Exploring the Veterinary Literature: A Bibliometric Methodology for Identifying Interdisciplinary and Collaborative Publications

Jessica R. Page, Heather K. Moberly, Gregory K. Youngen, and Barbara J. Hamel

Veterinary medical research traditionally focuses on animal health and wellness; however, research activities at veterinary colleges extend beyond these traditional areas. In this study, we analyzed eleven years of Web of Knowledge-indexed peer-reviewed articles from researchers at the twenty-eight United States American Veterinary Medical Association (AVMA) accredited veterinary colleges. We had three goals in assessing the published literature of veterinary college researchers. First, we identified a list of journals and research areas outside veterinary medicine in which veterinary researchers publish. This list of journals can be customized to identify those most essential at each institution. Second, we identified collaborative work by veterinary researchers across disciplines and institutions. Using textual analysis tools and visualizations helped us illustrate and clarify these data. Last, we developed a methodology for defining an interdisciplinary serials list outside a subject core that can be customized for specific institutions and subject areas.

Veterinary medicine, especially clinical veterinary medicine, is a well-defined field of study "pertaining to the diseases and other disorders of domestic animals."[1] Journals covering this discipline were first organized into a core list in 1978, then updated in 1981 and 1986 and again in 2010.[2] The veterinary medical aspects of research at the twenty-eight American Veterinary Medical Association (AVMA) Council on Education's (COE) accredited schools go beyond this description of veterinary medicine and are "interdisciplinary" in the truest sense of including two or more distinctly different areas.[3] The key for this study is that much of the veterinary science research, and therefore literature, combines veterinary medicine with one or more related, also well-defined, disciplines. These include areas of basic biological research,

Jessica R. Page is Assistant Professor and Head, Veterinary Medicine Library at The Ohio State University, e-mail: page.84@osu.edu; Heather K. Moberly is Professor and Coordinator of Veterinary Services at the Medical Sciences Library at Texas A&M University, e-mail: hmoberly@library.tamu.edu; Gregory K. Youngen is Associate Dean of Library Services at Indiana State University, e-mail: gregory.youngen@indstate.edu; and Barbara J. Hamel is Head of Collection Services, Steenbock Library University of Wisconsin-Madison, e-mail: bhamel@library.wisc.edu.

doi:10.5860/crl.75.5.664 crl13-476

such as biochemistry and molecular and cellular biology; biomedical research including immunology, virology, and neuroscience; and agriculture and animal production.

For librarians, this creates a collection development conundrum. Shrinking budgets, rising subscription costs, and limited or repurposed spaces preclude libraries from providing all the potential resources veterinary researchers may need beyond the expected core of their subject. There is no core list for these ancillary areas. Although there are commonalities and trends within the veterinary field, determining which journals outside veterinary medicine are essential must to a large extent be defined at a local level.

Project Background

Youngen and Gullen compiled and analyzed the published research output from eight of the twenty-eight AVMA accredited veterinary schools (see table 1) and reported in 2010 that nearly half the articles published by the researchers at these veterinary schools were in journals outside the core.[4] Youngen subsequently published an article defining the multidisciplinary complementary core journal list based on University of Illinois veterinary research.[5] The current study builds upon these works by examining the research output of all twenty-eight AVMA accredited veterinary schools.

Project Goals

This study has three goals. The first is to identify the publications of the veterinary researchers at the twenty-eight AVMA COE accredited Colleges of Veterinary Medicine (CVMs) in the United States and separate the core veterinary journals from the others, identifying a list of key nonveterinary journals that can be customized based on the research output of each CVM. A journal is considered core if it appears on the current core veterinary medical serial list of 123 titles covering 36 subjects, which was published in the *Journal of the Medical Library Association* in 2010.[6] The second goal of this paper is to identify collaborations between CVM researchers and researchers in other fields or at other institutions. The final goal is to create and document a transferrable, reproducible methodology for defining a local noncore serial list for interdisciplinary fields. We strive to make this method of bibliometric analysis accessible for all to identify collaborative efforts by disciplines in their local environment and identify collaborators in other disciplines and from other institutions. This includes a demonstration of how visualization tools may be used to represent complex data in clear and meaningful ways.

Literature Review

Collaborative Research

Scientific collaboration has been on the increase throughout the twentieth century.[7] The proportion of coauthored to single-author papers has changed such that coauthored papers predominate today, particularly in natural sciences such as biology.[8] In addition, the number of authors per paper in the sciences has steadily increased.[9]

This pattern holds true in veterinary medicine. An analysis of articles published from 1974 to 2004 in the *Journal of Veterinary Medical Education* showed an increase in the median number of authors per paper from one in the first decade of the study to three in the last decade, as well as an increase in interinstitutional collaboration since 1990.[10]

Interdisciplinary Research

Interdisciplinary research dates to the invisible colleges of the 17th century, but it has gained increased attention in recent years.[11] Scientists recognize the need to apply the understanding of multiple disciplines to address problems, and institutions have established interdisciplinary programs and research centers to assist in these efforts.[12] Funding

TABLE 1
AVMA-Accredited Colleges of Veterinary Medicine*

Abbreviation	CVM	Pilot Study CVM
AUB	Auburn University College of Veterinary Medicine	
CAL	University of California-Davis School of Veterinary Medicine	
CORNELL	Cornell University College of Veterinary Medicine	
CSU	Colorado State University College of Veterinary Medicine and Biomedical Sciences	
GEO	University of Georgia College of Veterinary Medicine	
ILLINOIS	University of Illinois College of Veterinary Medicine	X
ISU	Iowa State University College of Veterinary Medicine	X
KSU	Kansas State University College of Veterinary Medicine	
LSU	Louisiana State University School of Veterinary Medicine	
MICH ST	Michigan State University College of Veterinary Medicine	X
MISS	Mississippi State University College of Veterinary Medicine	
Mizzou	University of Missouri-Columbia College of Veterinary Medicine	X
NCSU	North Carolina State University College of Veterinary Medicine	
OkState	Oklahoma State University Center for Veterinary Health Sciences	
ORE	Oregon State University College of Veterinary Medicine	
OSU	Ohio State University College of Veterinary Medicine	X
Penn	University of Pennsylvania School of Veterinary Medicine	
Purdue	Purdue University School of Veterinary Medicine	X
TAMU	Texas A&M University College of Veterinary Medicine & Biomedical Sciences	
TENN	University of Tennessee College of Veterinary Medicine	

TABLE 1
AVMA-Accredited Colleges of Veterinary Medicine*

Abbreviation	CVM	Pilot Study CVM
Tufts	Tufts University Cummings School of Veterinary Medicine	
TUSK	Tuskegee University School of Veterinary Medicine	
UFL	University of Florida College of Veterinary Medicine	
UMN	University of Minnesota College of Veterinary Medicine	X
VIR TECH	Virginia Polytechnic Institute and State University Virginia-Maryland Regional College of Veterinary Medicine	
WesternU	Western University of Health Sciences College of Veterinary Medicine	
WISC	University of Wisconsin-Madison School of Veterinary Medicine	X
WSU	Washington State University College of Veterinary Medicine	

*List of the twenty-eight AVMA-accredited colleges of veterinary medicine with abbreviations used in this study, with the six institutions used in the 2010 pilot study noted.

initiatives for interdisciplinary research from such organizations as the National Science Foundation, National Institutes of Health, and Canadian Institutes of Health Research have helped encourage further interdisciplinary research.[13] This is particularly notable in applied sciences such as environmental science, public health, and biomedical sciences.[14] Interdisciplinary research is also common in veterinary medical research, which includes not only clinical veterinary medicine but broader veterinary science fields such as livestock production, food safety, public health, and translational medicine.

