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Quantifying the internationality and multidisciplinarity of authors and journals using ecological statistics

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Abstract Authors or journals often claim internationality or multidisciplinarity based on assertion or qualitative evidence, while scientometric studies employ sophisticated analyses or software beyond the resources of occasional users to assess these concepts. This paper demonstrates how statistics used to describe ecological communities can be applied to bibliometric data to quantify internationality or multidisciplinarity for individuals and journals, enabling tests of statistical significance using graphical user interface freeware accessible to even occasional users. *Margalef Richness*, *diversity* and *evenness* or *equitability* can be calculated to indicate whether papers or citations come predominantly from a small group of countries or disciplines, or are more widely distributed. Tests of statistical significance for differences in Margalef richness, diversity or evenness between authors or journals enable testing of diverse hypotheses including, for example: differences in internationality or multidisciplinarity between authors or between journals; or changes over time in these variables for authors or journals (perhaps in response to career changes or changes in editorial policy). Quantifying internationality and multidisciplinarity in an accessible way for many potential users, with the possibility of statistical hypothesis testing, is a significant advance over assertion and qualitative description on the one hand or conceptually and practically complex analysis on the other.

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Introduction

Interpretations of what internationality means in terms of a body of research differ, as do the criteria used to measure it (Gazni and Ghaseminik 2016). At its simplest, some measures have used the basic criterion of the research involving two or more countries (the Scimago Lab, http://www.scimagoir.com/index.php; and % international collaboration in Niu et al. 2014). Discriminating the degree of internationality (Perakakis et al. 2006) is more involved and, for journals, that has included criteria such as quantifying the multinational distribution of publishing authors, citing authors (including co-authorship linkages), subscribers, readers (now much more readily accessible via download data, e.g. Bollen et al. 2009) and editors (Zitt and Bassecoulard 1998; Ren and Rousseau 2002; Buela-Casal et al. 2006; Calver et al. 2010; Ding et al. 2012), or increases in English language papers in national journals of non-English speaking countries (Fernández-Quijada 2011; Pajić and Jevremov 2014). Multivariate approaches come closest to identifying all nuances of the topic, but can be time-consuming and difficult to execute (Buela-Casal et al. 2006; Calver et al. 2010). Thus, despite efforts at quantifying internationality for journals or authors a quick, easily interpreted indicator suitable for statistical hypothesis testing and useful for bibliometricians and occasional users remains elusive.

A quick index is also elusive for multidisciplinarity, in which understandings are taken from multiple disciplines in a study that stays within its own disciplinary boundaries, as distinct from interdisciplinarity that synthesises insights from different disciplines or transdisciplinarity that transcends conventional disciplinary divides to create an entirely new context (Choi and Pak 2006; Wagner et al. 2011). We focus on multidisciplinarity because it is the simplest of the concepts and therefore ought to be easiest to measure, while acknowledging the extensive work on seeking quantitative measures of the more advanced concept of interdisciplinarity (e.g. Wagner et al. 2011; Larivière and Gingras 2014; Rodríguez 2017). Assessments of multidisciplinarity often rely on the classification of a journal into the category 'multidisciplinary' in one of the major databases Web of Science (WoS) or Scopus (e.g. González-Alcaido 2014), or descriptive counting of papers across a range of disciplinary classifications (e.g. Ho et al. 2013). Keywords analyses, which seek to identify patterns in the use of keywords across papers, offer some insights into particular combinations of discipline-related keywords in certain journals (Niu et al. 2014), but still fall short of a quick, quantitative index. One approach could be to use the percentage of papers (or journals) that are cited in a paper's (or journal's) reference list that are classified in a different discipline or speciality (an adaptation of the method used by Larivière and Gingras 2014 to assess interdisciplinarity, see also the review of Wagner et al. 2011). It could also be used for citations received. Thus, as for internationality, it would be helpful to have a simple method of quantification of multidisciplinarity available to a wide range of users.

Arguably, one of the most useful indicators in both cases would be the international or multidisciplinary usage and influence of the research. As such, citation data measure at least part of the uptake and use of publications, albeit with some caveats (MacRoberts and

MacRoberts 1996, 2010; Calver 2015). These data could then be analysed according to the country or discipline in which they are being used.

