17 Dec 2015
Robert K. Swihart
715 West State Street
West Lafayette, IN 47907
Ph: 765-494-3590
Fax: 765-494-9461
rswihart@purdue.edu

RH: Swihart et al. • Factors Affecting Bibliometrics

Factors Affecting Scholarly Performance by Wildlife and Fisheries Faculty

ROBERT K. SWIHART, *Department of Forestry and Natural Resources, 715 W State Street, Purdue University, W Lafayette, IN 47907, USA*

MEKALA SUNDARAM, *Department of Forestry and Natural Resources, 715 W State Street, Purdue University, W Lafayette, IN 47907, USA*

TOMAS O. HÖÖK, *Department of Forestry and Natural Resources and Illinois-Indiana Sea Grant Program, 715 W State Street, Purdue University, W Lafayette, IN 47907, USA*

J. ANDREW DEWOODY, *Department of Forestry and Natural Resources, 715 W State Street, Purdue University, W Lafayette, IN 47907, USA*

ABSTRACT Publication- and citation-based metrics are commonly used to summarize the productivity and impact of individuals, institutions, and journals. We examined factors hypothesized to explain variation in 5 author-based performance metrics among 437 fisheries and wildlife faculty from 33 research-extensive universities in the United States. Regression analyses revealed that the elapsed number of years since conferral of the Doctor of Philosophy (Ph.D.) degree (academic age) was a strong predictor of performance metrics, with nonlinear age effects for Hirsch's h-index, Brown's h_b-index, the annual rate of increase in h (i.e., m quotient), and number of publications. Greater performance was observed for faculty with greater research appointments. Performance did not vary between Wildlife and Fisheries disciplines but did vary across sub-disciplines; metrics indicated that genetics and disease-related sub-disciplines had the greatest positive effect sizes, social sciences and management-oriented sub-disciplines had the smallest effects, and ecology, conservation, quantitative methods, and aquatic science showed intermediate effect sizes. On average, male faculty published more articles than females, but no sex differences were evident for the other 4 performance metrics. Earlier publication relative to attainment of the Ph.D. degree (publication precocity) was associated with performance for all metrics. Regression models explained 28–54% of the deviance and may prove useful in placing reported values for performance in context of performance by peers. As an alternative point of reference, named (i.e., distinguished) faculty on average exhibited performance 31–96% greater than the performance predicted for otherwise comparable faculty. Our regression models allow for more meaningful comparison of publication and citation performance relative to peers, but they represent only one aspect of faculty performance and should not replace qualitative peer review of productivity and impact.

KEY WORDS bibliometric, Brown's h_b-index, citations, Hirsch's h-index, m quotient, publications.

University faculty members are expected to demonstrate the impact of their scholarship. Over the past decade, the h-index (Hirsch 2005) has emerged as an impact metric (along with other measures, henceforth referred to collectively as bibliometrics) that is reported and considered during promotion, tenure, and annual merit evaluations. Such evaluations would benefit from an ability to place these metrics in the context of performance by peers (Abramo et al. 2010), and with an understanding of factors that influence variation in the metrics. Unfortunately, no such analysis has been conducted for faculty in fisheries and wildlife. Our objective was to provide such an analysis.

Dozens of bibliometrics have been introduced (Bornmann et al. 2011, Aoun et al. 2013, Wildgaard et al. 2014). The h-index indicates that a scholar has published a set of h papers, each with at least h citations (Hirsch 2005). By definition, h^2 is the minimum number of citations that can result in an h-index of h; excess citations are ignored. Similarly, other publications that have not accumulated at least h citations are ignored. Hirsch (2005) contended that 2 individuals with the same h-index were similar in terms of overall scientific impact, even if they differed in excess citations (or excess publications). Brown (2012) disagreed and defined the h_b-index as $h_b = h + \sqrt{e}$, where e is the sum of all citations for articles used in computing h (i.e., the h-core; Zhang 2009) in excess of h^2. Both h and h_b increase monotonically with time. Hence, if all else is equal, these metrics should increase during the course of an individual's career. To facilitate comparisons that are independent of career stage, Hirsch (2005) introduced the m quotient as a complement to h. The m quotient is defined as m = h/y, where y is the elapsed number of years in an individual’s career, with career commencement often measured from the date of first publication. Thus, m is the average annual rate at which h increases.

Faculty vary considerably in measures of research output and quality. We tested 5 attributes for their ability to explain variation in bibliometric scores among individuals: academic age (time since attaining Doctor of Philosophy degree [Ph.D.]), sex, percent of appointment allocated to research, disciplinary focus, and the year of first publication relative to attainment of the Ph.D. Specifically, we predicted that academic age should co-vary positively with h, h_b, and publication productivity because these measures increase monotonically with time. Sex differences in bibliometric scores have been demonstrated in other disciplines (Pagel and Hudetz 2011*b*) including ecology (Kelly and Jennions 2006). Based on those results, we predicted that on average males would exhibit greater bibliometric values than females. Universities typically allocate faculty time to activities associated with research, teaching, extension, service, and administration, and allocations routinely differ among faculty. We predicted that faculty with greater time allocated to research would produce larger bibliometric scores. Bibliometrics vary across fields of study (Kokko and Sutherland 1999, Abramo et al. 2010). Thus, we predicted that variation in bibliometric scores would be explained by the sub-disciplines in which faculty conducted research. In accordance with prior findings, we predicted that bibliometric differences among fields should be genetics > ecology > social science (Iglesias and Pecharromán 2007). We also expected a focus on management fields to result in lower bibliometric values, all other things equal (van Eck et al. 2013). Finally, early publication positively influences long-term publication success of biologists (Laurance et al. 2013); we predicted a similar effect on publication and citation metrics for fisheries and wildlife faculty.

METHODS

Data Collection

We assembled our database first by searching academic web sites of Fisheries, Wildlife and Natural Resources programs. We included universities and their affiliated academic programs that were members of the National Association of University Fisheries and Wildlife Programs (NAUFWP) in 2014 or 2015 and were listed as research-extensive institutions by the Carnegie Foundation (Appendix A). For all tenure-track faculty members, we recorded name, sex, professorial rank, whether they held a named or distinguished professorship related to research distinction, year in which they attained the Ph.D., whether they worked primarily on fisheries or wildlife-related topics, and affiliation with 36 fields of inquiry. These fields of inquiry were based primarily on descriptions of research on faculty and departmental web sites or, when lacking, perusal of publications. The fields were subsequently grouped into 8 sub-disciplines (Table 1). Sub-disciplines were not exclusive because individual faculty could be listed in >1 sub-discipline, and usually were (mean number of sub-discipline categories/faculty = 1.97, SD = 0.84). For faculty for whom web pages did not contain the year of Ph.D. attainment, we searched the ProQuest dissertations and theses database (http://search.proquest.com.ezproxy.lib.purdue.edu) to find the year of graduation. Institutional administrators, usually at the department or school level, provided data on appointment splits for each faculty member. Administrators also provided suggestions for which faculty to include, which was particularly helpful when dealing with departments that did not have fisheries and wildlife as their exclusive or primary focus.