Bibliometrics

Bibliometrics is the "application of mathematical and statistical methods to books and other media," and scientometrics (sometimes translated as measurement of science) is "the application of quantitative methods which are dealing with the analysis of science as viewed in an information process."[15] When they were first defined in 1969, each represented related fields of study, but they are now considered nearly synonymous.[16] Later, the term informetrics defined the statistical analysis of communication as a subfield of information studies.[17] Webometrics and cybermetrics further specify this type of study, but specifically about electronic resources.[18] This paper is a bibliometric or scientometric study intended to map and identify the works in which veterinary researchers publish.

The current study includes analysis using Bradford's Law, which states that a small number of journals account for a large portion of the articles published in a subject area, with a larger number of journals publishing fewer articles in that subject area.[19] Bradford's Law predicts that journals that publish articles in a field will fall within a set of zones based on their productivity, with all zones containing approximately the same number of articles, but each successive zone including more journals than the previous zone.

Data Visualization

Data visualization is a means of physically depicting data and presenting it to an audience in a way that can be easily processed and understood.[20] Some data visualizations are common and recognizable, such as comparing the sizes of two or more categories of data with a bar chart; comparing components of a set of data, as with a pie chart; and tracking changes over time, as with a line chart.[21] Other familiar visualizations include word clouds, which can show trends in word usage and which have been broadly used in libraries.[22]

Presenting bibliometric data generally requires additional visualization tools and different types of charts to represent relationships between data points. One such visualization type is the network diagram, which is a map showing the connections within a network. Each member of a network (for instance, an author or institution) is typically represented by a dot, with connections between members (such as coauthored publications, citations, social network connections) shown as a line or arrow. The dots in these diagrams often cluster, showing connectedness between members.[23] Another visualization type useful for showing relationships is the treemap. Treemaps show hierarchical data, typically as nested rectangles where each rectangle's size is in proportion to the data, though these visualizations take many forms.[24] While this type of visualization was designed to display computer directories, it has been used in a range of applications and can display the relative number of publications, citations, or other bibliometric measures within a large set of data. [25]

Methods

As an interdisciplinary subject, veterinary science is covered in a number of abstracting and indexing products such as CAB Abstracts, PubMed/MEDLINE, Web of Knowledge, Scopus, Google Scholar, and Biological Abstracts, in addition to smaller specialized products including VetMed Resource, Veterinary Information Network (VIN), and PrimateLit.[26] Others have compared the detailed features of the broadest of these databases, discussed what qualities and limitations to consider when choosing a database for a citation analysis, and compared the coverage of the veterinary literature across databases.[27] We needed to determine which of the products available to all coauthors provided sufficient interdisciplinary coverage to include a broad swath of academic fields beyond the broad life sciences or health sciences, clean data with minimal inconsistencies and requiring minimal cleanup, and institutional affiliation data for all authors (see table 2). Additionally, we needed to be able to export and manipulate the data efficiently. We chose Thompson Reuters' Web of Knowledge because it met all of these criteria.[28]

TABLE 2
Information Resources Considered and Variables Investigated

	Web of Knowledge	CAB Abstracts	Scopus	Google Scholar	PubMed
Interdisciplinary Coverage	X		X	X	
Clean Data	X	X			X
Affiliation Data for All Authors is Indexed	X		X		
All of This Study's Authors Have Access	X	X		X	X

We divided the 28 veterinary schools among the coauthors, and each author developed trial search strategies for his or her assigned CVMs to be conducted in Web of Knowledge in the Science Citation Index (SCI), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI) for the years 2000–2010. After comparing search results with and without lemmatization (Web of Knowledge's option to find search term variants), we chose to run the searches with lemmatization enabled.

We developed initial search strategies for each CVM using the institution's zip code and "vet" in the Address field, along with other institution-specific search terms, like names of specific departments and programs. Depending on the CVM, the result sets of these initial searches were often incomplete and error-ridden. Simple typographical errors and inconsistencies in author-provided affiliation information were widespread. For the same CVM, an author may have listed his or her affiliation in a number of different ways: the department, an abbreviation for the department, the college, an abbreviation for the college, the teaching hospital, an abbreviation for the teaching hospital, or the state diagnostic laboratory if the author or the college was affiliated with it. CVMs also conduct research in locations other than their primary campus location. For example, The Ohio State University's Ohio Agricultural Research and Development Center is located in Wooster, over 90 miles from its main campus in Columbus. Authors sometimes listed incorrect zip codes, including city zip codes rather than university-specific zip codes, as well as nonexistent zip codes.

Additionally, truncating the term "veterinary" to "vet" was problematic because of research published by Veterans Affairs facilities or the use of "veteran" in the name of a department, building, street, or coauthor affiliation. The term "veterinary" could also be in a coauthor's affiliation, whether copublishing with a private practitioner or someone at a department of veterinary medicine, that is not in a CVM. For example, in Pennsylvania the CVM is at the University of Pennsylvania, but the Pennsylvania State University has a Department of Veterinary and Biomedical Sciences in its College of Agricultural Sciences.

We developed test search strings, presented preliminary data and, based on feedback, consulted with the veterinary medicine librarian at each institution to ensure we included all programs and campus locations associated with their particular CVM.[29] The input from the CVM librarians was invaluable because it helped to clarify the false data hits and highlighted additional individual affiliation relationships. For some CVMs, librarian input confirmed that our search string was accurate; for others, librarian input increased the complexity and accuracy of the search (see table 3). We agreed to share our data about each CVM with that school.

TABLE 3
Sample Search Strings, before and after Local Librarian's Assistance

Example CVM	Original Search String	Revised Search String
Virginia Polytechnic Institute and State University	AD=(vet med or vet coll or coll vet) same (virginia tech or virginia polytechnic) same blacksburg)	AD=(vet med or vet coll or coll vet) same (virginia tech or virginia polytech or virginia polytechnic or virginia maryland reg or VA MD or anim clin sci) same blacksburg) or (equine med same leesburg)
Western University of Health Sciences	AD=(vet SAME western SAME pomona)	AD=(vet SAME western SAME pomona)

Once we were satisfied that we had the best search strategy for each institution, we again searched Web of Knowledge for articles from each CVM published from 2000 to 2010. The resulting data set consisted of 51,721 records. We used the Analyze Results function in Web of Knowledge to create subsets of the search results using the following parameters: Source Titles, Subject Areas, Institutions, Countries/Territories, and Publication Years. All were sorted by record count except for Publication Years, which were sorted chronologically.