Several authors including Calver et al. (2010), Rafols and Meyer (2010), Zhou et al. (2012), Soós and Kampis (2012), Appio et al. (2014, 2016) and Karlovčec and Mladenić (2015) have argued that bibliometric data are analogous to ecological communities, so that techniques adapted from community ecology can be used to describe and analyse them. Community ecologists summarise complex data on the number and relative abundance of species in statistics such as richness (the number of species, often with a correction for sampling intensity), diversity (the relative distribution of individual organisms across species) and evenness or equitability (diversity standardised to a 0–1 scale where 1 represents the maximum diversity possible in the sample). These are used to describe and compare communities, or to determine the effects of environmental perturbations or gradients on community structure in time and space. Applying the concept to bibliometrics, citations to papers in a journal or to an author can be profiled to determine:

- the number of countries of affiliation of the citing authors (richness, with or without a correction for sampling intensity),
- the relative numbers of citing authors from different countries (diversity) and,
- the evenness of the distribution of citations across countries representing citing authors.

These data would quantify the degree of internationality of the journal's or author's citations as a measure of global usage of the research. A similar exercise could be conducted using the subject category of the citing papers rather than the country of affiliation, thereby quantifying multidisciplinarity in the usage of the research as measured using citations.

Given that many of the applications to date for quantifying internationality or multidisciplinarity are conceptually or computationally complex, which is a deterrent to widespread adoption, in this paper we seek to broaden applications of ecological statistics, based on accessible applications of computer graphical user interface (GUI) freeware. Our focus is explicitly on the absolute values measured for individual authors and journals, rather than establishing relative or baseline values for internationality or interdisciplinarity that might apply to broad groups of authors or disciplines. We aim to provide user-friendly approaches for:

(i) hypothesis testing of author statistics, using the examples of comparing the international and multidisciplinary influence of authors (as defined above), and whether or not an author's internationality has changed during a career;
(ii) hypothesis testing of journal statistics, using the example of whether or not a change in a journal's editorial policy increased the journal's international profile or multidisciplinary influence (as defined above).

In each case, we seek to demonstrate an approach that individual researchers or journal editors can apply to evaluate hypotheses using freely available, user-friendly tools.

Methods

Ecological statistics applicable to analysing internationality and multidisciplinarity

One measure of an author's or journal's international or multidisciplinary influence is to determine the range of countries or subject categories represented in citations to the author's work or citations to papers in the journal over a given time range. Succinct numerical summaries can be made using richness (the number of countries or subject categories represented, Appio et al. 2014, 2016), diversity (considering not only the range of countries or disciplines but also the distribution of records across them, Soós and Kampis 2012; Karlovčec and Mladenić 2015) and evenness statistics (diversity converted to a 0–1 scale, where 1 is the maximum value diversity can assume under the conditions of the study, Appio et al. 2014, 2016) (see Table 1 for descriptions of each statistic and its application in bibliometrics).

Table 1 Ecological statistics listed with their applications in bibliometrics

Ecological statistic	Application in bibliometrics
Species Richness—the number of species present in an ecological community. In some cases, all the species can actually be counted, but in others an estimate of species richness must be made on the basis of samples. In the latter case a correction is needed for sampling intensity if comparisons are made between different communities where the sampling intensity was not equal (Krebs 1999)	The analogy of species richness is the number of countries or subject categories represented in the citations to the work of an author or the papers in a journal over a defined time period. To correct for sample size effects, richness is often represented as Margalef's richness index (MR $= S - 1/\ln(n)$ (where S is the number countries or subject categories represented and n is the total number of citing authors or subject categories)) (Hammer and Harper 2006). It is important to use the observed values, not summary ratios or percentages
Species Diversity—this depends not only on the number of species in the community, but also their relative abundance. Thus it can distinguish between the situation where most individuals in a community belong to one species and the situation in which individuals are more evenly distributed across the species Krebs 1999; Hammer and Harper 2006)	Diversity is assessed most commonly with the Shannon-Weiner statistic (H'), which considers not only the range of countries or disciplines but also the distribution of records across countries or disciplines ($H' = -\Sigma p_i(\log_2 p_i)$ (where $p_i =$ the proportion of citing authors from country i or discipline i)) (Krebs 1999, see Rafols and Meyer (2010), Zhou et al. (2012) for alternative diversity statistics applied in some bibliometric studies). Although H' was presented originally using logarithms to base 2, any base of logarithms can be used. Therefore it is important to know the base used when comparing results from different studies
Evenness—for ease of interpretation, species diversity can be converted to a 0–1 scale by dividing the observed species diversity for a community by the maximum species diversity possible if the individuals present were distributed equally across all species Krebs 1999; Hammer and Harper 2006)	Interpretation of diversity is aided by calculating evenness, defined as: $J = H'/H'\max$ (where $H'\max =$ the highest value H' can assume when citing authors are distributed equally across countries or subject categories) (see Krebs 1999 for a derivation based on ecological community data)

Hypothesis testing: comparing internationality and multidisciplinarity for three authors

We consider three real authors (anonymised as Authors 1, 2 and 3). Author 1 has a publishing history from 1976 to 2013, Author 2 from 1985 to 2014, and Author 3 from 1986 to 2014. The analysis is based on citations to their work.