We collected bibliometric data from the Web of Science™ using all available databases. We completed article searches for each faculty member during the first 6 months of 2015. For faculty with common last names, we added information such as institutional addresses or refined our searches by research areas and source titles. We also compared results with personal web pages and publication lists to avoid errors of omission or commission. In 18 instances where we could not reliably distinguish articles produced by the target faculty member from other articles produced by individuals of the same name, we omitted the individual from further consideration. For remaining individuals, we recorded the year of first publication, total number of publications and citations through 2014, h-index, and the citation count for each publication in the h-core. Four faculty had no citations in the database; we assigned them values of 0 for h. From these data we computed h_b-index, m quotient, and citations per year. We chose to focus on Hirsch's h-index because its use is well established (Bornmann et al. 2008, Pagel and Hudetz 2011*a*, Acuna et al. 2012, Selek and Saleh 2014), the m quotient because it offers a complementary measure of research impact to the h-index (Hirsch 2005), and the h_b-index because it addresses a perceived disadvantage associated with the h-index (Brown 2012). We included measures of publication productivity (Hönekopp and Khan 2012) and citation rate (Mazloumian 2012) because they have been related to future success and impact, respectively.

We computed bibliometrics for each of 2 measures of academic age: number of years since first publication and number of years since attainment of Ph.D. The 2 ages were highly correlated ($r = 0.93$, $P < 0.001$). We used elapsed years since attainment of Ph.D. degree in all subsequent analyses because we consider it a more uniform measure of professional development across faculty and because it typically is intermediate in value to the measure based on year of first publication and an alternative measure based on the year of entry into a tenure-track position.

Data Analysis

In addition to summary statistics and scatterplots for the bibliometrics, we computed correlation coefficients for each pair of predictor variables. We constructed a set of nested candidate models based on our predictions, with an intercept-only model followed by sequential incorporation of academic age, percent of appointment allocated to research, sex (0 = female, 1 = male), sub-discipline (Table 1), and the difference in the years of Ph.D. conferral and first publication (i.e., publication precocity). We examined covariates for multi-collinearity, inspected residuals to assess model assumptions, and added quadratic terms (after centering on the mean) if warranted. We fitted generalized linear models for h-index, h_b-index, m quotient, number of publications, and annual citation rate, computed as total citation count divided by elapsed years since attainment of Ph.D. We fitted negative binomial models to h-index, h_b-index, number of publications, and citation rate (after rounding to the nearest integer) with function glm.nb from the MASS library (Venables and Ripley 2002) in R 3.0 (R Project for Statistical Computing, Vienna, Austria) because considerable over-dispersion was evident in models fitted to a Poisson distribution. We fitted Gaussian regression models for m quotient using R function glm after transformation of academic age to ln(age + 0.5). We compared nested models using likelihood-ratio tests, and fitted a best model to each of the response variables.

RESULTS

Of universities belonging to NAUFWP in either 2014 or 2015, 33 qualified as research-extensive according to the Carnegie Foundation, and within this set 3 universities had multiple academic units that served as tenure homes for fisheries and wildlife faculty (Appendix A). We collected data for 437 tenure-track faculty, of which 180 (41.2%) were classified as focusing on fisheries and 257 (58.8%) were classified with a focus on wildlife. The mean (± 1 SD) elapsed time since attainment of a Ph.D. degree was 18.6 ± 10.2 years. Nearly half (46.7%) of faculty were full professors, whereas 32.5% were associate professors and 20.8% were assistant professors. Faculty time allocated to research (48.4 ± 20.8%) exceeded allocations for teaching (35.3 ± 20.6%) or extension (11.9 ± 23.4%), with the remainder devoted to service or administrative duties. The difference in representation of sex was substantial, with males (78.7%) nearly 4 times as prevalent as females (21.3%) among the ranks of tenure-track faculty. Among females, assistant professors (31.1% of all faculty at this rank) had greater representation in faculty ranks than associate (26.6%) or full (13.2%) professors. The first publication by a faculty member appeared 3.6 ± 4.0 years (mean ± 1 SD) before the Ph.D. was received. For all predictor variables used together in models, correlations were < |0.2|.

Mean ± 1 standard deviation (median) values of h-index, h_b-index, m quotient, number of publications, and citation rate were 14.6 ± 9.2 (13), 33.3 ± 21.5 (33.3), 0.95 ± 0.70 (0.8), 62.0 ± 56.2 (46), and 54.3 ± 55.9 (36.9), respectively. Values of h- and h_b-

indexes were most highly correlated ($r = 0.96$, $P < 0.001$); correlations were smallest in magnitude, but nonetheless significant, between h-index and m quotient ($r = 0.18$, $P < 0.001$), h_b-index and m quotient ($r = 0.18$, $P < 0.001$), and number of publications and m quotient ($r = 0.10$, $P = 0.03$). All other correlations among response variables were intermediate to these extremes.

There was no effect due to disciplinary focus (fisheries vs. wildlife) for any of the bibliometric variables (all $P \geq 0.19$; Table 2). Hence, we pooled fisheries and wildlife faculty for all analyses. The final models (Table 3) for h-index and h_b-index explained 54.0% and 50.4% of the deviance. Slightly lower levels of deviance were explained by the best models for number of publications (48.5%) and m quotient (47.4%). The model for annual citation rate explained the lowest level of deviance (28.2%).

As predicted, academic age had a positive effect on h-index, h_b-index, publication count, and citation rate (Tables 2 and 3). For h-index, h_b-index, and publication count, a quadratic term was significant, which indicated that their rates of increase slowed with academic age (Tables 2 and 3; Fig. 1). In contrast, m quotient exhibited a negative relationship with academic age (Tables 2 and 3); predicted values of m quotient decayed rapidly at first and then more gradually at greater academic ages (Fig. 2).

Contrary to our predictions, sex had an effect only on number of publications (Table 2); all else equal, males on average produced 18.9% (i.e., $e^{0.173} = 1.189$) more publications than females (Table 3; Fig. 3). We found no evidence for an interaction effect between sex and age (Table 2).

As predicted, faculty with greater time allocated to research produced greater bibliometric scores (Table 3; Fig. 1). An increase from 10% to 90% in research allocation yielded expected increases of 59% for h-index and 64% for h_b-index (Fig. 1), 92% for number of publications (Fig. 3), and 174% for annual citation counts (all based on odds ratios), and 49% for m quotient (based on an average faculty member specializing in aquatic science, see Fig. 2).

Significant amounts of variation in all bibliometric scores were explained by the sub-disciplines in which faculty conducted research (Table 2; Fig. 4). Among sub-disciplines, genetics had the greatest effect size for all bibliometrics except number of publications, for which disease had the largest effect (Table 3). Social sciences and management were the only sub-disciplines to consistently yield negative effects (Table 3; Fig. 4). Aquatic science failed to yield an effect for any of the bibliometric variables (Table 3).

Earlier initiation of publication had a positive effect on all bibliometric variables that we considered (Tables 2 and 3). For illustration, a 40% increase is predicted in the number of publications from the best model with initial publication 7 years before the Ph.D. (about twice as early as the average faculty member) versus initial publication in the same year as attainment of the Ph.D. (Fig. 3). Using the same time period yielded predicted increases of 17% for h-index, 21% for h_b-index, 46% for annual citation count, and 19% for m quotient (for an average faculty member specializing in aquatic science, see Fig. 2).

The 39 named faculty exhibited mean h-index and h_b-index values of 25.5 and 58.2, respectively, and addition of a categorical variable for named professorships to the best model revealed a positive effect between this categorical variable and h-index (mean for other faculty = 13.5, $Z = 6.14$, $P < 0.001$) and h_b-index (mean for other faculty = 30.9, $Z = 5.77$, $P < 0.001$). Named faculty had a mean m quotient of 1.00 (vs. 0.95 for other faculty), and addition of a binary naming covariate improved the model ($t = 4.79$, $P <$

0.001). Named faculty had similar effects for number of publications (named mean = 139.5, other faculty = 54.4, $Z = 6.14$, $P < 0.001$) and annual citation count (named mean = 110.9, other faculty = 48.8, $Z = 5.59$, $P < 0.001$).