We exported the analyses and the complete list of articles for each CVM into Microsoft Excel. The results for all CVMs were combined into a single worksheet for each parameter, creating a master Excel file. Data were then normalized as needed: journal titles were standardized, as were institutional names and the names of countries. This became the final data set.

A list of all the journals was compared against the core list of veterinary journals.[30] This information was then used to establish the top core and noncore journals overall and for each CVM.

We used Excel to create pivot table reports for each of the parameters. Pivot tables allow users to summarize and rearrange long lists of data from spreadsheets and generate totals without using calculations.[31] This allowed us to view trends in the data. Data were then uploaded to IBM's Many Eyes, allowing us to create visualizations to better represent and communicate these trends.[32]

We investigated several data visualization tools designed for interpreting bibliographic data, including CiteSpace, Network Workbench, and Sci2 Tool.[33] However, we found these tools difficult to learn and use. While these tools produced visualizations useful for mapping citation networks, they were not suitable for mapping coauthorship networks or collaboration data.

We selected Many Eyes as our data visualization tool because it is freely available, was easy to use and share data and visualizations, and produced visualizations that enhanced our ability to understand and describe our particular set of data. Many Eyes consolidates a number of online visualization tools (among these are the Wordle word cloud generator, network diagramming, simple pie charts, and histogram chart types) into a single platform.[34] This allowed us to upload the dataset once, then visualize the data in several ways, exploring which options presented the information in the clearest and most meaningful way.

Results and Discussion

Data analysis identified trends in interdisciplinary work across CVMs, specialties within specific CVMs, and relationships between CVMs. A comparison of publications from the CVMs highlights differing needs, scopes, and focus. Veterinary schools with exceptional research output, unusual programs, or areas of emphasis are evident.

Interdisciplinary Work

Subject areas in Web of Knowledge are assigned to articles mainly at the journal title level using 253 subject categories. Subject areas are assigned at the article level for broad content titles like *Science* or *Nature*. More than one subject category may be assigned to any given journal title (or article in the case of the broad content titles).

It was interesting to note that only 47 percent of the articles by authors at CVMs were published in journals assigned to the Veterinary Sciences subject category, and that 93 percent of the articles were published in journals that included additional subject categories. The most common of these nonveterinary subject categories are shown in table 4.

TABLE 4
Top 30 Non Veterinary Subjects across All CVMs

Subject
Biochemistry Molecular Biology
Immunology
Microbiology
Cell Biology
Agriculture
Neurosciences Neurology
Reproductive Biology
Virology
Pharmacology Pharmacy
Biotechnology Applied Microbiology
Toxicology
Genetics Heredity
Infectious Diseases
Physiology
Parasitology
Zoology
Endocrinology Metabolism
Environmental Sciences Ecology
Life Sciences Biomedicine Other Topics
Pathology
Science Technology Other Topics
Research Experimental Medicine
Food Science Technology
Oncology
Chemistry
Public Environmental Occupational Health
Developmental Biology
Cardiovascular System Cardiology
Entomology
Hematology

Subject categories also highlighted different research emphases among CVMs. Each CVM's research output was tagged with different nonveterinary subject categories in different quantities, giving each school a unique research profile (see figure 1).

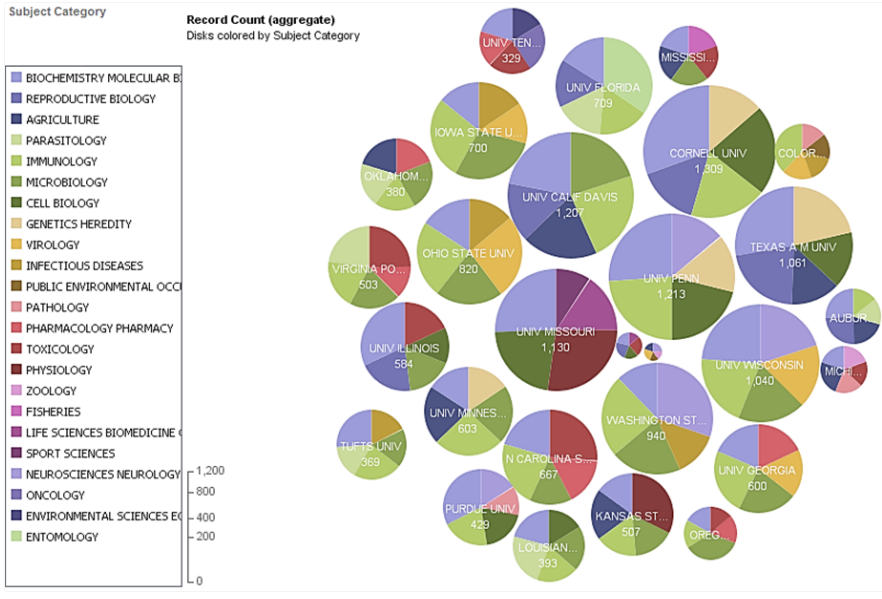
We were able to extract additional information about interdisciplinary publishing by identifying the core veterinary journals among all of the journals in which CVM authors published during our study period. Overall, 56 percent of the articles in the study were published in core veterinary journals. Across all CVMs, 71 percent of the journals in which these articles were published were outside the veterinary core, though the distribution of articles among journals varied by CVM (see figure 2). The top five core veterinary journals and the top five journals outside this core for all CVMs are listed in table 5.

We also observed that, while the number of publications from CVMs increased overall during the study period (see figure 3), the number of publications outside the core veterinary journals increased at a more rapid rate than those in the core journals (see figure 4).

We used Bradford's Law to further quantify the distribution of publications within our data set. This law is valid for our data set, which comprises four Bradford zones (see table 6). The fourth zone is noticeably much larger than predicted, which is due to this set of articles being broadly published across a very large number of journals. Bradford's Law is generally applied to a subset of a large data set. In our case, we limited the analysis to journals in which researchers from at least one CVM published at least two articles, giving us a data set of 1,349 journals and 46,172 articles. Had we included the complete set of 51,721 articles, the already larger than anticipated fourth zone would have been even more exaggerated, with the total number of journals at 2,700, demonstrating the incredible breadth of veterinary literature.