Both the Cited Reference Search in the Web of Science (Core Collection) (hereafter WoSCRS) and Scopus can profile the country of origin of citing authors (called countries/territories in WoSCRS and country in Scopus) and the subject categories of citing papers (called Web of Science categories in WoSCRS and subject area in Scopus), providing the raw data for such an analysis (see "Appendices 1 and 2" for descriptions of search techniques in each database). Note that WoSCRS also offers a classification of subject areas called research categories, within which the finer grain Web of Science categories are nested. We have used the Web of Science categories for our analyses. We base the analysis on WoSCRS, because at the time of data collection (August 2014) Scopus did not claim to have complete citation data earlier than 1996 [although there is a project to extend this to 1970 (Elsevier 2016)], whereas the WoS subscription available to us covered all years when the target authors published.

For both the countries (internationality) and subject categories (multidisciplinarity) of the citations we calculated Margalef richness, Shannon diversity and evenness from the WoSCRS output using the options in the diversity menu in the freeware PAST V 3.01 (Hammer et al. 2001, available for download from http://folk.uio.no/ohammer/past/) (note that PAST refers to evenness as defined here as equitability, and that it calculates Shannon diversity using natural logarithms rather than log to the base 2). PAST also uses bootstrapping routines to calculate 95% confidence limits for diversity and evenness (Hammer and Harper 2006, Chapter 6.2).

Data from WoSCRS present two limitations when applying diversity statistics. Firstly, the record counts include only unique countries for the authors in each citation (i.e. multiple authors from the same country are entered only once for each citation). Ideally, the country of each citing author should be noted, although this would require checking each individual citation. Secondly, the database may not give the affiliation of each author in a citing paper. These issues do not apply to the results for subject category, because every citing paper is in the WoS (Core Collection) and almost all are allocated to one or more subject areas, all of which appear in the output.

We assessed the consequences of these biases for assessing internationality by selecting a random sample of 100 papers citing Author 1's publications. We then compared the H' and evenness calculated from the standard WoSCRS output with those calculated by checking each citation individually and noting the country of each citing author (if necessary, going to a hard copy of the original document or locating the document online). We found two cases where an author gave affiliations in two countries. Rather than count both, we included only the first mentioned country. Margalef richness, Shannon diversity and evenness for these two samples were compared using the 'compare diversities' option in the diversity menu in PAST. This tests for a significant difference between the two samples of the country-affiliation of the citing authors for each variable using a permutation technique (Hammer and Harper 2006, Chapter 6.4).

We also compared Margalef richness, Shannon diversity and evenness for the internationality and multidisciplinarity of Authors 1, 2 and 3 using PAST. Significance values

for paired comparisons were set at 0.017 (Bonferroni correction) because of the multiple tests.

Hypothesis testing: has an author changed in internationality of his publications over time?

We consider the case of Author 3, whose work has shifted from a predominantly regional focus to consideration of global issues. We predict that his citations should show an increase in internationality over his career in line with this shift. To test this, we grouped his publications into the categories 1986–1996, 1997–2006 and 2007–2012 (excluding more recent papers on the grounds that they had considerably less time to accrue citations). These periods corresponded to when Author 3 made deliberate changes to publication direction, and therefore indicate a personal concern rather than a theoretical abstract. We profiled the international citations for the papers published in each period using WoSCRS. We then compared Margalef richness, Shannon diversity and evenness between pairs of categories using PAST, predicting that these statistics should be higher in the last two periods relative to the first. We set the p value for significance testing at 0.017 (Bonferroni correction) to allow for the multiple comparisons.

Hypothesis testing: evaluating a prediction regarding journal internationality and multidisciplinarity

To illustrate the use of ecological statistics to test hypotheses regarding journals, we evaluated a case of the impact of a change in journal editorial policy. In 2009, the editorial board of the journal *Wildlife Research* amended editorial polices to broaden the '… topical, disciplinary and geographical coverage' and aspire to being '… one of the leading international journals in applied ecology and environmental management' (White et al. 2009). We predicted that if the changes were successful, then (i) the richness, diversity and evenness of international and subject category citations received by *Wildlife Research* in the 5 years following the reform (2010–2014) should be greater than those received in the 5 years preceding it (2004–2008), and (ii) richness, diversity and evenness of international and subject category citations received by three other journals publishing similar material but not making the same change in policy (*Pacific Conservation Biology*, *Australian Zoologist* and *Australian Journal of Zoology*) should not have increased when comparing their citations between the same periods.