DISCUSSION

Our models represent the first attempt to examine factors influencing scholarly productivity of fisheries and wildlife faculty. However, our dataset reveals some notable trends at research-extensive universities independent of the bibliometric analysis. Nearly 4 of 5 faculty held the rank of full or associate professors. At first glance, this proportion seems inordinately skewed against assistant professors. But if we assume that an average career duration is 30–35 years and promotion from assistant professor occurs after 6–7 years, a steady state containing 20% assistant professors is plausible. Female faculty were much more likely to occur at the rank of assistant professor (30% of females) than were male faculty (18%). In contrast, only 29% of female faculty were full professors compared to 51% for males. These discrepancies may reflect historical biases and prevailing societal norms that favored males in terms of admission into graduate and faculty hiring practices, and lowered retention of female faculty (Perna 2005, Xu 2008, Moss-Racusin et al. 2012). The fact that 31.1% of assistant professors are female, compared with 26.6% of associate and 13.2% of full professors, is a promising sign. Nonetheless, fisheries and wildlife remains a male-dominated field at research-extensive universities.

Our results suggest that the relative dearth of female faculty is not likely due to deficiencies in performance. We observed no effect of sex in any performance metric except number of publications. Kelly and Jennions (2006) noted an effect of sex when they examined factors influencing h-index for members of editorial boards from journals in ecology and evolutionary biology. In other fields a male effect on performance metrics has been observed (Pagel and Hudetz 2011*a*, Laurance et al. 2013, van Dijk et al. 2014), although not for all metrics. For example, Pagel and Hudetz (2011*a*) observed greater h-index values for male faculty in anesthesiology, but citations per publication were comparable.

Academic age was a strong predictor of performance metrics for faculty but in ways not entirely consistent with our hypotheses. We expected the metrics that measure productivity and impact in a cumulative fashion (h- and h_b- indexes, no. publications) to increase with academic age. Instead, these performance measures exhibited a unimodal relationship with age (Figs. 1 and 3) in which the metrics increased over time and then leveled off. Our results are consistent with models of human capital, which suggest a humped-shaped progression of individual research productivity with academic age because a stock of research capital needs to accrue early in one's career, but retirement or lifespan place upper limits on the duration of new investments (Perianes-Rodriguez and Ruiz-Castillo 2015). It also is possible that the quadratic term reflects changes over time that have occurred in citation and publication practices within fisheries and wildlife. The m quotient, which was derived by Hirsch (2005) to account for age effects that occur in the h-index, exhibited an exponential decay with academic age (Fig. 2). Similar age-dependence of the m quotient has been reported in other disciplines (e.g., astronomy; Pepe and Kurtz 2012), with smaller values accompanying more advanced academic age.

As predicted, percent of appointment devoted to research had a positive effect on performance metrics. To the extent that appointment splits are indicative of effort expended in research, teaching, extension, service, or administrative activities, our result is not surprising. Our anecdotal observations suggest that few faculty members consciously allocate effort in relation to their appointments. Still, it is likely that appointment splits approximate effort based on simple accounting. A faculty member with a large teaching appointment (or extension, administrative, or service appointment) will expend more effort on activities related to those responsibilities and hence less effort on research than a faculty member with a small appointment devoted to responsibilities other than research. Expectations associated with particular appointment splits likely vary among institutions and over time within institutions, thereby introducing variation into our coefficient estimates. Nonetheless, research appointment had a consistently strong effect on all performance metrics (Table 2).

The sub-disciplinary covariates consistently contributed to model fit for all of the performance metrics we considered (Table 2). Moreover, individual sub-disciplinary effects conformed to our predictions. Specifically, effect sizes for all performance metrics were greatest for genetics, least for social sciences, and intermediate for ecology (Table 3). Across all 5 metrics, mean effect sizes were 1.42 (genetics) > 1.17 (ecology) > 0.81 (social sciences). Web of Science Journal Citation Reports, which allow calculation of citations per article for different disciplines, reveals the same ordering for genetics, ecology, and social sciences (Iglesias and Pecharromán 2007; R. K. Swihart, Purdue University, unpublished data). Thus, fisheries and wildlife faculty with a disciplinary base in genetics are expected, by virtue of disciplinary differences in citation and publication practices, to produce larger performance metrics than their peers with disciplinary roots in ecology or social sciences. The magnitude of differences in expectations depends on the sub-disciplines being compared (Fig. 4). The mean effect size for management (0.81) is comparable to the value for social sciences. Lower publication and citation-based performance metrics have been observed for more applied researchers in a variety of areas including biology (Imperial and Rodriguez-Navarro 2007), medicine (van Eck et al. 2013), and pharmacy (Thompson and Nahata 2012).

Our models provide a convenient tool for computing expected values of faculty with particular sets of attributes (Figs. 1–4). Thus, it is relatively straightforward for faculty or administrators to determine whether an individual's performance as indicated by these metrics is above or below average. Other studies have used reference groups as a basis for comparison. Typically, reference groups are individuals who have been recognized for research accomplishments (Podlubny and Kassayova 2006, Hirsch 2007, Petersen et al. 2012, Malesios and Psarakis 2014). In our study 39 faculty were recognized by their institutions for research accomplishments that resulted in naming designations, and our analysis indicates that the average named faculty member exhibited performance metrics that are better than non-named faculty. On average, named faculty members were more senior than the average faculty member as a whole (27.7 vs. 18.6 years post-Ph.D.) and more often male than female (90% vs. 79%). Named faculty focused more on management (62% vs. 45%), ecology (74% vs. 63%), social sciences (18% vs. 10%), and aquatic science (13% vs. 5%), on average. Plugging values for the average named professor into our models allows assessment of an average faculty member relative to an average named professor, after correcting for differences in academic age and other attributes. These comparisons reveal performances by named faculty for h-index, h_b-index, m quotient, number of publications, and annual citation rate that are 31%, 33%, 72%, 56%, and 96% greater, respectively, than the performance predicted for faculty of comparable academic age, research appointment, and sub-disciplinary focus (Figs. 1–3). Such comparisons could serve as barometers against which faculty may compare their performance as measured by publications and citations.

Our results reinforce the importance of interpreting performance metrics in the context of prevailing norms that vary among sub-disciplines. Fortunately, our model-based approach provides a direct means of estimating performance that accounts for these norms (Table 3). Moreover, our approach allows assignment of individuals to >1 sub-discipline in an additive fashion. For instance, if we wish to compute the predicted h-index for a wildlife conservation geneticist with a 50% research appointment who received the Ph.D. 20 years ago and first published 2 years before the Ph.D. was conferred, we would apply the coefficients in Table 3 and exponentiate:

$$\hat{h} = \exp(1.37 + 0.044 age - 0.001 age_c^2 + 0.006 research + 0.022 precocity + 0.264 genetics + 0.101 conservation).$$

In this example, academic age is 20 years, the squared age after centering on the mean (18.57 years) is 2 years, research appointment is 50%, precocity is 2, and the levels for the binary sub-discipline factor variables genetics and conservation are 1. Using these values in, and solving the equation, yields $e^{2.96}$, or $\hat{h} = 19$. From this example, and inspection of coefficients in Table 3, it is easy to see that, all else equal, a faculty member with sub-disciplinary activity in all categories except social sciences and management would be expected to produce the largest values for performance metrics. Of course such research breadth across fields is rarely achieved; the average faculty member in our database was active in 2 sub-disciplines, and no faculty member was categorized as active in more than 4.