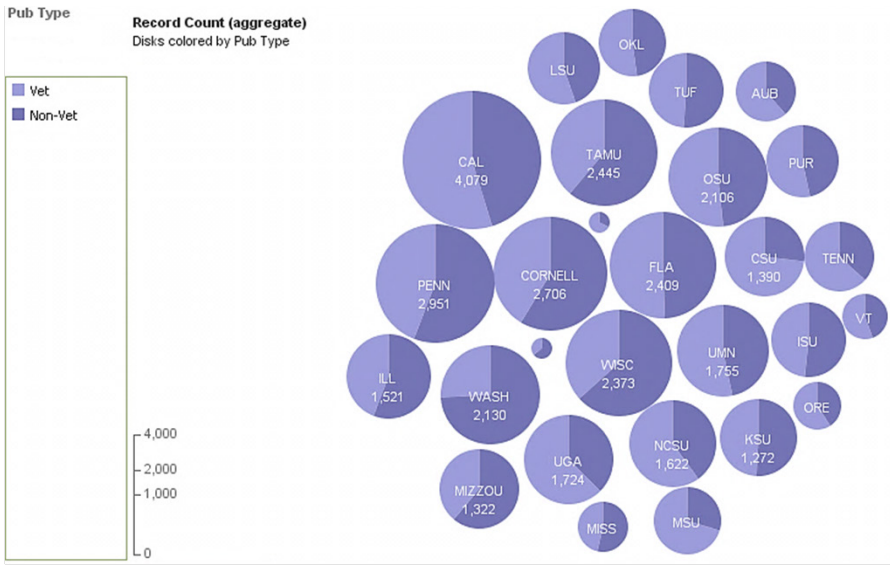
This set of CVM publications also conform to the S-shaped Bradford-Zipf curve, in which the number of articles are plotted against the log journal rank (see figure 5). The zones laid out by analysis using Bradford's Law suggest core and supplemental journal title lists that may benefit libraries collecting in veterinary medicine to varying levels.

FIGURE 1
Top 5 Non-Veterinary Subject Categories for Each CVM*



*Bubble chart shows the top 5 non-veterinary subject categories for each CVM. The size of the bubble represents the number of articles published by the CVM in these subject categories. View at http://www-958.ibm.com/software/data/cognos/manyeyes/visualizations/top-5-non-veterinary-subject-categ

FIGURE 2
Proportion of Articles Published by Each CVM



*Bubble chart shows the proportion of articles published by each CVM in core veterinary journals and other journals. The size of the bubble represents the CVM's total number of publications. View at http://www-958.ibm.com/software/data/cognos/manyeyes/visualizations/vet-vs-non-vet-pubs

TABLE 5
Top 5 Core Veterinary Journals and Non Core Journals across All CVMs

Top 5 Core Veterinary Journals
Javma Journal Of The American Veterinary Medical Association
Journal Of Veterinary Internal Medicine
American Journal Of Veterinary Research
Journal Of Veterinary Diagnostic Investigation
Veterinary Surgery
Top 5 Non Veterinary Journals
Journal Of Virology
Faseb Journal
Infection And Immunity
Journal Of Clinical Microbiology
Journal Of Biological Chemistry

FIGURE 3
Number of Articles Published by Publication Year across All CVMs

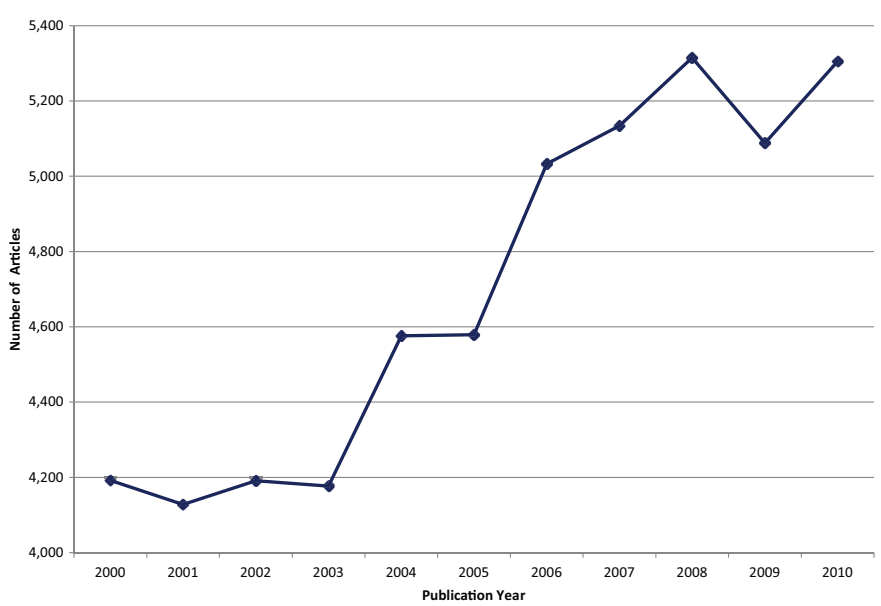


FIGURE 4
Articles Published in Core Veterinary Journals and Interdisciplinary Journals during Study Period, Showing Increasing Proportion of Interdisciplinary Publications