We profiled the international citations and the subject category citations of each journal in each year range using Scopus because the approach is simpler than for the WoSCRS, the year ranges in question are covered in Scopus, and Scopus lists all the journals under investigation (see "Appendices 1 and 2" for details on how to profile citations by country of citing author and discipline of citing journal). We then compared Margalef richness, Shannon diversity and evenness between the year ranges for each journal using PAST.

Results

Data files for all analyses are provided in Excel format in Online Supplementary Tables 1 and 2.

Hypothesis testing: comparing internationality and multidisciplinarity for three authors

Superficially, the absence of data on the country of origin of citing authors in some citations appeared only a small problem: the percentage of citing papers containing no author affiliation details at all is given in the WoSCRS output, and was less than 1.5% for all our analyses (Table 2). However, affiliations are not necessarily available for every author, even though there may be affiliations for a subset of authors in the address field. This was shown clearly for the random sample of 100 of Author 1's citations when comparing the number of country records for citing authors from the WoSCRS output with a complete data set obtained by examining each individual citing-paper; the number of citing authors assigned to a country more than doubled (Table 2). WoSCRS only gave affiliations of all authors for 47 documents published in 2007 or later. For 40 papers published between 1998 and 2006 only unique addresses were given (for example, if there were four authors all from the same address and a fifth author from a different address, only two addresses would be given with no indication of which address went with which author). Therefore, if the number of authors exceeded the number of addresses, it was unclear from the WoSCRS output how many authors should be allocated to each address. Prior to 1998, only an address for reprints was given for some papers and only unique addresses for others, so complete coverage of affiliations only occurred for a subset of papers. Margalef richness (but not uncorrected richness), H' and evenness were lower when the country of each citing author was considered (Table 2), although the difference between the two samples for these measures was not statistically significant using permutation approaches ($p = 0.078$, $p = 0.165$ and $p = 0.126$ respectively).

Table 2 Summary statistics for the evaluation of the international profiles of three authors, based on the country of origin of people citing their papers

Author or journal	Sum of citing authors assigned to a unique country for each citation	% Records with no data on citing authors' countries	Richness (*N* of countries)	Margalef richness	Diversity (H')	Evenness
Author 1[1]	1743	0.94	59	7.77	2.67 (2.60–2.75)	0.65 (0.65–0.69)
Author 1[2]	116	1.40	27	5.47	2.61 (2.34–2.74)	0.79 (0.75–0.85)
Author 1[3]	286	0.94	27	4.60	2.39 (2.22–2.49)	0.72 (0.70–0.77)
Author 2	548	1.42	37	5.71	2.04 (1.96–2.20)	0.57 (0.54–0.61)
Author 3	1097	0.75	73	10.29	2.50 (2.36–2.58)	0.58 (0.57–0.62)

For diversity and evenness, 95% confidence limits calculated by bootstrapping are indicated in parentheses. Statistics for Author 1 were calculated three ways: (1) based on the complete citations and using the uncorrected output from WoSCRS; (2) based on a random sample of 100 citations and using the uncorrected output from WoSCRS; and (3) based on a random sample of 100 citations and checking the national affiliation of each citing author manually in the WoS records or from the actual papers

With regard to the internationality of authors citing Authors 1, 2 and 3 (using the full WoSCRS dataset in each case), permutation tests showed that Authors 1 and 3 had a significantly greater Margalef richness and diversity of countries than Author 2 ($p < 0.001$ in both comparisons). Author 3 had a significantly greater Margalef richness of countries than Author 1, but a significantly lower diversity and evenness ($p < 0.001$ in all comparisons) (see Table 2 for data).

There were only two significant differences when considering the multidisciplinarity of papers citing these authors: Author 3 had a higher Shannon diversity than Author 2 ($p < 0.001$), and Author 3 had a higher evenness than Author 1 ($p = 0.012$). Otherwise, for all comparisons $p \geq 0.041$, above the significance level of 0.017 after Bonferroni correction (see Table 3 for data).

Hypothesis testing: evaluating changes in internationality of an author's publications over time

As predicted, citations to Author 3's work increased significantly in Shannon diversity and evenness over the three-year groupings. Margalef richness increased from 1986–1996 to 1997–2006, but not from 1997–2006 to 2007–2012 (Table 4).

Hypothesis testing: evaluating predictions regarding journal internationality and multidisciplinarity

In keeping with our prediction that changed editorial policy would broaden the international use of *Wildlife Research* in 2010–2014 relative to 2004–2008, the journal significantly increased the Shannon diversity and evenness of its citations from different countries, although the Margalef richness of countries was not significantly different (Table 5). This was not a general trend, because *Pacific Conservation Biology* and *Australian Zoologist* experienced no change in the Margalef richness, Shannon diversity and evenness of their citations from different countries over the same period while *Australian Journal of Zoology* declined in Margalef richness and Shannon diversity, but not in evenness (Table 5).