Use of our models to predict the expected performance for an individual with a specified set of covariate values has some limitations. Firstly, accounting for publication precocity increases the expected value and thus holds an early publisher to a higher standard than someone who published more recently relative to attainment of the Ph.D. Secondly, the approach is limited to comparison of an individual to the average performance predicted by the model. Direct comparison of individuals in different sub-disciplines or stages of career requires an alternative approach (R. K. Swihart, unpublished data). Lastly, m quotient values are highly variable at early academic ages; hence, model predictions for m quotient are likely to be less accurate for individuals in the first 10 years since receiving the Ph.D. (Fig. 2).

Our 8 sub-disciplinary categories suffer from some arbitrariness in their selection; we chose them based on an ad hoc clustering of the original 36 fields, which we selected based on subjective examination of descriptions provided on web sites and key words in publications. Consequently, the classification of researchers into disciplines is undoubtedly imperfect. Similar problems afflict other studies that attempt discipline-based normalization, because subject categories invariably bleed into each other, and categories can be chosen poorly (Opthof and Leydesdorff 2010). Future use of tools such as Scholarometer (Kaur et al. 2012), in which a scholar’s disciplinary ties can be represented as a vector of weights intended to reflect activity in the various fields, could improve the accuracy of regression models or other approaches to normalization (Kaur et al. 2013). Alternatively, automated collection and clustering of keywords could be used to more objectively identify sub-disciplines (van Eck et al. 2013).

What do our results imply about the effect of early-career performance on longer-term success? Publication precocity predicted performance for all 5 metrics; faculty who published earlier in their career exhibited greater levels of performance, all else equal. Our results are consistent with the findings of Laurance et al. (2013). They examined factors that affected success of 182 faculty in biological and environmental sciences from 35 universities across 4 continents. They defined success as number of publications produced during the decade following attainment of the Ph.D. Publication precocity and the number of refereed papers published by attainment of the Ph.D. were predictors in their top-ranked models. We did not consider as a predictor the number of publications produced by attainment of the Ph.D. because it is highly autocorrelated with the resulting performance metrics (Penner et al. 2014). Nonetheless, it is clear that early publication success is an important factor in subsequent performance. Faculty advisors and their new graduate students who are considering academic careers may benefit from frank discussions related to the conduct of high-quality research and timely submission of such work for publication.

Sub-disciplinary differences in citation and publication practices raise an issue that is not dealt with by performance metrics based on these currencies, namely, the audiences and impact of scholarship can vary considerably across sub-disciplines. Consider 2 wildlife researchers—one hired to work with state agencies on habitat issues of concern to them, and the other hired to ask fundamental questions about adaptation to changing environments. The first faculty member publishes a paper that reports effects of mowing schedules on mortality and recruitment of small game species, whereas the second faculty member publishes a paper that tests hypotheses about the evolution of mammalian dispersal using a novel method in genetics. Our results suggest that the mowing paper may be cited much less than the genetics paper. But our performance metrics are silent on the broader impacts of the mowing paper. Were its findings distributed by extension specialists and to the media? How did it influence management of public and private lands in the state or region? How many hectares were affected? How many thousands of additional game animals were produced? Our point is simple: although our regression models can account for variation in citation- and publication-based performance, they are not designed for and are incapable of measuring impact in a more holistic manner. Pillay (2013) noted that a mandate to conduct research in particular sub-disciplines may be detrimental to performance measured via publications and citations, and argued that consideration of a faculty member's complete academic profile is vital. We agree and emphasize that the metrics we considered, while appealing, consider only one aspect of faculty performance.

MANAGEMENT IMPLICATIONS

Our models provide a potentially useful tool with which to evaluate the component of performance of faculty related to publications and citations, because they permit performance in this realm to be placed quantitatively within a broader context of performance by peers. We emphasize that quantitative metrics, although alluring, cannot and should not replace qualitative assessment of performance by peers. Our final models generally explained about 50% of the deviance, although the model for annual citation rate explained only 28% (Table 1). Thus, considerable variation was left unexplained. Other covariates may contribute in a meaningful way to the explanation of this residual deviance. In addition, there are dozens of performance metrics (reviewed by Bornmann et al. 2011, Wildgaard et al. 2014), some of which might respond quite differently to the covariates we used. We encourage future efforts to improve on the covariate set presented here, and to assess its robustness with a wider array of performance metrics. Even then, administrators should avoid placing too much importance on minor differences in performance metrics of individuals (Engqvist and Frommen 2008), and take care to use performance metrics as one tool in a comprehensive system for evaluation of faculty performance (Hicks et al. 2015).

ACKNOWLEDGMENTS

We thank the dozens of administrators at participating universities, all of whom responded to our request for information on functional appointments of faculty. S. A. Hamilton helped with collection of covariate data and organization of the database. J. D. Antonides, J. L. Berl, J. M. Doyle, Z. S. Feiner, N. B. Fernandez, Y. Ji, K. F. Kellner, N. I. Lichti, S. Mathur, D. L. Nelson, M. Nizamlioglu, T. J. Smyser, and J. R. Willoughby provided helpful comments on an earlier version of the manuscript. M. Sundaram was supported in part by funds from the Fred M. van Eck Forest Foundation for Purdue University.

LITERATURE CITED

Abramo, G., C. A. D'Angelo, and F. Viel. 2010. A robust benchmark for the h- and g-indexes. Journal of the American Society for Information Science and Technology 61:1275–1280.

Acuna, D. E., S. Allesina, and K. P. Kording. 2012. Predicting scientific success. Nature 489:201–202.

Aoun, S. G., B. R. Bendok, R. J. Rahme, R. G. Dacey, Jr., and H. H. Batjer. 2013. Standardizing the evaluation of scientific and academic performance in neurosurgery – critical review of the “h” index and its variants. World Neurosurgery 80(5):E85–E90.

Bornmann, L., R. Mutz, S. E. Hug, and H.-D. Daniel. 2011. A multilevel meta-analysis of studies reporting correlations between the h index and 37 different h index variants. Journal of Informetrics 5:346–359.

Bornmann, L., G. Wallon, and A. Ledin. 2008. Is the h index related to (standard) bibliometric measures and to the assessments by peers? An investigation of the h index by using molecular life sciences data. Research Evaluation 17:149–156.

Brown, O. R. 2012. The h_b-index, a modified h-index designed to more fairly assess author achievement. Redox Report 17:176–178.

Engqvist, L., and J. G. Frommen. 2008. The h-index and self-citations. Trends in Ecology and Evolution 23:250–252.

Hicks, D., P. Wouters, L. Waltman, S. de Rijcke, and I. Rafols. 2015. The Leiden Manifesto for research metrics. Nature 520:429–431.

Hirsch, J. E. 2005. An index to quantify an individual’s scientific research output. Proceedings of the National Academy of Sciences 102:16569–16572.

Hirsch, J. E. 2007. Does the h index have predictive power? Proceedings of the National Academy of Sciences, USA 104:19193–19198.

Hönekopp, J., and J. Khan. 2012. Future publication success in science is better predicted by traditional measures than by the h index. Scientometrics 90:843–83.

Iglesias, J. E., and C. Pecharromán. 2007. Scaling the h-index for different scientific ISI fields. Scientometrics 73:303–320.

Imperial, J., and A. Rodríguez-Navarro. 2007. Usefulness of Hirsch's h-index to evaluate scientific research in Spain. Scientometrics 71:271–282.