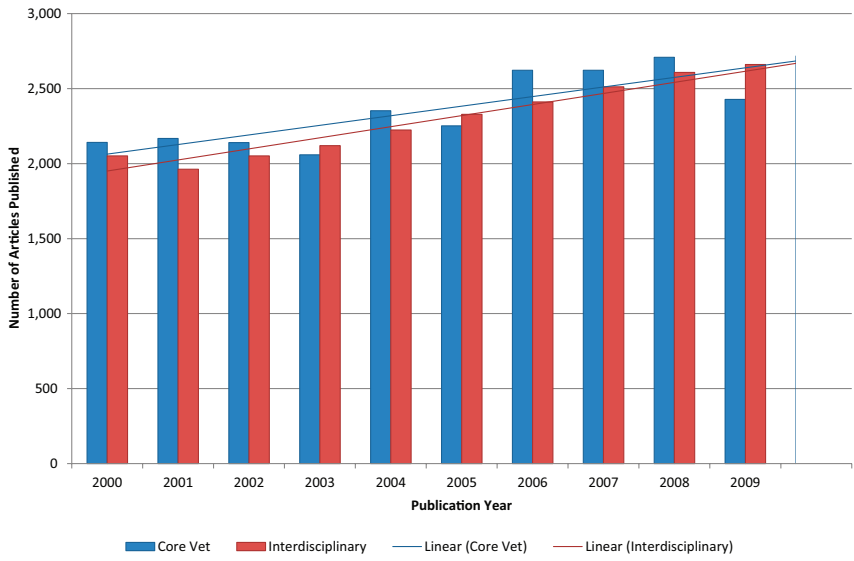


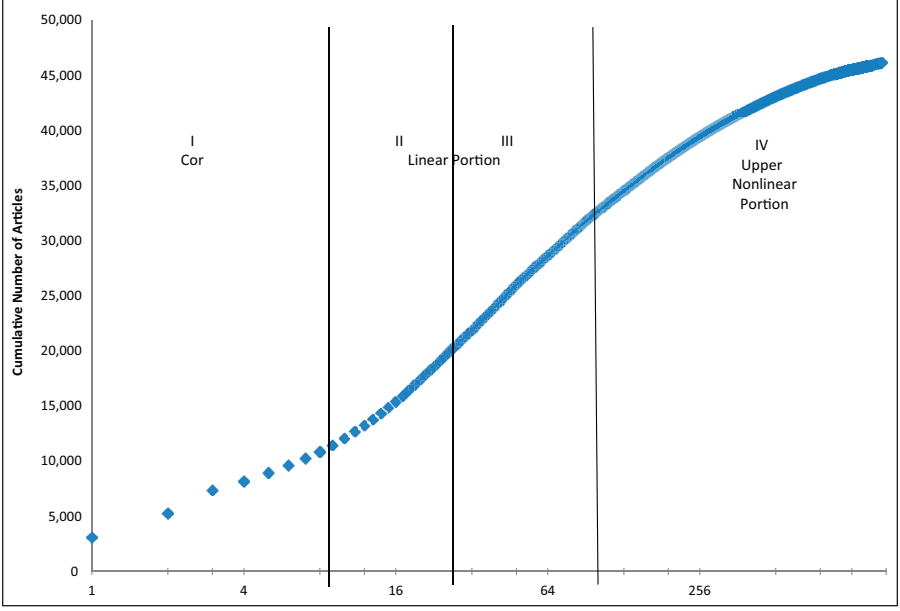
TABLE 6
Bradford Zones of Scatter For Journals Including at Least Two CVM Publications, 2000-2010

Zones	No. of Journals	No. of Articles	Cumulative No.	Cumulative %	Description
1	9	11,466	11,466	25%	Producing between 614 and 3,086 articles
2	27	11,566	23,032	50%	Producing between 279 and 609 articles
3	93	11,565	34,597	75%	Producing between 60 and 276 articles
4	1,220	11,575	46,172	100%	Producing from 2 to 59 articles
Total	1,349	46,172			

Interinstitutional Partnerships

CVMs varied both in the number of collaborative articles produced and in number of collaborating institutions (see figure 6). While most collaborations were among CVMs, other institutions that do not have CVMs also play key roles in veterinary research. Some of these institutions are schools with veterinary science departments, such as the University of Kentucky and the Pennsylvania State University; others, such as the U.S. Department of Agriculture (USDA) or the Centers for Disease Control, have veterinary and animal health research programs that are important resources for all CVMs. In

FIGURE 5
Bradford-Zipf Plot of CVM Articles, 2000-2010



other cases, such as Harvard University, which does not have veterinary medicine or veterinary science programs, this collaboration likely represents interdisciplinary research (see table 7). Collaborating institutions include those outside the U.S., but only one non-U.S. institution appeared in the top collaborating pairs. The University of Tokyo pairs with the University of Wisconsin because of research associated with avian influenza (see table 8).

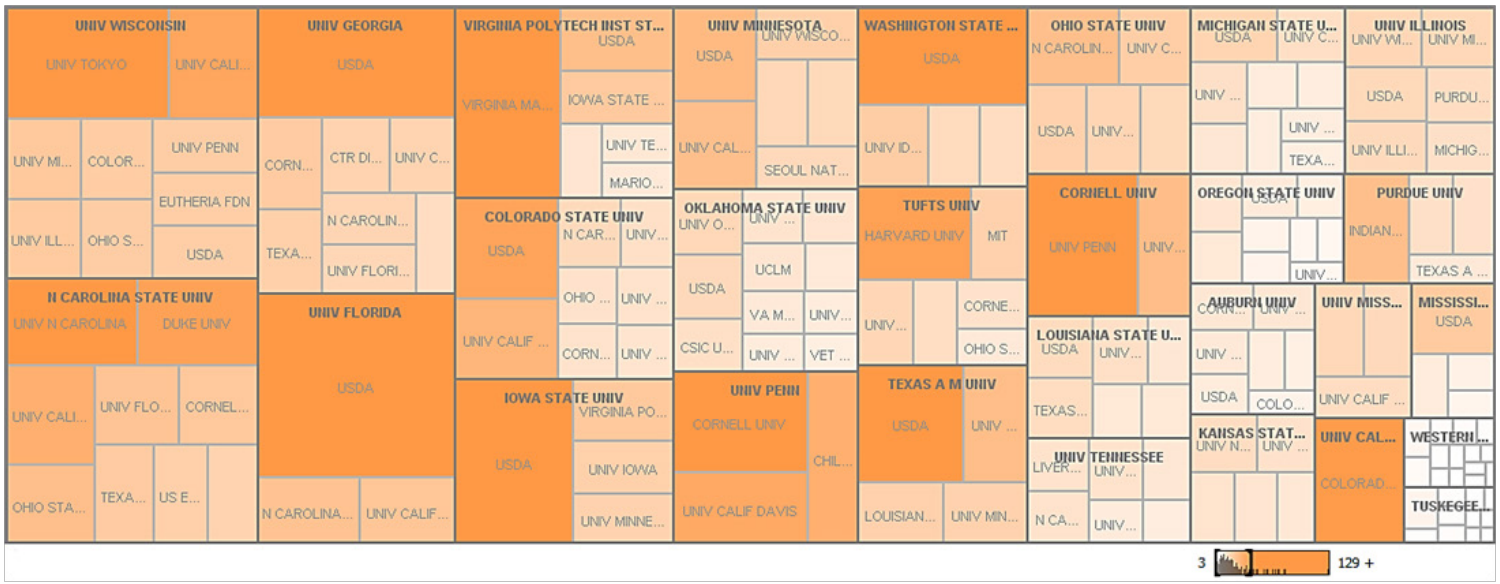
Graphical representation of the research collaborations shows institutions are interconnected by coauthorship in a single large and complex network rather than in smaller discrete groups (see figure 7).

Unique Qualities of Specific CVMs

The publication record of each CVM reflects a unique research profile for each school. These distinct profiles may indicate interdisciplinary or cross-disciplinary research hubs at the university, emerging fields, or unofficial areas of focus or specialization. The collaborations with researchers at other institutions may reflect official partnerships, consortia, or geographic proximity; they may also reflect professional relationships between individual researchers.

For individual CVMs, publication output can show distinct areas of strength. Knowing and being able to present this information may be helpful to CVM administrators involved in marketing, grant-seeking, recruitment, and development. This information may also benefit librarians and researchers outside veterinary medicine who need to know which veterinary program to contact for particular needs. These distinct profiles include CVMs with unique emphasis or centers of emphasis. Two examples where the content of articles reflect established programs are shown in figure 8: researchers at Mississippi State University published many articles referring to channel catfish in their titles, which likely reflects MSU's Catfish Diagnostic Laboratory and support of the catfish farming industry. At Iowa State University, many articles include the title

FIGURE 6
Top Collaborating Institutions for Each CVM*



*Treemap shows the top collaborating institutions for each CVM. The size of the space given to each CVM represents the number of articles its authors produced in collaboration with other institutions. The size and color intensity of each collaborating institution's space within a CVM's area represents the number of collaborative articles produced. View at http://www-958.ibm.com/software/data/cognos/manyeyes/visualizations/collaborating-institutions-all-cvm.