Table 3 Summary statistics for the evaluation of the multidisciplinary profiles of three authors, based on the subject area category of publications citing their papers

Author or journal	Sum of unique subject categories for each citing paper	% Records with no data on the subject category	Richness (*N* of subject categories)	Margalef richness	Diversity (H')	Evenness
Author 1	2173	0.272	64	8.20	2.55 (2.47–2.59)	0.61 (0.61–0.65)
Author 2	811	0.401	46	6.72	2.40 (2.27–2.49)	0.63 (0.62–0.67)
Author 3	1353	0.628	62	8.46	2.71 (2.61–2.76)	0.66 (0.65–0.69)

For diversity and evenness, 95% confidence limits calculated by bootstrapping are indicated in parentheses

Table 4 The richness (Margalef richness), Shannon diversity and evenness of the country of origin of authors citing papers by one author in the periods 1986–1996, 1997–2006 and 2007–2012

Sum of citing authors assigned to a unique country for each citation	Measure	1986–1996 *A*	1997–2006 *B*	2007–2012 *C*	p ($A \times B$)	p ($A \times C$)	p ($B \times C$)
158	Richness (Margalef richness)	10 (1.78)	54 (8.63)	51 (8.00)	< 0.001 (< 0.001)	< 0.001 (< 0.001)	< 0.523 (< 0.211)
465	Shannon diversity	0.76	2.29	2.75	< 0.001	< 0.001	< 0.001
529	Evenness	0.33	0.57	0.70	< 0.001	< 0.001	< 0.001

The significance of comparisons for each statistic between paired periods is given as a p-value determined by permutation, with a significance level of 0.017 to allow for multiple comparisons

Table 5 The richness (Margalef richness), Shannon diversity and evenness of the country of origin of authors citing papers from four journals in the period 2004–2008 compared to 2010–2014

Journal	Sum of citing authors assigned to a unique country for each citation 2004–2008 (2010–2014)	Measure	2004–2008	2010–2014	Permutation p
Wildlife Research	4403 (1412)	Richness (Margalef richness)	104 (12.28)	78 (10.62)	0.517 (0.54)
		Shannon diversity	2.38	2.83	0.001
		Evenness	0.51	0.65	0.001
Pacific Conservation Biology	1185 (224)	Richness (Margalef richness)	65 (9.04)	34 (6.10)	0.518 (0.532)
		Shannon diversity	2.10	2.13	0.878
		Evenness	0.50	0.60	0.115
Australian Zoologist	433 (167)	Richness (Margalef richness)	35 (5.60)	19 (3.52)	0.092 (0.092)
		Shannon diversity	1.40	1.35	0.795
		Evenness	0.39	0.46	0.255
Australian Journal of Zoology	2363 (416)	Richness (Margalef richness)	76 (9.66)	34 (5.47)	0.008 (0.008)
		Shannon diversity	2.30	1.86	0.003
		Evenness	0.53	0.53	0.999

The significance of comparisons for each statistic for each journal between the two periods is given as a *p* value determined by permutation

The prediction of increased multidisciplinarity in citations to *Wildlife Research* in 2010–2014 relative to 2004–2008 was not supported, with no statistically significant differences in Margalef richness, Shannon diversity or evenness of subject category citations. The same was true for *Australian Journal of Zoology*, while *Pacific Conservation Biology* and *Australian Zoologist* showed increases in Shannon diversity and evenness, but not in Margalef richness, of subject area citations (Table 6).

Idiosyncrasies noticed during analyses

In conducting our analyses, we noted idiosyncrasies arising from political change and the policies of Scopus and WoS in relation to recognising national affiliations and classification of disciplines. These are listed, with implications, in Table 7.

Table 6 The richness (Margalef richness), Shannon diversity and evenness of subject area classification of papers citing publications in four journals in the period 2004–2008 compared to 2010–2014

Journal	Sum of citing documents assigned to a subject category 2004–2008 (2010–2014)	Measure	2004–2008	2010–2014	Permutation p
Wildlife Research	5386 (1623)	Richness (Margalef richness)	25 (2.79)	22 (2.84)	0.503 (0.991)
		Shannon diversity	1.48	1.50	0.487
		Evenness	0.46	0.49	0.156
Pacific Conservation Biology	1375 (271)	Richness (Margalef richness)	21 (2.77)	15 (2.50)	0.718 (0.742)
		Shannon diversity	1.42	1.76	0.001
		Evenness	0.47	0.65	0.001
Australian Zoologist	540 (214)	Richness (Margalef richness)	13 (1.91)	13 (2.24)	1.000 (0.16)
		Shannon diversity	1.36	1.60	0.023
		Evenness	0.53	0.62	0.023
Australian Journal of Zoology	2627 (488)	Richness (Margalef richness)	23 (2.79)	17 (2.58)	0.616 (0.700)
		Shannon diversity	1.58	1.51	0.264
		Evenness	0.50	0.53	0.817

