trueba and Guerrero, 2004). In many areas the first author conducted the experimental work, supervised by the last author, and assisted by the authors in between (Rennie *et al*, 1997; Moed, 2000). This convention fits quite well with the results of our study. Tenured scientists sign more often as first authors, while professors tend to sign as last authors; similar results were observed in other studies (Davis and Wilson, 2001; Liang *et al*, 2004). In relation to single-authorship, it increases slightly as we go up in the professional category. It seems to be more frequent among men, probably due to the lower presence of women in the upper categories.

Research performance by category

The increase in productivity (and citations) of scientists as we go up in the professional category is an interesting finding also pointed out in other studies (Carayol and Matt, 2004; Turner and Mairesse, 2004). Especially relevant is the good performance of professors according to the bibliometric indicators used: they obtain a higher number of citations per document than the other two categories, but also the lowest percentage of non-cited documents and the highest number of highly cited papers. Professors were less likely to be non-cited and more likely to have highly cited papers. These results can be explained in three ways:

1. Bibliometric indicators verify the decisions previously taken by the experts who decided promotion to the highest category by means of the assessment of the professional career of scientists;
2. Expert opinions rely heavily — although not explicitly — on bibliometric indicators;
3. The cumulative effect can contribute to the better scientific performance of those in the highest positions (Merton, 1968; Prpic, 1996).

In any case it is clear that professional promotion is highly related to international publications. Research professors obtain the best results in international productivity and visibility.

Integrating indicators

The application of factor analysis shows the relationship among variables and discovers different patterns of behaviour of scientists in the area. Successful activity — measured in terms of number of documents, prestige of publication journals and impact obtained through citations — can be obtained in different ways. For some scientists this behaviour is linked to promotion (second factor), while for others (mainly newcomers) it is independent of category and linked to a highly internationally oriented strategy towards high-impact factor journals (first factor). As stated by Moed (2000), different publication strategies can exist in an area, which could be related to the position of scientists in the social structure of science. Fierce competition is the norm in Spain to get tenure in the CSIC, so only the 'best' obtain a permanent position, and a very selective publication strategy is needed to build a sound scientific career and get tenure. However, as the scientific career advances, scientists get involved in research management activities, and their career is not so impact factor-oriented.

Methodological problems

Our experience is that obtaining bibliometric indicators at the individual level is a complex task. It requires special care in collection of data, calculation of indicators and final interpretation of results. The participation of experts in the assignment of doubtful publications to scientists as well as in the review of final indicators is crucial to guarantee the reliability of the study and give credibility to it. As an example of the difficulties in the correct identification of scientists' publications, we can mention that even within a specific institute two scientists with the same name can co-exist, with similar research profiles from the point of view of a non-expert, but easily discriminated by an expert.

Carefully designed search strategies are needed to retrieve the publications of scientists as completely as possible. Among the main problems to be tackled we can mention the following: lack of normalisation of author and centre names; difficulties in the correct identification of scientists with very common names; and mobility of scientists with corresponding changes in address over time, which make it even more difficult to collect their scientific output under different addresses. Publications signed by scientists during temporary visits in foreign centres are especially difficult to trace, since there is no way of recognising an author as the one studied if their name is quite common. However, frequently scientists in a foreign stay include both centres in their documents, the domestic and the foreign one, so these documents can be retrieved. In our study, publications by scientists signed during their stay in a foreign centre were considered only if the Spanish address was recorded.

Problems concerning the correct identification of scientists' publications could be minimised if the curriculum vitae of the scientists were available as a source of data for these types of studies. If that were the case, the completeness of the data could be guaranteed since the risk of incorrect identification of author publications would be avoided. However, although scientists increasingly tend to make their curriculum available on the Internet, this is not yet generalised. Moreover, important problems have been described in the management of these *curriculum vitae* which are not normalised either in format or in content (Dietz *et al*, 2000). An important prerequisite to assure valid and reliable bibliometric studies at the micro-level in the future is the development of normalised curricula of scientists by institutions.

