Scientometrics (2015) 102:357–364
DOI 10.1007/s11192-014-1385-5

Publish (in a group) or perish (alone): the trend from single- to multi-authorship in biological papers

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Received: 20 January 2014 / Published online: 29 July 2014

Abstract The global number of papers in different areas has increased over the years. Additionally, changes in academic production scenarios, such as the decrease in the relative number of single-authored (SA) papers, have been observed. Thus, the aims of this study are to assess the trend of SA papers in four subareas of biology and also to estimate the year when 0.1 % of papers in these subareas will be SA (considering two adjusted models). The subareas investigated were Ecology, Genetics, Zoology and Botany. Our hypothesis is that all subareas show a decay in the number of SA papers. However, this pattern is more pronounced in subareas that were originally interdisciplinary (Genetics and Ecology) than in disciplinary areas (Zoology and Botany). In fact, SA papers have declined over the years in all subareas of biology, and according to the best model (Akaike Criteria), the first area that will have 0.1 % SA papers is Genetics, followed by Ecology. A partial regression indicates that the decrease in SA papers can be related to the increase in the number of authors and number of citations, suggesting the greater scientific impact of interdisciplinary research. However, other variables (e.g., political, linguistic and behavioral) can contribute to the decrease in SA papers. We lastly conclude that the number of SA papers in all subareas of biology in the coming years might continue decreasing and becoming rare, perhaps even to the point of extinction (to use a very common term in biology). In addition, all subareas of biology have become more interdisciplinary,

Electronic supplementary material The online version of this article (doi:10.1007/s11192-014-1385-5) contains supplementary material, which is available to authorized users.

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combining the knowledge of various authors (and perhaps authors from different areas). The consequence of this approach is increasingly collaborative work, which may facilitate the increased success of the group.

Keywords Ecology · Genetics · Zoology · Botany · Non-linear models

Introduction

The "Publish or Perish" idea is not novel and has long been discussed in universities (e.g., Mackay 1974; Hamilton 1990). Even today, the obsession with quantity has been discussed in academia (e.g., Fischer et al. 2012, see also Loyola et al. 2012). Surely, all researchers worldwide know the importance of producing papers (quantity and/or quality), mainly because scientific productivity is considered in the distribution of financial resources and in admission to participation in research groups and graduate programs (De Meis et al. 2003; Barré 2005). Moreover, the scientific production of nations is related to the socio-economic characteristics of the countries (King 2004; Jaffe et al. 2013).

The global number of papers published in different areas has increased over the years (King 2004). Associated with this increase in scientific productivity, changes in academic production scenarios, such as the increased participation of women (Nelson and Brammer 2008), increases in the contribution of scientific production in developing countries (Holmgren and Schnitzer 2004) and increased numbers of multi-authored papers (Hudson 1996) have been observed. In fact, there has been a decrease in the number of single-authored (SA) papers over the years (Abt 2007), which may be due to the need for interdisciplinary research (Porter and Rafols 2009).

Biology is a very broad area composed of professionals from various subareas with distinct histories and scientific behaviors (Kinchin 2011). For example, Genetics and Ecology are recent subareas that utilize different tools from other scientific areas (e.g., Chemistry, Geography) in their research (e.g., Shwarts et al. 2013). These subareas show a high level of interdisciplinary publications, with a high percentage of journals multi-assigned to more than one discipline (Bordons et al. 2005). However, Botany and Zoology are examples of disciplinary subareas in which a deep knowledge of taxonomic groups is needed (e.g., Pyšek et al. 2013). In this sense, although the scientific production of biological papers has increased over the years (e.g., Carneiro et al. 2008; Padial et al. 2010; Nabout et al. 2012) and many general patterns of authorship (e.g., the number of authors, NAs) observed in other areas should be present, differential patterns may emerge from considerations of the particularities of subareas, such as the level of interdisciplinarity.

Considering only biological publications, the aim of this study was to assess the trend of SA papers in four subareas of biology and also to estimate the year when 0.1 % of papers will be SA in each of these subareas. Moreover, we investigated the relative influence of the number of researchers and number of citations (NCs) on the trends in single authorship. The subareas investigated are Ecology, Genetics, Zoology, and Botany. Our hypothesis is that all subareas will show a decrease in the number of SA papers (see Abt 2007); however, because these subareas have distinct patterns of publication, this decay pattern will be more pronounced in originally interdisciplinary subareas (Genetics and Ecology) than in disciplinary subareas (Zoology and Botany). Additionally, we investigate whether the trend of SA decay may be predicted by variables such as the NAs and/or the NCs. This pair of predictors will allow us to evaluate whether the supposed increase in the number of multi-authored papers is a consequence of increased NAs publishing papers and also of the more frequent citation of multi-authored papers, reflecting a higher scientific impact of interdisciplinary research.