Kaur, J., D. T. Hoang, X. Sun, L. Possamai, M. JafariAsbagh, S. Patil, and F. Menczer. 2012. Scholarometer: a social framework for analyzing impact across disciplines. PLoS ONE 7(9):e43235.

Kaur, J., F. Radicchi, and F. Menczer. 2013. Universality of scholarly impact metrics. Journal of Informetrics 7:924–932.

Kelly, C. D., and M. D. Jennions. 2006. The h index and career assessment by numbers. Trends in Ecology and Evolution 21:167–170.

Kokko, H., and W. J. Sutherland. 1999. What do impact factors tell us? Trends in Ecology and Evolution 14:382–384.

Laurance, W. F., D. C. Useche, S. G. Laurance, and C. J. A. Bradshaw. 2013. Predicting publication success for biologists. BioScience 63:817–823.

Malesios, C. C., and S. Psarakis. 2014. Comparison of the h-index for different fields of research using bootstrap methodology. Quality and Quantity 48:521–545.

Mazloumian, A. 2012. Predicting scholars' scientific impact. PLoS ONE 7(11):e49246.

Moss-Racusin, C. A., J. F. Dovidio, V. L. Brescoll, M. J. Graham and J. Handelsman. 2012. Science faculty's subtle gender biases favor male students. Proceedings of the National Academy of Sciences, USA 109:16474–16479.

Opthof, T., and L. Leydesdorff. 2010. Caveats for the journal and field normalizations in the CWTS ("Leiden") evaluations of research performance. Journal of Informetrics 4:423–430.

Pagel, P. S., and J. A. Hudetz. 2011*a*. H-index is a sensitive indicator of academic activity in highly productive anaesthesiologists: results of a bibliometric analysis. Acta Anaesthesiologica Scandinavica 55:1085–1089.

Pagel, P. S., and J. A. Hudetz. 2011*b*. An analysis of scholarly productivity in United States academic anaesthesiologists by citation bibliometrics. Anaesthesia 66:873–878.

Penner, O., R. K. Pan, A. M. Petersen, K. Kaski, and S. Fortunato. 2014. On the predictability of future impact in science. Scientific Reports 3:3052.

Pepe, A., and M. J. Kurtz. 2012. A measure of total research impact independent of time and discipline. PLoS ONE 7(11):e46428.

Perianes-Rodriguez, A., and J. Ruiz-Castillo. 2015. Within- and between-department variability in individual productivity: the case of economics. Scientometrics 102:1497–1520.

Perna, L. W. 2005. Sex differences in faculty tenure and promotion: the contribution of family ties. Research in Higher Education 46:277–307.

Petersen, A. M., M. Riccaboni, H. E. Stanley, and F. Pammolli. 2012. Persistence and uncertainty in the academic career. Proceedings of the National Academy of Sciences, USA 109:5213–5218.

Pillay, A. 2013. Academic promotion and the h-index. Journal of the American Society for Information Science and Technology 64:2598–2599.

Podlubny, I., and K. Kassayova. 2006. Towards a better list of citation superstars: compiling a multidisciplinary list of highly cited researchers. Research Evaluation 15:154–162.

Selek, S., and A. Saleh. 2014. Use of h index and g index for American academic psychiatry. Scientometrics 99:541–548.

Thompson, D. F., and M. C. Nahata. 2012. Pharmaceutical science faculty publication records at research-intensive pharmacy colleges and schools. American Journal of Pharmaceutical Education 76(9):173.

van Dijk, D., O. Manor, and L. B. Carey. 2014. Publication metrics and success on the academic job market. Current Biology 24:R516–R517.

van Eck, N. J., L. Waltman, A. F. J. van Raan, R. J. M. Klautz, and W. C. Peul. 2013. Citation analysis may severely underestimate the impact of clinical research as compared to basic research. PLoS ONE 8(4):e62395.

Venables, W. N., and B. D. Ripley. 2002. Modern applied statistics with S, fourth edition. Springer, New York, New York, USA.

Wildgaard, L., J. W. Schneider, and B. Larsen. 2014. A review of the characteristics of 108 author-level bibliometric indicators. Scientometrics 101:125–158.

Xu, Y. J. 2008. Gender disparity in STEM disciplines: a study of faculty attrition and turnover intentions. Research in Higher Education 49:607–624.

Zhang, C.-T. 2009. The e-index, complementing the h-index for excess citations. PLoS ONE 4(5):e5429.

Associate Editor: Michael Morrison.

Figure Captions

Figure 1. Scatterplot of h- and h_b-indexes against professional age for 437 tenure-track faculty in fisheries and wildlife from 33 American universities in 2015. Lines depict predicted values of the response variables for 3 levels of research allocation across a range of years since obtaining a Doctor of Philosophy (Ph.D.) degree, assuming a research focus in aquatic sciences and average publication precocity (i.e., 3.6 yr). Solid circles represent faculty holding named professorships. Black squares are observed index value for the average named faculty (upper square in panel) and predicted (lower) index value for a faculty member with covariate values equal to those of an average named faculty member.

Figure 2. Scatterplot of m quotient against professional age for 437 tenure-track faculty in fisheries and wildlife from 33 American universities in 2015. Lines depict predicted values of the response variable for percentage research appointment (10%, 90%) and the number of years before the Doctor of Philosophy (Ph.D.) degree that the first publication appeared (lag, 0 or 7 yr). Curves are based on fitted models for a faculty member with a focus in aquatic science. We excluded 2 faculty members with professional age = 1 year from the graph to enhance visualization; they had m quotient values of 6 and 7. Solid circles represent faculty holding named professorships. Black squares are observed index value for the average named faculty (upper) and predicted (lower) index value for a faculty member with covariate values equal to those of an average named faculty member.

Figure 3. Scatterplot of number of publications against academic age for 437 tenure-track faculty in fisheries and wildlife from 33 American universities in 2015. Lines depict predicted values of the response variable for percentage research appointment (10%, 90%) and the number of years before the Doctor of Philosophy (Ph.D.) degree that the first publication appeared (lag, 0 or 7 yr), based on fitted models for a faculty member with a research focus in aquatic science. Solid circles represent faculty holding named professorships. Note that the scale of axes for panels displaying males and females differ. Black squares are observed index values for the average named faculty (upper square in each panel) and predicted (lower) index values for a faculty member with covariate values equal to those of an average named faculty member.

Figure 4. Scatterplots of h-index and m quotient against academic age for 437 tenure-track faculty in fisheries and wildlife from 33 American universities in 2015. The colored lines depict predicted values of the response variables for each sub-discipline considered separately, based on fitted models for a faculty member with a 50% research allocation and average publication precocity (i.e., first published 3.6 yr before attaining a Doctor of Philosophy [Ph.D.] degree). Gold circles represent faculty holding named professorships.

Table 1. Categories of sub-disciplines derived from 36 areas of scholarship identified by 437 tenure-track faculty in 2015 from 33 universities in the United States in the bibliometric analysis.

Quantitative	Conservation	Disease	Genetics	Social sciences	Management	Aquatic science	Ecology
Quantitative	Conservation	Disease	Genetics	Human dimensions	Management	Water quality	Ecology
Geospatial		Physiology	Evolution	Planning	Extension	Limnology	Behavior
		Ecotoxicology	Molecular biology	Policy	Aquaculture	Hydrology	Natural history
		Nutrition	Systematics	Economics	Habitat	Geochemistry	
		Animal health		Sociology	Restoration	Geomorphology	
		Parasitology		Citizen science			
		Morphology		Decision-making			
		Epidemiology		Education			

Table 2. Likelihood ratio tests of significance for nested models to predict h-index, h_b-index, m quotient, number of publications, and annual citation rates for 437 tenure-track faculty in 2015 in wildlife and fisheries from 33 universities in the United States. We used

negative binomial regression models for h- and h_b-indexes, number of publications, and annual citation rates, whereas we used a general linear model with Gaussian error for m quotient. Residual degrees of freedom (residual df), likelihood ratio test statistic (LR), and *P*-value (*P*) are reported for each model.