The significance of comparisons for each statistic for each journal between the two periods is given as a *p* value determined by permutation

Discussion

The validity of applying ecological statistics to studying internationality and multidisciplinarity

The procedures reported here allow individuals to provide evidence of the international or multidisciplinary reach of their work, or editors to demonstrate the international or multidisciplinary use of their journals. However, to be taken seriously they must possess the three properties Gingras (2014, p. 112) considered essential for a valid indicator:

1. Adequacy of the indicator for the object it measures.
2. Sensitivity to the intrinsic inertia of the object measured.
3. Homogeneity of the dimensions of the indicator.

With regard to the first property, we argue that the range of country affiliations or subject categories represented in citations to a body of publications is a reasonable measure of their international or multidisciplinary appeal, especially if a correction for sample size

Table 7 Idiosyncrasies arising from political change and the policies of Scopus and WoS in relation to recognising national affiliations and classification of disciplines

Idiosyncrasy	Implication
Change in national affiliation	It may be necessary to consider how to handle changes in national affiliation, such as the case of Czechoslovakia dividing into the Czech Republic and the Slovak Republic in 1993. The simplest solution may be to manually merge the countries created by the split to ensure that data are classified similarly across the entire range. We also note that WoSCRS records the members of the United Kingdom (England, Scotland, Wales and Northern Ireland) separately, which will inflate Shannon diversity and Margalef richness relative to combining them into a single count as the United Kingdom, as is the practice in Scopus
Variation in year ranges in the databases	Choosing Scopus or WoSCRS for analysis will depend on the year range in question. Scopus covers a broader range of journals than WoS, albeit over a narrower range of years (although Scopus is expanding its date range from 1996 back to 1970 (Elsevier 2016) and WoS is increasing its coverage of regional journals)
Variation in subject classifications in the databases	Scopus and WoSCRS also have very different ranges of subject area classifications (see http://service.elsevier.com/app/answers/detail/a_id/12007/supporthub/publishing/related/1/, Elsevier (2016) and http://images.webofknowledge.com/WOKRS56B5/help/WOS/hp_subject_category_terms_tasca.html, respectively). Thus analyses of subject category are not comparable between them

is incorporated to allow for the expected increase in the value as more papers/citations are sampled. Margalef richness meets this criterion. Thus the more countries or subject categories represented in the citations to an author's work (after correction for sample size), the more international or multidisciplinary is that author's profile. Of course, richness itself gives no indication of the relative abundance of citations across countries or subject categories, so diversity and evenness quantify this important consideration. For authors with similar richness, those with a greater diversity or evenness of citations across countries or subject areas have a greater international or multidisciplinary influence because their citations are spread more evenly across countries or subject categories. In the case of Authors 1 and 3 in this study, Author 3 had a greater Margalef richness of countries amongst the citations, but Author 1 had a more even distribution of citations across countries. This interpretation does, though, assume accuracy in literature searches and also in the databases used—both points that may be problematic and need to be justified (García-Pérez 2010; Calver et al. 2013).

Our analyses of the changes in Margalef richness, Shannon diversity and evenness over time for countries and subject categories measured on four journals offer some indication of the inertia in these measurements, especially given the time periods involved. Considering the countries first, the significant increases in the Shannon diversity and evenness of the countries of authors citing *Wildlife Research* was in line with the prediction of a change arising from a major shift in editorial policy, while two of the control journals exhibited no change and a third declined in Shannon diversity but not in evenness. Margalef richness only showed a statistically significant change for *Australian Journal of Zoology*, where it declined. With regard to Margalef richness, Shannon diversity and evenness in the subject categories of citing papers, changes in Shannon diversity and

evenness were found for only two journals and no journal changed in Margalef richness. Considering both countries and subject categories, all indicators showed none or relatively modest change in percentage terms (the 43% drop in Margalef richness for countries for *Australian Journal of Zoology* is the only exception). Our analyses with regards to internationality of Author 3 did show substantial changes in Margalef richness, Shannon diversity and evenness over time, but the time periods were broad and the changes corresponded to a change in research focus to more global issues. Overall, the measures do reflect intrinsic inertia in these statistics as measures of internationality and multidisciplinarity.

Lastly, Margalef richness, Shannon diversity and evenness are all homogeneous. A change in any of them has a single, unambiguous interpretation in terms of internationality or multidisciplinarity.