TABLE 7
Top Collaborating Pairs Identified by the Number of Publications and by The Percentage of the CVM's Publications

Number of Publications		
CVM	**Collaborating Institution**	**Publication Count**
Univ Florida	USDA	406
Univ Georgia	USDA	247
Iowa State Univ	USDA	217
Univ Wisconsin	Univ Tokyo	207
Washington State Univ	USDA	186
Cornell Univ	Univ Penn	178
Univ Penn	Cornell Univ	152
Texas A M Univ	USDA	138
N Carolina State Univ	Univ N Carolina	129
Univ Calif Davis	Colorado State Univ	125
Tufts Univ	Harvard Univ	118
N Carolina State Univ	Duke Univ	117
Colorado State Univ	USDA	115
Univ Wisconsin	Univ Calif Davis	112
Univ Penn	Univ Calif Davis	108
N Carolina State Univ	Univ Calif Davis	100
Univ Penn	Childrens Hosp Philadelphia	100
Univ Calif Davis	Univ Calif San Francisco	97
Univ Calif Davis	Univ Minnesota	94
Colorado State Univ	Univ Calif Davis	93
Percentage Of CVM's Output		
CVM	**Collaborating Institution**	**% Of CVM's Publications**
Univ Florida	USDA	14.97%
Iowa State Univ	USDA	14.18%
Tuskegee Univ	Auburn Univ	13.22%
Univ Georgia	USDA	11.38%
Mississippi State Univ	USDA	10.29%
Washington State Univ	USDA	9.59%
Western Univ Hlth Sci	Univ Calif Davis	9.30%
Tufts Univ	Harvard Univ	8.89%
Colorado State Univ	USDA	7.36%

TABLE 7
Top Collaborating Pairs Identified by the Number of Publications and by The Percentage of the CVM's Publications

Percentage Of CVM's Output		
CVM	**Collaborating Institution**	**% Of CVM's Publications**
Univ Wisconsin	Univ Tokyo	6.99%
Western Univ Hlth Sci	N Carolina State Univ	6.98%
Colorado State Univ	Univ Calif Davis	5.95%
Virginia Polytech Inst State Univ	USDA	5.72%
Purdue Univ	Indiana Univ	5.60%
Oregon State Univ	Cornell Univ	5.55%
Western Univ Hlth Sci	Texas A M Univ	5.43%
Western Univ Hlth Sci	Univ Minnesota	5.43%
Texas A M Univ	USDA	5.12%
N Carolina State Univ	Univ N Carolina	5.01%
Tuskegee Univ	Univ Calif Los Angeles	4.96%

words porcine, swine, and pigs, as one might expect given Iowa State's Swine Medicine Education program. In other cases, a CVM's research output may reflect more informal areas of strength, such as the emphasis on viral research suggested by Ohio State's title terms. The level of research output also varied between newer and more established programs.

Limitations of Web of Knowledge and Many Eyes

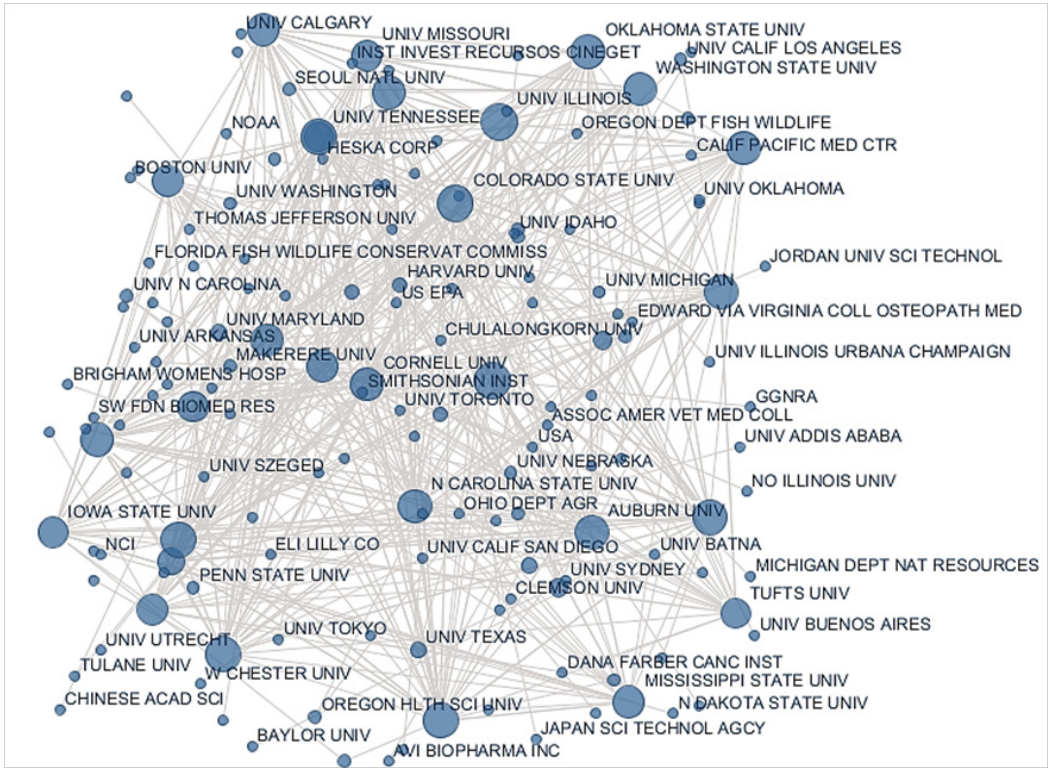
We found some limitations when using the Web of Knowledge. Because Web of Knowledge assigns subject categories at the journal title level, individual articles that cross disciplines could only be identified by broad subject. Using Web of Knowledge, we were able to export the affiliations of all authors at the institutional level. However, we were not able to export data showing author affiliations at the college, department, or programmatic level, which would have given us a clearer picture of interdisciplinary partnerships within institutions.

Web of Knowledge does not index all journals, and its coverage is more complete in some subjects than in others. Web of Knowledge selects journals with high Journal Citation Report impact factors. Therefore, newer journals and those in emerging fields, including many open access journals, may be omitted. Open access journals account for only a small number of veterinary publications but may represent a greater portion

TABLE 8
Top 10 Countries with Collaborators Who Published with CVM Authors

Country	Number of Articles Co Authored with U.S. CVMs
Uk	1,710
Canada	1,710
Germany	1,031
Japan	913
Australia	660
France	640
Italy	500
Brazil	448
Switzerland	437
Spain	415

FIGURE 7
Network Diagram Showing Co Authorship Relationships between CVMs and Collaborating Institutions*



*View at http://www-958.ibm.com/software/data/cognos/manyeyes/visualizations/collaborations-in-cvm-publications.