Model[a]	Residual df[b]	h-index		h_b-index		No. of publications		Cites/year		m quotient	
		LR	*P*	LR	*P*	LR	*P*	LR	*P*	LR	*P*
Intercept only	436										
D	435	1.715	0.19	0.763	0.38	0.6	0.44	−0.037	0.99	0.3	0.58
D + age[c]	434	182.434	<0.01	162.922	<0.01	193.6	<0.01	6.700	<0.01	72.5	<0.01
D + age + age^2	433	14.176	<0.01	12.823	<0.01	6.1	0.01	0.600	0.41		
D + age + age^2 + res	432	50.852	<0.01	45.875	<0.01	39.6	<0.01	42.708	<0.01	9.5	<0.01
D + age + age^2 + res + sex	431	0.240	0.63	0.542	0.46	6.7	0.01	0.852	0.36	2.3	0.13
D + age + age^2 + res + sex + age×sex	430					1.2	0.26				

D + age + age^2 + res + sex + age×sex + SD	422	90.700	<0.01	88.455	<0.01	37.8	<0.01	96.483	<0.01	16.7	0.03
D + age + age^2 + res + sex + age×sex + SD + lag	421	14.200	<0.01	17.400	<0.01	31.4	<0.01	18.487	<0.01	2.8	0.09

[a]Variable acronyms: D = discipline (wildlife or fisheries); age = academic age; age^2 = square of age, after centering on mean age; res = percent of appointment allocated to research; SD = sub-discipline (disease, genetics, social sciences, management, ecology, quantitative, conservation, aquatic science); lag = publication precocity.

[b]For m quotient, residual degrees of freedom are reduced by 1 for intercept only, D, and D + age models.

[c]For m quotient, age was transformed as ln (age + 0.5).

Table 3. Final models for predicting 5 bibliometric indexes as a function of academic age, sex, research allocation, research sub-discipline, and publication precocity for 437 tenure-track fisheries and wildlife faculty in 2015 from 33 universities in the United States. The over-dispersion parameter of the negative binomial models is given by θ. Coefficient estimates marked with ** are significant at an α of 0.05 and values marked by * are significant at an α of 0.1.

	h-index	h_b-index	No. publications	Cites/year	m quotient

Predictor[a]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	1.370**	0.089	2.220**	0.094	2.176**	0.129	2.305**	0.167	2.129	0.140
Age	0.044**	0.002	0.045**	0.002	0.056**	0.003	0.022**	0.004	−0.555	0.037
Age^2	−0.001**	0.0002	−0.0008**	0.002	−0.001**	0.0002				
% research	0.006**	0.001	0.006**	0.001	0.008**	0.001	0.012**	0.002	0.004**	0.001
Sex					0.173**	0.073				
Disease	0.213**	0.058	0.223**	0.062	0.306**	0.081	0.442**	0.113	0.178**	0.071
Genetics	0.264**	0.068	0.292**	0.074	0.237**	0.096	0.596**	0.133	0.281**	0.084
Social	−0.212**	0.076	−0.209**	0.079	−0.112	0.101	−0.351**	0.14	−0.146*	0.087
Management	−0.204**	0.044	−0.181**	0.048	−0.11*	0.062	−0.344**	0.086	−0.195**	0.054
Ecology	0.135**	0.047	0.155**	0.05	0.07	0.064	0.289**	0.09	0.093*	0.056
Quantitative	0.172**	0.057	0.233**	0.061	0.12	0.08	0.494**	0.11	0.132*	0.069
Conservation	0.101**	0.047	0.137**	0.05	0.09	0.066	0.309**	0.091	0.064	0.057
Aquatic	0.148	0.092	0.166	0.101	0.06	0.132	0.346*	0.184	0.113	0.115
Lag	0.022**	0.005	0.027**	0.006	0.048**	0.008	0.054**	0.01	0.022**	0.006

θ	9.55	1.09	5.624	0.459	3.06	0.22	1.53	0.102

[a]Variable acronyms: age = academic age; age^2 = square of age, after centering on mean age; % research = percent of appointment allocated to research; sub-disciplines (disease, genetics, social sciences, management, ecology, quantitative, conservation, aquatic science); lag = publication precocity.

Appendix A. Universities and academic units for which data from tenure-track faculty were included in the bibliometric analysis. We considered only universities that were members of the National Association of University Fisheries and Wildlife Programs in either 2014 or 2015 and classified as Doctoral/Research Universities-Extensive[a]. Universities are listed alphabetically.

University	School, Academic Unit, or Program
Auburn University	Fisheries, Aquaculture and Aquatic Sciences
	Forestry and Wildlife Sciences
Clemson University	Agricultural, Forest, and Environmental Sciences
Colorado State University	Fish, Wildlife and Conservation Biology

Cornell University	Natural Resources
Iowa State University	Natural Resource Ecology and Management
Louisiana State University	Renewable Natural Resources
Michigan State University	Fisheries and Wildlife
Mississippi State University	Wildlife, Fisheries and Aquaculture
North Carolina State University	Forestry and Environmental Resources
	Applied Ecology
Ohio State University	Environment and Natural Resources
Oklahoma State University	Natural Resource Ecology and Management
Oregon State University	Fisheries and Wildlife
Pennsylvania State University	Ecosystem Science and Management
Purdue University	Forestry and Natural Resources
Texas A&M University	Wildlife and Fisheries Sciences
Texas Tech University	Natural Resources Management
University of Arizona	Natural Resources and the Environment
University of California-Davis	Wildlife, Fish and Conservation Biology

University of Connecticut	Natural Resources and the Environment
University of Florida	Fisheries and Aquatic Sciences
	Wildlife Ecology and Conservation
University of Georgia	Forestry and Natural Resources
University of Idaho	Fish and Wildlife Sciences
University of Kentucky	Forestry
University of Maine	Wildlife, Fisheries and Conservation Biology
University of Massachusetts	Environmental Conservation
University of Minnesota	Fisheries, Wildlife and Conservation Biology
University of Missouri	Natural Resources
University of Nebraska	Natural Resources
University of Tennessee	Forestry, Wildlife, and Fisheries
University of Wisconsin-Madison	Forest and Wildlife Ecology
Virginia Tech University	Fish and Wildlife Conservation
Washington State University	Environment
West Virginia University	Wildlife and Fisheries Resources

[a]From www.washington.edu/tools/universities.html. Under the most recent classification (carnegieclassifications.iu.edu) institutions are further subdivided into Comprehensive Doctoral, Doctoral-STEM dominant, and Doctoral-professional dominant.

Figure 1.