Data collection

To assess the proportion of single authorships in biological papers, we selected four subareas (Ecology, Genetics, Botany, and Zoology) and four important journals for each subarea. The journals selected for each subarea were as follows: (i) Ecology: *Ecology*, *Acta Oecologica-International Journal of Ecology*, *Oikos*, *Oecologia*. (ii) Genetics: *Nature Genetics*, *Genetics*, *Genetica*, *PLOS Genetics*. (iii) Zoology: *Journal of Zoology*, *Zootaxa*, *Zoological Journal of the Linnean Society*, *Zoologica Scripta*. (iv) Botany: *Annals of Botany*, *Botanical Journal of the Linnean Society*, *Systematic Botany*, *Journal of Vegetation Science*. These journals were selected because the scope of the journal involves only the area of interest in each case. Thus, journals with a broad scope (e.g., *Science*) or a focus on the intersection of areas (e.g., *Landscape Ecology*) or subareas (e.g., *Molecular Ecology*, *Tree Genetics & Genomes*) were not included due to their particular perspective on each subarea investigated.

For each biological subarea, we searched the papers in the Thompson-ISI database (www.isiknowledge.com, searched in December of 2012). For this study, we selected only original articles (type of document), excluding notes, reviews, errata and others. We adopted this strategy to control the influence of the type of document on the NAs (several papers discussed the influence of the type of document on the citations; see Padial et al. 2010). The selection of papers considered all periods available in the Web of Science database; however, for analysis, papers were chosen from the years beginning in 1966 (the first year that all subareas were represented by journals). For each paper, the following data were obtained: (i) NAs, (ii) NCs and (iii) year of publication.

Temporal trends of SA

Scientific productivity in each of the subareas has increased over the years (Fig. 1), and in general, the temporal trends were similar for each of the four subareas (evidenced by the high Pearson correlation coefficient; see data analysis in Supplementary Material A). Two subareas showed "jumps" in scientific production: Genetics in the early 1990s and Zoology in the early 2000s. For Genetics, the jump in the number of papers can be explained by the popularity of molecular tools (Schlotterer 2004; Davey et al. 2011); the jump in Zoology can be explained by the entry of an important journal (*Zootaxa*) into the database. For Ecology, Botany and Zoology we found an average of two authors per article (considering all years), and Genetics had the largest average NAs (average of five authors per article; Fig. 1a: Supplementary Material B). Moreover, the average NAs was greater in recent years than in previous years (early years 1966–1975 and concluding years 2002–2011) in all subareas (Fig. 1b: Supplementary Material B). This result clearly demonstrates the increasing NAs per article over the years.

The number of single authorships has decreased over the years for all subareas of biology (Fig. 2). We used two regression models to fit the data. In these models, Y was %SA and X was years. We used Akaike Criteria to evaluate these models (see details in

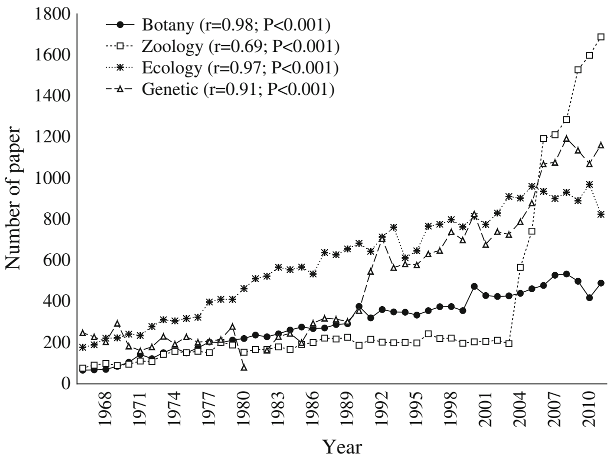

Fig. 1 Temporal trend of scientific papers published in journals of different subareas of biology

Supplementary Material A). The models used were the logistic and the exponential (see Tjorve 2003). The logistic model had the best fit for all subareas (see Table 1). Using the best model for each subarea, it is possible to estimate the year when 0.1 % of the papers in the subareas will have only one author. Based on these predictions, the first subarea that will have 0.1 % of SA is Genetics (2036), followed by Ecology (2054). Moreover, an ANCOVA indicated that the trends of decay are distinct, considering all subareas together ($F_{4,46} = 293$; $P < 0.001$) and also for each pair of subareas (Table 2; see details in Supplementary Material A).