Because of all these difficulties, the bibliometric profile of individual scientists should be managed with caution, supervised by experts and complemented with other indicators. A certain margin of error in the results can be expected if the indicators were obtained without the support of the CV of scientists. This margin of error is well known and assumed in macro-level studies, but it becomes more relevant at the micro-level. However, we think that it does not invalidate these types of studies, although it limits their applications. Micro-level studies can give support to committees and experts in their decisions concerning scientific management of centres and areas or in the assessment of the research performance of individual scientists, if combined with other types of indicators. It is strongly recommended not to take decisions relying only on bibliometric indicators, but in combination with other input and output data it can be very fruitful. Moreover, the aggregated analysis of individual bibliometric profile of scientists is an interesting application which provides a general overview of the behaviour of scientists in a given area.

Acknowledgements

We would like to thank Spanish experts in natural resources, especially Joaquín Tintoré and Xavier Bellés, for their interest and comments during the development of the study. We are grateful to Laura Barrios for her valuable statistical assistance. Rodrigo Costas completed this study thanks to an I3P grant at CINDOC.

References

M Bordons, F Morillo, M T Fernandez and I Gomez (2003), 'One step further in the production of bibliometric indicators at the micro-level: differences by gender and professional category of scientists', *Scientometrics*, 57(2), pages 159–173.

N Carayol and M Matt (2004), 'Does research organization influence academic production? Laboratory level evidence from a large European university', *Research Policy*, 33(8), pages 1081–1102.

B Cronin (2001), 'Hyperauthorship: a postmodern perversion or evidence of a structural shift in scholarly communication practices?', *Journal of the American Society for Information Science and Technology*, 52(7), pages 558–569.

M Davis and C S Wilson (2001), 'Elite researchers in ophthalmology: aspects of publishing strategies, collaboration and multidisciplinarity', *Scientometrics*, 52(3), pages 395–410.

J S Dietz, I Chompalov, B Bozeman, E O'Neil Lane and J Park (2000), 'Using the curriculum vitae to study the career paths of scientists and engineers: and exploratory assessment', *Scientometrics*, 49(3), pages 419–442.

M T Fernandez, A Cabrero, M A Zulueta and I Gómez (1993), 'Constructing a relational database for bibliometric analysis', *Scientometrics*, 3(1), pages 55–62.

A K Formann (1992), 'Academia personnel selection: description and prognosis of the decisions made by the committee for the selection and candidates for a full professorship', *Scientometrics*, 25(3), pages 401–414.

M Gatto, G D Leo and G Paris (1999), *Il 'Chi e' della ricerca ambientalle in Italia: valutazione statistica della produzione scientifica italiana nel settore ambientale* (Fondazione Lombardia per l'Ambiente, Milan). <http://www.flanet.org/download/publications/marinogatto.pdf> last accessed 7 January 2005.

M Gaughan and B Bozeman (2002), 'Using curriculum vitae to compare some impacts of NSF research grants with research center funding', *Research Evaluation*, 11(1), pages 17–26.

B Godin, F Trempe-Bertrand, J P Robitaille and G Cote (2002), *Bibliometric Profile of Environmental Science in Canada: 1980–1998* (Observatoire des sciences et des technologies, Quebec). <http://www.ost.qc.ca/OSTE/pdf/rapports/2002/Env_Can_105_EN.pdf> last accessed 7 January 2005.

S Hemlin and M Gustafsson (1996), 'Research production in the arts and humanities: a questionnaire study of factors influencing research performance', *Scientometrics*, 37(3), pages 417–432.

J C Huber (2001), 'A new method for analyzing scientific productivity', *Journal of the American Society for Information Science and Technology*, 52(13), pages 1089–1099.