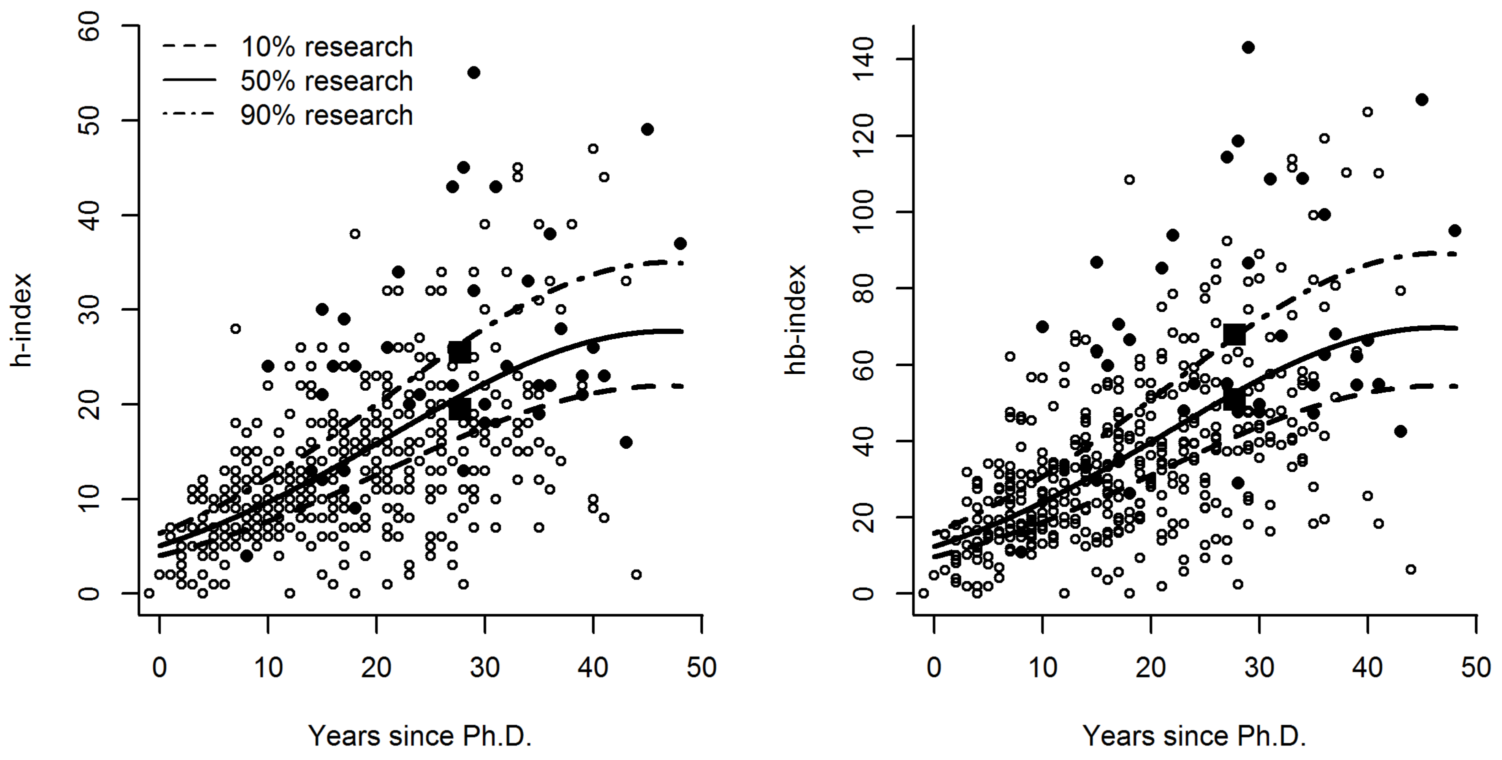

10% research
50% research
90% research
h-index
0
10
20
30
40
50
60
Years since Ph.D.
0
10
20
30
40
50
hb-index
0
20
40
60
80
100
120
140
Years since Ph.D.
0
10
20
30
40
50

Figure 2.