In fact, studies that investigated the NAs indicate a decrease in the number of SA in a variety of areas of science (Abt 2007) and an increase in the number of multi-authored papers (Glänzel and Schubert 2005). In the present study, all subareas showed a decrease in the number of SA, supporting the first hypothesis of this research. Moreover, our results indicated that SA in Genetics and Ecology showed a more marked decrease than Zoology and Botany, supporting the second hypothesis. Importantly, these projections are based on current trends, and they are not a prophecy nor a requirement. Moreover, the confidence interval for each model (see Supplementary Material C) shows the possible variations of these projections that may change over time due to behavioral changes in the area of biology.

Therefore, the decrease in SA papers (and increasing NAs per article) may indicate that all subareas of biology have become more interdisciplinary. In fact, subareas such as Zoology and Botany have been utilized as tools and have provided theoretical approaches to other subareas of biology (Ecology and Genetics) and other types of scientific fields (i.e., Geography). This growth in interdisciplinary research is also evidenced by the increasing number of journals that aggregate subareas (e.g., Journal of Animal Ecology, Molecular Ecology, Tree Genetics and Genome). Other subareas, such as Ecology and Genetics, frequently use novel technology (e.g., bioinformatics, transgenics), and this characteristic promotes multi-authored papers. Indeed, the trend toward interdisciplinary science is not easy to measure, but the growth in the number of multi-authored papers may be indicative of increased collaboration (both intra- and interdisciplinary; Whitfield 2008).

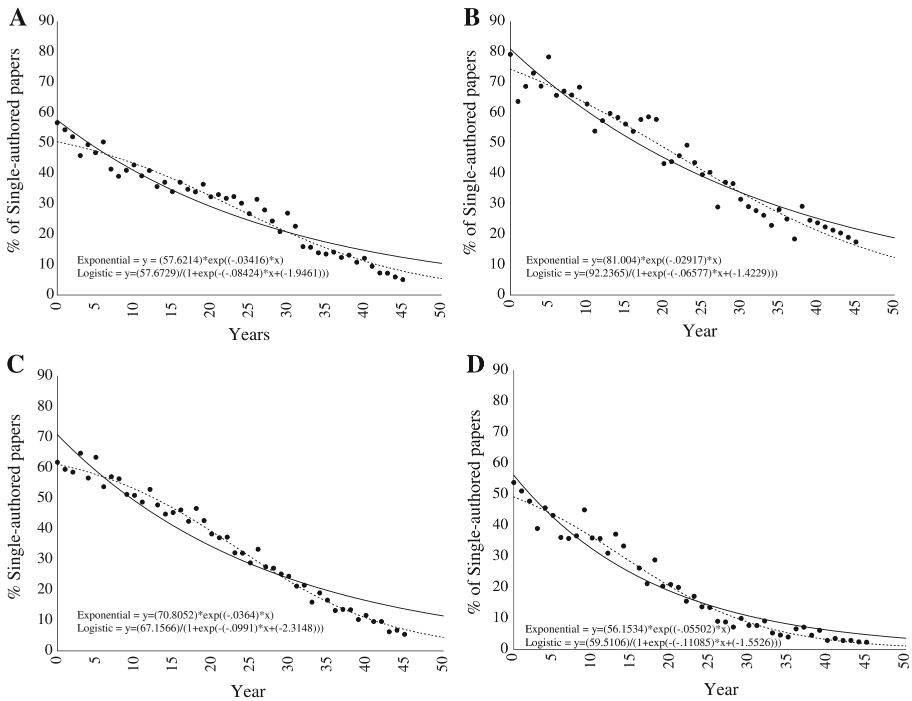

Fig. 2 Proportion of single-authored papers for Botany (**a**), Zoology (**b**), Ecology (**c**) and Genetics (**d**). The proportion of single-authored papers for each year (number of single-authored papers in 1 year/total number of papers in same year) was related to years. For this purpose, the years were ranked and ordered from 0 (first year, 1966) to 46 (last year, 2011). Models: exponential (*continuous line*), logistic (*line with short dashes*)

Table 1 Coefficient of determination (R^2), and *P* value for each model fit to the data from each biological subarea

	Exponential		Logistic		Year
	R^2	AIC_c	R^2	AIC_c	(0.1 %)[a]
Botany	0.91	132.86	0.96	**106.04**	2063
Zoology	0.92	156.02	0.95	**136.19**	2090
Ecology	0.92	152.58	0.99	**76.26**	2054
Genetics	0.94	128.44	0.97	**101.78**	2036

The best models according AICc is indicated in boldface. The year when the number of single-authored papers is less than 0.1 % are also given

[a] This year was estimated only using the best fitting model. See parameters estimated for each model in Supplementary Material C