FIGURE 8
Word Clouds*

FIGURE 8A

FIGURE 8B

*Word clouds illustrate the prevalence of words in article titles at each of two sample CVMs, the Mississippi State University (Figure 8a) and Iowa State University (Figure 8b). Word clouds are based on raw, non-standardized article title words. Text size corresponds to the frequency of word appearance. Word color aids readability, but does not have meaning. Word clouds for each CVM were generated with Many Eyes and can be accessed from http://www-958.ibm.com/software/data/cognos/manyeyes/topiccenters/24eef230513011e2b719000255111976.

of publications in other fields.[35] Our view of the interdisciplinary publication output of veterinary researchers may have some gaps as a result. Additionally, not all veterinary journals are indexed in Web of Knowledge. A small number of core veterinary journals are omitted, as are some newer, open access, and international titles.[36]

We found limitations specific to using word cloud visualizations in Wordle or Many Eyes. These tools allow removal of standard lists of stop words in 29 languages, as well as user-selected words. They are nonetheless based on frequency of individual words present, and, unless the data been normalized, concepts may not appear with proper emphasis. For example, the National Center for Veterinary Parasitology is located at the Oklahoma State University. In figure 1, "parasitology" is displayed as one of the five top subject areas for the university. In the word clouds, this emphasis is not readily apparent because titles rarely use the general term "parasitology" but, instead, specific species or diseases. These terms are often two-word phrases (such as

Anaplasma marginale), which Wordle renders as single words unless they are normalized by joining them with a tilde.

Other limitations were also encountered when using Many Eyes for data visualization. Only a limited number of visualization types are available, and not all visualization types allow the user to customize colors, fonts, and layout options. Large amounts of data can overwhelm viewers, making visualizations difficult to interpret. Despite these challenges, we found Many Eyes, with its web-based interface and plain language instructions, a simple tool to learn, producing easily understood images. This makes Many Eyes a potentially useful tool for others who want to collect, interpret, and share data.

Application to Other Disciplines

While this study looked at the publication output of researchers in a discipline with an already well-defined journal core, the methodology could be used to analyze other less-defined research disciplines and could in fact define their core. Our study encompassed colleges of veterinary medicine, but slices of research output from academic departments in other disciplines, governmental agencies, or research centers could also be examined. For example, the methodology could be applied to subjects that have no recently defined core body of literature. By analyzing the research output of such programs in academic institutions, a body of literature being published through those programs could be identified. Close examination of that body of literature could yield both core and ancillary journal lists. These lists could be used to guide collection development decisions for libraries serving particular programs, or to identify collaborative research with other institutions.

Even within veterinary medicine, there are areas remaining to be studied such as research output from zoos and aquariums, wildlife centers, pharmaceutical companies, or the USDA. Results would provide these organizations a type of self-study and identify their most relevant and necessary research resources.

Conclusions

Veterinary medicine has a recently defined list of core journals.[37] Developing a methodology to analyze the research output of a set population allowed us to determine the noncore journals in which the population publishes. Our population, researchers at the 28 accredited Colleges of Veterinary Medicine in the United States, publish in a wide variety of journals both within and outside the core veterinary journals. Analyzing the citation data using features built into Web of Knowledge and Excel provided sufficient data flexibility to identify institution-specific emphases and centers of excellence, strengths, unique areas of focus, and collaborations across institutions. Importing data into visualization tools and examining segments clarified results and illuminated commonalities and trends. Data visualization proved to be an effective communication tool that librarians can use to engage with their library colleagues and the administrators and researchers at their CVMs. A meaningful image can resonate with a viewer differently from the same message presented as text or a table.

Three primary collection situations could benefit from this methodology. Collection specialists with a focused discipline, in this case veterinary librarians, can use this analysis technique to ensure that the collection supports their institutional mission and current research agenda, providing resources or access within and outside the core literature of the field. Managers of more generalized collections can use this technique to analyze segments of their collection against ancillary subjects (for example, this data set could support a university with a veterinary science department but not veterinary medical school). Collection managers for new programs could find value in analyzing existing collections against the core to determine needs for the new program.

This study can serve as a model for studies in other disciplines and can yield similarly useful information about the research output of the field, particular programs, and collection development needs.

Notes

1. *Dorland's Illustrated Medical Dictionary*, 32nd ed. (St. Louis, Mo.: Saunders, 2011).

2. Atha Louise Henley, "Organization and Compilation of a Basic List of Veterinary Medical Serials," *Journal of Veterinary Medical Education* 5, no. 3 (1978); C. Trenton Boyd et al., "Basic List of Veterinary Medical Serials 2nd Edition, 1981, with Revisions to April 1, 1986," *The Serials Librarian* 11, no. 2 (1986); Ana G. Ugaz et al., "Basic List of Veterinary Medical Serials, Third Edition: Using a Decision Matrix to Update the Core List of Veterinary Journals," *Journal of the Medical Library Association* 98, no. 4 (2010).

3. American Veterinary Medical Association, "Veterinary Colleges Accredited by the AVMA," available online at https://www.avma.org/ProfessionalDevelopment/Education/Accreditation/Colleges/Pages/colleges-accredited.aspx [accessed 11 April 2012]; J.A. Simpson and E.S.C. Weiner, The Oxford English Dictionary, (Oxford: Oxford University Press, 1989), available online at www.oed.com [accessed 24 September 2012].

4. Gregory K. Youngen and Amy Gullen, "The Diverse and Interdisciplinary Nature of Veterinary Research: An Analysis of Research Trends at Six Midwestern Colleges of Veterinary Medicine," in *Agriculture without Borders: US Agriculture Information Network Annual Conference* (West Lafayette, Ind.: Purdue University, 2010); Ugaz et al., "Basic List of Veterinary Medical Serials, Third Edition."

5. Gregory K. Youngen, "Multidisciplinary Journal Usage in Veterinary Medicine: Identifying the Complementary Core," *Science & Technology Libraries* 30, no. 2 (2011).

6. Ugaz et al., "Basic List of Veterinary Medical Serials, Third Edition."

7. Jian Huang et al., "Collaboration over Time: Characterizing and Modeling Network Evolution" (Palo Alto, Calif., 2008); Timothy L. O'Brien, "Change in Academic Coauthorship, 1953–2003," *Science Technology & Human Values* 37, no. 3 (2012).

8. M.E.J. Newman, "Coauthorship Networks and Patterns of Scientific Collaboration," *Proceedings of the National Academy of Sciences of the United States of America* 101, no. 1, suppl. (2004); O'Brien, "Change in Academic Coauthorship, 1953–2003."

9. James D. Adams et al., "Scientific Teams and Institutional Collaborations: Evidence from U.S. Universities, 1981–1999," *Research Policy* 34, no. 3 (2005); O'Brien, "Change in Academic Coauthorship, 1953–2003."

10. Lynne E. Olson, "Content Analysis of a Stratified Random Selection of *JVME* Articles: 1974–2004," *Journal of Veterinary Medical Education* 38, no. 1 (2011).

11. David A. Kronick, "The Commerce of Letters: Networks and 'Invisible Colleges' in Seventeenth- and Eighteenth-Century Europe," *Library Quarterly* 71, no. 1 (2001).