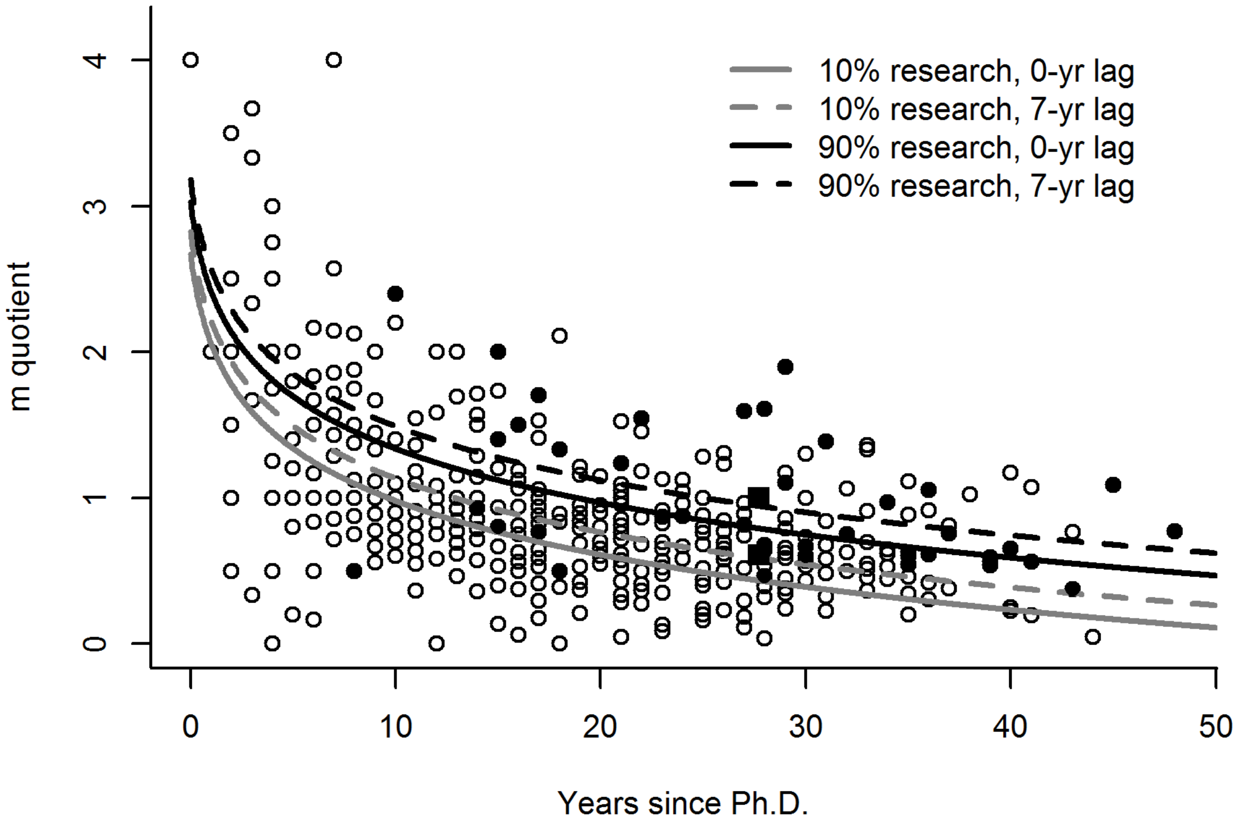
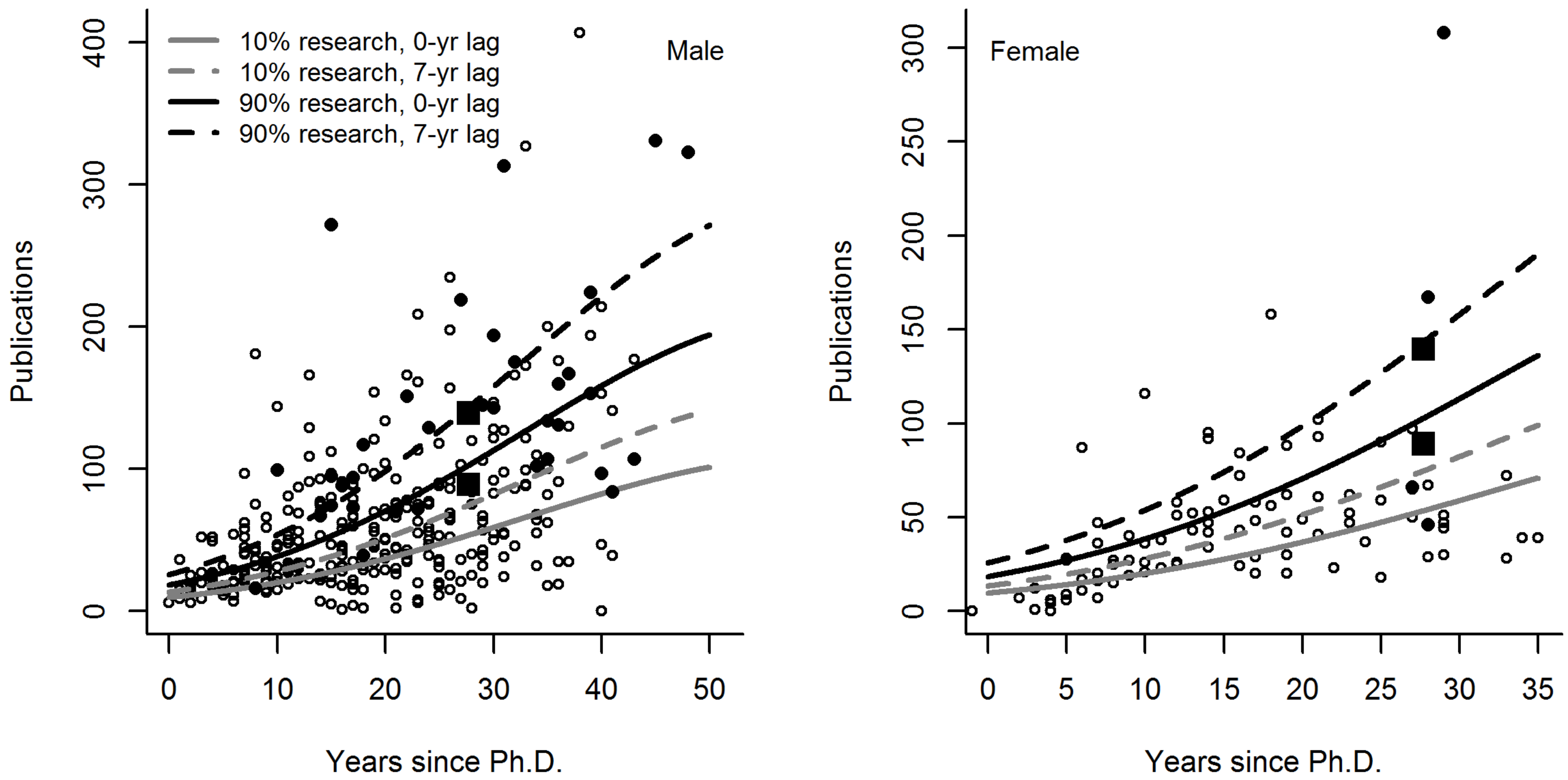
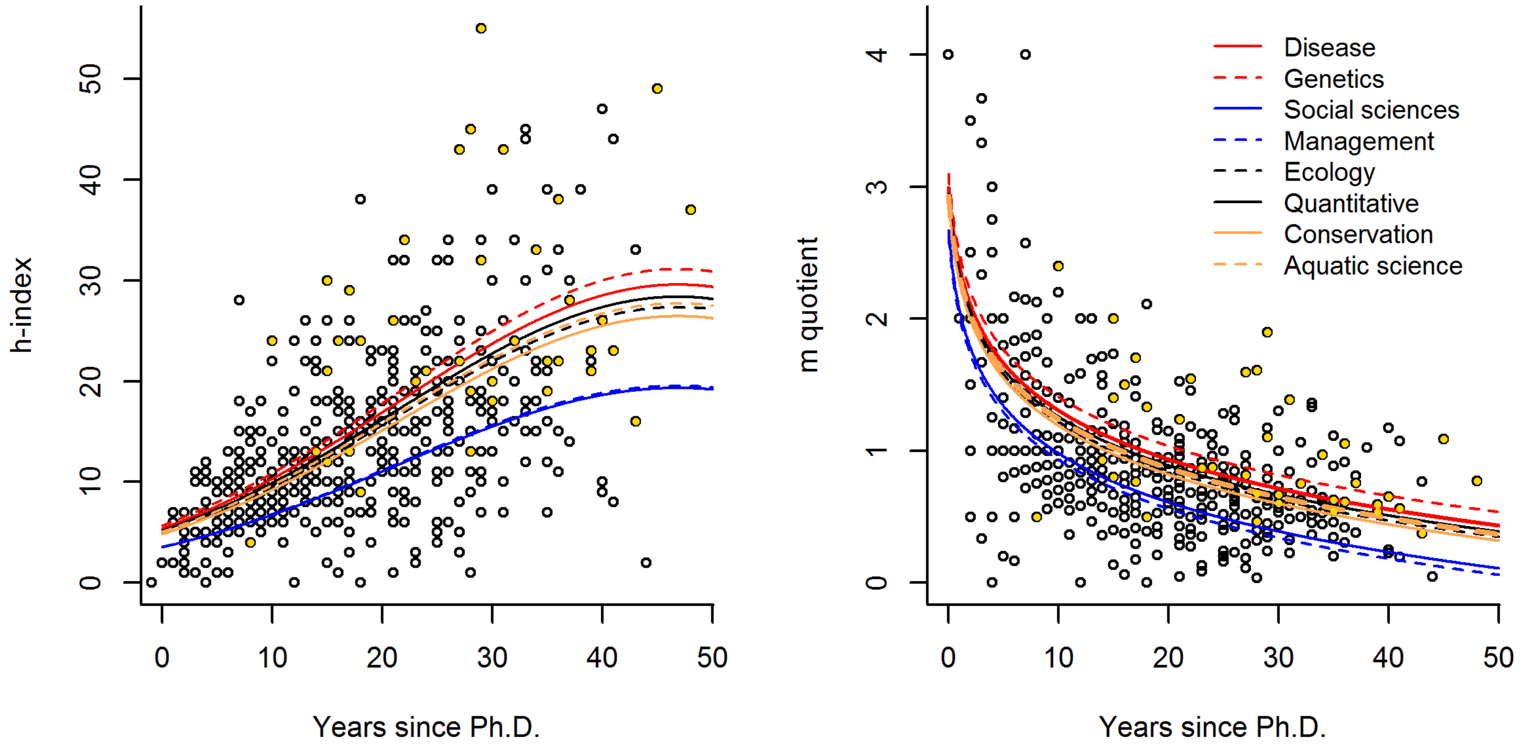

10% research, 0-yr lag
10% research, 7-yr lag
90% research, 0-yr lag
90% research, 7-yr lag
m quotient
Years since Ph.D.
0
1
2
3
4
0
10
20
30
40
50

Figure 3.



10% research, 0-yr lag
10% research, 7-yr lag
90% research, 0-yr lag
90% research, 7-yr lag
Male
Publications
Years since Ph.D.
Female
Publications
Years since Ph.D.

Figure 4.



h-index
0
10
20
30
40
50
Years since Ph.D.
m quotient
0
1
2
3
4
Disease
Genetics
Social sciences
Management
Ecology
Quantitative
Conservation
Aquatic science