Several studies have demonstrated a quantitative increase in scientific collaboration and the benefits of these collaborations in various areas (see Price 1963; Adams et al. 2005; Glänzel and Schubert 2005; Mattsson et al. 2008; Wutchy et al. 2007, 2009; Vermeulen et al. 2013). Based on this literature and our own understanding of collaboration we

Table 2 The analysis of covariance for each pair of subarea, showing values of $F_{1,46}$ (below diagonal) and *P*-values above the diagonal

	Botany	Zoology	Ecology	Genetics
Botany	–	0.001	0.001	0.001
Zoology	260.4850	–	0.001	0.001
Ecology	61.097	197.846	–	0.001
Genetics	124.920	615.955	294.324	–

Table 3 Partial regression, demonstrating the relative importance (R^2) of the number of authors (NA) and the number of citations (NC) in % of single-authorships in each subarea

	Botany		Zoology		Ecology		Genetics	
	R^2	*P*-value	R^2	*P*-value	R^2	*P*-value	R^2	*P*-value
Purely NA [a]	0.12	0.0001	0.34	0.0001	0.16	0.0001	−0.005	0.93
Shared NA and NC [b]	0.79		0.03		0.77		0.56	
Purely NC [c]	0.001	0.16	0.42	0.0001	0.01	0.0003	0.18	0.0001
Residual [d]	0.08		0.18		0.04		0.25	

highlight several factors that promote collaboration in biology: (1) multifaceted approaches have become necessary to address increasingly complex biological questions. Collaboration allows researchers with complementary skills to explore complex questions with a multidisciplinary perspective that could not be addressed in any other way. For example, the study of global climate change and its impacts on biodiversity involves a variety of professionals (biologists and non-biologists) for purposes of conservation planning (Nabout et al. 2012). (2) Laboratory studies (e.g., molecular analyses) involve sophisticated and costly equipment. Collaboration allows these costs to be shared. For example, the Human Genome Project was built on partnerships with laboratories in several countries. (3) In many parts of the world, the biodiversity is poorly known, and many species remain to be described for various taxonomic groups (see Nabout et al. 2013). It is estimated that 86 % of all species on the earth have not been described (Mora et al. 2011). These gaps have been filled with collaborative multi-taxa inventories that gather professionals from various taxonomic groups. Many research programs have greatly contributed to the knowledge of biodiversity (e.g., SisBiota in Brazil; BIOTA-Africa in African countries and Germany; Rapid Assessment Program in Conservation International) and the training and assistance of taxonomists (e.g., PROTAX in Brazil; all catfish species inventory in USA). These researches programs involve researchers from different areas and different countries; (4) decreasing travel and communication costs have also stimulated collaboration in biology (Vermeulen et al. 2013).

Apart from these factors that encourage collaboration, several deterministic and non-behavioral variables can be used to estimate the reduction in SA (and the increase in multiauthorship), including the increasing number of professionals and even the NCs (Glänzel 2002; Hsu and Huang 2011). We used these two variables as predictors of %SA in a partial regression analysis (see details in Supplementary Material A). The decrease in SA over the years may be explained by combining the NAs and the NCs, as observed in the component “b” of the partial regression (Table 3). This component was high in almost all subareas (except Zoology), whereas the single components (“a” and “c”) varied in each subarea. Therefore, the increased NAs and citations alone does not explain the decrease in

SA. This observation underscores that for biology subareas, most active researchers aim for a network of collaboration, resulting in multi-authored papers of high quality (as shown by their high NCs). However, note that several factors have promoted collaboration among authors (as described in the previous paragraph). Regardless of these factors, the collaborative studies, indicated by the greater NAs, have promoted work with greater impact (i.e., more citations).

We lastly conclude that the number of SA in all subareas of biology in the coming years should continue to decrease and that SA should become rare, perhaps even extinct (to use a very common term in biology). In addition, all subareas of biology have become more interdisciplinary, combining the knowledge of various authors (possibly from different areas) and producing high-impact papers. The consequence of this trend is increasingly collaborative work, which may cause the group to be increasingly successful. Thus, biological researchers should consider the following statement by Vermeulen et al. (2013, p. 171): "Collaboration will continue to be one of the driving forces that change the face of science and young scientists and research managers will experience shifts during their career…".

Acknowledgments We thank two anonymous reviewers for discussions and suggestions that improved previous versions of the manuscript. MRP received a scholarship from CNPq (PIBIC). JCN, FBT, HFC, SSC were partially supported by CAPES and Fundação de Amparo a Pesquisa do Estado de Goiás (Auxpe 2036/2013). JCN and TNS were supported by CNPq productivity fellowships. FBT, HFC, and SSC were supported by University Research and Scientific Production Support Program (PROBIP/UEG)

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