E Jimenez, F D Moya and E Delgado (2003), 'The evolution of research activity in Spain: the impact of the National Commission for the Evaluation of Research Activity (CNEAI)',

Research Policy, 32(1), pages 123–142.
M M S Karki (1990), ‘Environmental science research in India: an analysis of publications’, *Scientometrics*, 18(5–6), pages 363–373.
J S Katz and J Plevin (1998), ‘Environmental science in the UK: a bibliometric study’, *Research Evaluation*, 7(1), pages 39–52.
L Liang, J Liu and R Rousseau (2004), ‘Name order patterns of graduate candidates and supervisors in Chinese publications: a case study of three major Chinese universities’, *Scientometrics*, 61(1), pages 3–18.
A J Lotka (1926), ‘The frequency distribution of scientific productivity’, *Journal of the Washington Academy of Science*, 16, pages 317–323.
R K Merton (1968), ‘The Matthew effect in science’, *Science*, 159, pages 56–63.
H F Moed (2000), ‘Bibliometric indicators reflect publication and management strategies’, *Scientometrics*, 47(2), pages 323–346.
A J Nederhof and A F J van Raan (1987), ‘Peer review and bibliometric indicators of scientific performance: a comparison of cum laude doctorates with ordinary doctorates in physics’, *Scientometrics*, 11(5-6), pages 333–350.
C Nicolini, S Vakula, M Italo Balla and E Gandini (1995), ‘Can the assignment of university chairs be automated?’, *Scientometrics*, 32(2), pages 93–107.
J R Perez Alvarez-Ossorio, M J Martin Sempere, M T Fernandez, M Vazquez, C Galban, L Plaza, I Aguillo, C Ronda, A Cabrero, S Hernando and I Gomez (1997), ‘Analisis de la producción científica española en ecología y medio ambiente, 1989–1993’, *Revista Española de Documentación Científica*, 20(4), pages 363–375.
K Prpic (1996), ‘Characteristics and determinants of eminents scientists’ productivity’, *Scientometrics*, 36(1), pages 185–206.
K Prpic (2000), ‘The publication productivity of young scientists: an empirical study’, *Scientometrics*, 49(3), pages 453–490.
D Rennie, V Yank and L Emanuel (1997), ‘When authorship fails: a proposal to make contributors accountable’, *Journal of the American Medical Association*, 278(7), pages 579–585.
J Rey and M J Martin (1999), ‘The role of domestic journals in geographically-oriented disciplines: the case of Spanish journals on earth sciences’, *Scientometrics*, 45(2), pages 203–216.
C Y K So (1998), ‘Citation ranking versus expert judgment in evaluating communication scholars: effects of research specialty size and individual prominence’, *Scientometrics*, 41(3), pages 325–333.
G Sonnert (1995), ‘What makes a good scientist?: determinants of peer evaluation among biologists’, *Social Studies of Science*, 25, pages 35–55.
T W Steele and J C Stier (2000), ‘The impact of interdisciplinary research in the environmental sciences: a forestry case study’, *Journal of the American Society for Information Science*, 51(5), pages 476–484.
P M Trenchard (1992), ‘Hierarchical bibliometry: a new objective measure of individual scientific performance to replace publication counts and to complement citation measures’, *Journal of Information Science*, (18), pages 69–75.
F J Trueba and H Guerrero (2004), ‘A robust formula to credit authors for their publications’, *Scientometrics*, 60(2), pages 181–204.
L Turner and J Mairesse (2004), ‘Individual productivity differences in public research: how important are non individual determinants? An econometric study of French physicists’ publications and citations (1986–997)’, in *Workshop: The Empirical Economic Analysis of the Academic Sphere* (Louis Pasteur University, Strasbourg), <http://cournot2.u-strasbg.fr/EEAAS/turner_mairesse.pdf> last accessed 12 January 2005.
A F J van Raan (1996), ‘Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises’, *Scientometrics*, 36(3), pages 397–420.
P Vinkler (1995), ‘Some aspects of the evaluation of scientific and related performances of individuals’, *Scientometrics*, 32(2), pages 109–116.