12. Christoph Neuhaus and Hans-Dieter Daniel, "Data Sources for Performing Citation Analysis: An Overview," *Journal of Documentation* 64, no. 2 (2008).

13. Wolfgang Glänzel, "Bibliometrics as a Research Field: A Course on Theory and Application of Bibliometric Indicators. Course Handouts," Universidade Federal de Pernambuco, available online at www.cin.ufpe.br/~ajhol/futuro/references/01%23_Bibliometrics_Module_KUL_BIBLIOMETRICS%20AS%20A%20RESEARCH%20FIELD.pdf [accessed 2 January 2013].

14. Christina C. Hicks, Clare Fitzsimmons, and Nicholas V.C. Polunin, "Interdisciplinarity in the Environmental Sciences: Barriers and Frontiers," *Environmental Conservation* 37, no. 4 (2010); Amy Hardin, Philip G. Crandall, and Tony Stankus, "The Zoonotic Tuberculosis Syndemic: A Literature Review and Analysis of the Scientific Journals Covering a Multidisciplinary Field That Includes Clinical Medicine, Animal Science, Wildlife Management, Bacterial Evolution, and Food Safety," *Science & Technology Libraries* 30 (2011); Ruimin Pei and Alan L. Porter, "Profiling Leading Scientists in Nanobiomedical Science: Interdisciplinarity and Potential Leading Indicators of Research Directions," *R & D Management* 41, no. 3 (2011).

15. Dragan Ilic, Katrina Tepper, and Marie Misso, "Teaching Evidence-Based Medicine Literature Searching Skills to Medical Students During the Clinical Years: A Randomized Controlled Trial," *Journal of the Medical Library Association* 100, no. 3 (2012); Ana Andrés, *Measuring Academic Research: How to Undertake a Bibliometric Study* (Oxford: Chandos Publishing, 2009), 1–3; V.V. Nalimov and Zinaida Maksimovna Mulchenko, *Scientometrics: The Study of Science as an Information Process*, trans. Foreign Technology Division United States Air Force Systems Command Translation Division, Fiziko-Matematicheskai◎a◎ Biblioteka Inzhenera (Moscow: Nauka, 1969).

16. W. Glänzel and H.J. Czerwon, "A New Methodological Approach to Bibliographic Coupling and Its Application to the National, Regional and Institutional Level," *Scientometrics* 37, no. 2 (1996).
17. O. Nacke, "Informetrie: Eine Neuer Name Für Eine Neue Disziplin," *Nachrichten für Dokumentation* 30, no. 6 (1979).
18. Tomas C. Almind and Peter Ingwersen, "Informetric Analyses on the World Wide Web: Methodological Approaches to 'Webometrics'," *Journal of Documentation* 53, no. 4 (1997); *Cybermetrics*, ed. Ronald Rousseau (Madrid: CSIC Cybermetrics Lab, 1997).
19. Samuel C. Bradford, "Sources of Information on Specific Subjects," *Engineering* 137 (1934).
20. Andy Kirk, *Data Visualization: A Successful Design Process* (Birmingham, U.K.: Packt Publishing, 2012), chap. 1, pt. 3, available online at http://proquest.safaribooksonline.com/9781849693462 [accessed 13 May 2013].
21. Ibid., chap. 5, pt. 1.
22. Rhonda Huisman, Willie Miller, and Jessica Trinoskey, "We've Wordled, Have You? Digital Images in the Library Classroom," *College & Research Libraries News* 72, no. 9 (2011); Carolyn Foote, "It's a Mad, Mad Wordle: For a New Take on Text, Try This Fun Word Cloud Generator," *School Library Journal* 55, no. 7 (2009); Rhonda K. Huisman and Kathleen A. Hanna, "A Picture Is Worth 150 Words: Using Wordle to Assess Library Instruction," in *Proceedings of the 38th National LOEX Conference*, ed. Brad Sietz, Library Orientation Series No. 43 (Ann Arbor, Mich.: Pierian Press, 2011); Rachel Bridgewater, Anne-Marie Deitering, and Karen Munro, "Library Instruction 2.0," *Public Services Quarterly* 5, no. 2 (2009).
23. Chris Belter, "Visualizing Networks of Scientific Research," *Online* 36, no. 3 (2012).
24. H. Schulz, "Treevis.net: A Tree Visualization Reference," *Computer Graphics and Applications, IEEE* 31, no. 6 (2011), available online at http://vcg.informatik.uni-rostock.de/~hs162/treeposter/poster.html#detailview [accessed 13 May 2013].
25. Ben Shneiderman and Catherine Plaisant, "Treemaps for Space-Constrained Visualization of Hierarchies," available online at www.cs.umd.edu/hcil/treemap-history/index.shtml [accessed 13 May 2013].
26. Wisconsin National Primate Research Center Library, "Primate Portal," University of Wisconsin System Board of Regents, available online at http://primateportal.org/ [accessed 17 May 2013].
27. Peter Jacso, "As We May Search—Comparison of Major Features of the Web of Science, Scopus, and Google Scholar Citation Based and Citation-Enhanced Databases," *Current Science* 89, no. 9 (2005); Neuhaus and Daniel, "Data Sources for Performing Citation Analysis"; Douglas J.C. Grindlay, Marnie L. Brennan, and Rachel S. Dean, "Searching the Veterinary Literature: A Comparison of the Coverage of Veterinary Journals by Nine Bibliographic Databases," *Journal of Veterinary Medical Education* 39, no. 4 (2012).
28. Thomson Reuters, "Web of Science" (New York: Thomson Reuters, 2012).
29. Gregory K. Youngen et al., "Identifying and Analyzing Interdisciplinary and Inter-Institutional Research from United States Veterinary Colleges," in *Medical Library Association Annual Meeting* (Minneapolis, Minn., 2011).
30. Ugaz et al., "Basic List of Veterinary Medical Serials, Third Edition."
31. Office.com, "PivotTable Reports 101," available online at http://office.microsoft.com/en-us/excel-help/pivottable-reports-101-HA001034632.aspx [accessed 13 May 2013].
32. IBM Research, "Many Eyes," available online at http://www-958.ibm.com/software/data/cognos/manyeyes/ [accessed 13 May 2013].
33. Chaomei Chen, "Citespace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature," *Journal of the American Society for Information Science and Technology* 57, no. 3 (2006); Network Workbench Tool, Indiana University, Northeastern University, and University of Michigan, available online at http://nwb.slis.indiana.edu [accessed 24 September 2012]; Science of Science (Sci^2) Tool, Indiana University and SciTech Strategies, available online at http://sci2.cns.iu.edu [accessed 22 June 2012].
34. Jonathan Feinberg, "Wordle," available online at www.wordle.net/ [accessed 17 May 2013].
35. André J. Nault, "Open Access of Publications by Veterinary Faculty in the United States and Canada," *Journal of Veterinary Medical Education* 38, no. 1 (2011).
36. Ugaz et al., "Basic List of Veterinary Medical Serials, Third Edition."
37. Ibid.