Despite meeting Gingras' (2014) three criteria, these procedures quantify only part of the complex concepts of internationality and multidisciplinarity. For example, internationality for an author could be deemed to include the nationalities of co-authors and the country of publication of the journals the author publishes in (although this is problematic for multinational publishers), as well as the distribution of citations across countries. In the case of a journal, it could include the geographic locations of the authors publishing in the journal, the reviewers, the members of the editorial board and the authors citing the journal's papers (Calver et al. 2010). Multidisciplinarity for an author could include the subject categories of the journals the author publishes in, the subject categories of co-authors, the subject categories of the references cited in the author's papers, and the subject categories within the citations the author receives. Other metrics could be suggested. Thus for both internationality and multidisciplinarity a multivariate approach comes closest to identifying all nuances of the topic (Perakakis et al. 2006; Calver et al. 2010). However, the component data for such multivariate analyses may be time-consuming or difficult to collect, so we have proposed measures that can be calculated readily from services provided by major databases and routines in freeware.

In terms of multidisciplinarity, here we used the disciplinary distribution of citations received by a body of work. However, Larivière and Gingras (2014), used a percentage-based measure of interdisciplinarity in the references made by a paper. They argued these were two sides of the same coin, and found that the two measures were correlated in their study of 14 disciplines.

Ease of use has also governed our choice of ecological statistics to summarise internationality and multidisciplinarity. Quantification of biodiversity in natural communities is a rapidly expanding research area and the range of available statistics, each with benefits and limitations, is growing (compare, for example, the options in Krebs 1999 with those in Hammer and Harper 2006 or Hammer 2013). Rather than transfer this proliferation directly into bibliometric analyses, we have used long-standing statistics that are intuitive to grasp and apply. Nevertheless, the caveats below should be noted.

Caveats for assessing internationality and multidisciplinarity with ecological statistics

Based on our analyses of Author 1's citations, we conclude that the biases caused by listing multiple authors from the same country only once for each citation and incompleteness of country affiliation details for citing authors (especially for earlier papers) mean that the WoSCRS output deflates the importance of the most commonly represented countries when analysing internationality. This leads to higher values of Margalef richness, Shannon

diversity and evenness (although these differences were not statistically significant in our example). The same would be true of Scopus. Nevertheless, given the ease of using the standard output relative to a thorough examination of each paper we suggest that this be the preferred approach, with the caution in interpretation that the calculated values will be inflated mildly. When completing analyses it is also important to be aware of any changes in the status of countries over the period of the analysis, as well as differences between Scopus and WoS in the classification of countries and discipline areas, and in the range of years covered.

Interpreting the results of hypothesis testing

While the sample sizes presented here are small, they are likely to be typical of the analyses that individuals implement for their own records, or editors may run for their own journals. This is in keeping with our wish to present approaches suitable for occasional users.

When interpreting Margalef richness, diversity and evenness, there is no implied value judgement in saying that an author or a journal is more or less international or multidisciplinary than another using these statistics. High internationality does not imply quality (Buela-Casal et al. 2006), and the same is true for multidisciplinarity. Differences only become important in relation to perceived aims. For example, the increased diversity and evenness in internationality demonstrated for *Wildlife Research* after its 2009 changes in editorial policy show that the journal policy succeeded in its aims to increase the journal's international reach, at least in the short term. Whether or not the aims were laudable is a subjective judgement.

The results of hypothesis testing presented here are also based on absolute values (those measured specifically for an author or a journal) and we made no attempt to establish a relative value (a baseline reflective of a group of authors such as biochemists, or a group of journals such as electrical engineering journals) against which to compare individual cases (Zitt and Bassecoulard 1998). This is in keeping with our approach of providing a method for occasional users to test specific hypotheses of interest, rather than characterising properties of internationality or multidisciplinarity for larger units. Establishing relative values could be the focus of a future paper.

Concluding remarks

Despite the above cautions, as well as the limitations placed by our modest sample sizes, quantitative assessments of internationality and multidisciplinarity using ecological statistics are a significant advance on qualitative claims. They also permit hypothesis testing for differences between individuals or journals, or the effects of shifts in journal editorial policy on internationality or multidisciplinarity. The hypothesis testing is straight forward using GUI freeware, so the approach is accessible to occasional users. More sophisticated multivariate methods are better suited to major research questions, or to establishing benchmarks characteristic of disciplines.

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Appendix 1: Procedure for profiling international citations or subject area citations of an author or journal in WoSCRS

Before undertaking a search, it is prudent to check the year range of the WoS subscription to ensure that it embraces the years over which the target author published, or the years over which a journal profile is desired (for more detail, refer to http://clarivate.libguides.com/woscc/coverage).

Procedure for authors

In brief, the procedure involves conducting a Cited Reference Search for the chosen author in the WoS (Core Collection), retrieving the citations to the work of the chosen author, and then profiling the countries of affiliation for the authors in the citations. The steps below apply to the current version of the WoS (Core Collection), but interface changes could occur.

1. In the WoS (Core Collection) choose the CRS option from the dropdown menu of search options and enter the search term for the desired author.
2. Scan the output and select all entries that are publications of the target author. This may be difficult when the searcher has no knowledge of the target author's full curriculum vitae (Jacsó 2007; Calver et al. 2013). There is no need to locate and aggregate cases where the same publication has multiple entries because of errors by citing authors—the country of origin of the citing authors will be identified correctly.
3. Once all citations attributed correctly to the target author have been selected, clicking the finish search button displays all the citations to the work of the target author. Clicking the 'analyze results' button on the screen advances to the next stage. There is no need to set the checkboxes of all the references displayed before clicking analyse results.
4. The results analysis screen indicates the number of papers citing a work by the target author. Set the 'display options' to 500 results with a minimum record count of one, and the 'sort by' option to 'record count'. Then in the 'rank the records by this field' box, select 'countries/territories' for an international analysis or 'Web of Science categories' for a multidisciplinary analysis. Click the analyse button. The percentages in the resulting output indicate the percentage of records (citations to the target author's work) that include at least one author from the countries displayed, or one citation from the subject category displayed.

Some records will contain authors from two or more countries or two or more subject categories, so percentages across all countries or categories will sum to a value greater than 100 and the sum of all the countries or Web of Science categories will exceed the number of citing papers. The analysis also counts each country attributed to a record only once. For example, if a paper had three authors from Canada and one author from New Zealand, it would be counted as one Canadian author and one New Zealand author. Error messages at the bottom of the screen will indicate if any records did not contain data in the country or subject category field, or if the display options chosen did not include all possible records. There is also an option to export the results as a text file.

Procedure for journals

1. Even if a journal is not listed in WoS, citations to it from sources covered/processed by WoS can still be retrieved via a CRS, so an evaluation can proceed.
2. The procedure is similar to that for evaluating an individual author. Given the long spans of publication of some journals, it may be appropriate to restrict the search to specific years. For example, examining the international profile of successive decades may be useful in detecting if the international profile of a journal is changing (see the example in Calver and Bryant 2008).

Appendix 2: Procedure for profiling international citations or subject area citations of an author in Scopus

In brief, the procedure involves combining the results of a standard search and a secondary documents search for the chosen author, retrieving the citations to the work of the chosen author, and then profiling the countries of affiliation for the authors in the citations. The steps below apply to the current version of Scopus, but interface changes could occur.

Despite the greater journal coverage in Scopus compared to WoS (Jacsó 2005), until recently Scopus did not claim to have accurate data earlier than 1996 (although there is ongoing expansion of coverage of the earlier literature to 1970 (Elsevier 2016)). Therefore Scopus may not be suitable for assessing the international or multidisciplinary citations of authors with papers earlier than 1996.

1. Use any of the Scopus search options to list and select the publications of the target author. Then click the 'view cited by' link to display all the citations to these documents. Select all these citations and transfer them to the 'My List' store.
2. Return to the original list of the target author's publications and click the 'secondary documents search' to display all citations from documents in Scopus to any of the target author's publications not in Scopus, broadening the range of citations retrieved. Scan the output carefully to select only those documents actually by the target author (a good knowledge of the relevant CV is essential). Some publications may have duplicate entries because of small variations made by authors when citing, but it is not necessary to aggregate these because the country of the citing authors is all that is needed. Once the documents belonging to the target author are selected, the 'view cited by' link can be clicked to display the citing papers. The citing documents can then be selected and transferred to 'My List', which will then contain all the citations from the primary search and the secondary documents search.
3. Selecting the entries in 'My List' and clicking 'analyze results' displays an output page where 'country' can be selected to display the countries of the citing authors, or 'subject category' to display the subject area of the citations. These data can be interpreted in the same way as the output from a WoSCRS. The full data set can be downloaded as a.csv file for opening in spreadsheet software.

Procedure for journals

1. Scopus does not have complete data earlier than 1996 [although there is a project to extend the range to1970 (Elsevier 2016)], so the range of years that can be searched is restricted.
2. The procedure is similar to that for evaluating an individual author. Instead of entering an author name, the full journal title is entered and the search is set to 'Source title.
3. It is prudent to include a check for secondary documents, which may return papers from the journal cited incorrectly or published earlier than 1996.

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