Global *Drosophila* Research: a bibliometric analysis.

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Abstract

The scientific productivity of *Drosophila*-related research among researchers, countries, institutions, journals, and subject areas was investigated by a bibliometric analysis of *Drosophila* research from 1900 to 2008. The search includes the Pub Med, using the keywords listed in the medical subject headings thesaurus, and the Science Citation Index databases with the word *Drosophila* in the title. From Pub Med 36,486 documents were obtained, whereas a total of 48,981 documents were obtained from Science Citation Index. 76.9% of the documents are research papers, mostly (95.2%) written in English, and (55.8%) produced in the United States. The study includes 4,600 institutions and 45,415 author names. Most prolific are 34 authors, who account for 9% of the articles published, with more than 100 research papers produced by each author. We considered 1,648 journals; 60 of them (3.6%) published 66% of the articles. *Genetics* is the main journal most used for *Drosophila* research publications (9.9%). Genetics and heredity as well as biochemistry, molecular biology, and cell biology are the dominant research subjects. We compare research in *Drosophila melanogaster* with 10 other organisms, frequently used as biological models: *Escherichia coli*, *Saccharomyces cereviseae*, *Arabidopsis thaliana*, *Zea mays*, *Neurospora crassa*, *Dictyostelium discoideum*, *Chlamydomonas reinhardtii*, *Caenorhabditis elegans*, *Schizosaccharomyces pombe*, and *Danio rerio*. *Escherichia coli* is the most extensively used model organism for genetics research since 1950, with 94,873 documents. **Keywords:** Fruit fly**,** history, genetics, biological experimental models, SCI, Pub Med.

Introduction

The fruit fly *Drosophila melanogaster* is one of the most extensively characterized multicellular organisms. Over more than 100 years of research, *Drosophila melanogaster* as an experimental organism has played an important role in different research areas, such as chromosome behavior, cell biology, gene biology, developmental biology, population genetics, ecology, evolution, and genomics. Beginning in 1906 with Thomas Hunt Morgan and the "fly room" at Columbia University in New York to the publication of the DNA sequence of the complete euchromatic regions of the chromosomes of *Drosophila melanogaster* in 2000, many concepts, phenomena, and biological processes have been elucidated with the fruit fly. Evolutionary considerations have been important in *Drosophila melanogaster* genetics, in part because the heyday of *Drosophila melanogaster* genetics in the 1930s coincides with the formulation of the modern synthesis of evolutionary theory, which combined Darwinian natural selection with Mendelian heredity (Sturtevant, 1965). Other *Drosophila* species have been the subject of evolutionary research, but to a more limited extent than *Drosophila melanogaster*. The modern synthesis of evolutionary theory was first articulated to a large extent through the analysis of polymorphisms in the banding patterns of the salivary gland chromosomes within species and comparisons of the banding patterns between species (Dobzhansky, 1937). For several decades, every important concept in population genetics and evolution was influenced to some extent by studies of natural or laboratory populations of *Drosophila* (Lewontin, 1974). *Drosophila melanogaster* is a model organism well-suited for the application of the tools of genetics, biochemistry, molecular biology, and physiology, among others; and, recently, of bioinformatics. The very well-known *Drosophila melanogaster* biology makes this organism most valuable to study and identify the function of genes conserved during evolution (Banfi *et al.* 1997). Between 1940 and 1970 new techniques were developed and mutants increased in number and complexity, all fairly freely shared by a gradually increasing number of investigators.

In the 1970s and 1980s, genetics, developmental, and molecular biology came together in a successful combination, which brought *Drosophila melanogaster* research to a climax. Molecular biology rose later than the other subjects, associated mostly with the ability to manipulate DNA and RNA, so that researchers could work with individual genes that produced phenotypic alterations. Lewis (1963) studied mutations that caused bizarre transformations of the body plan: mutations in genes in the “bithorax complex” led to flies with two sets of wings or legs on abdominal segments. The strangeness of the changes produced became a clue to discover the crucial role of master control genes that program the final body plan of the organism. Nüsslein-Volhard and Wieschaus (1980) began working together with *Drosophila melanogaster* flies in a laboratory in Heidelberg, Germany. They systematically searched for mutant genes that affect the formation of segments in the fly embryo. They identified a series of new genes that drive the early development of the organism and also were able to classify the genes into functional groups. They showed that these genes are conserved in vertebrates. It would soon become clear that close relatives of these genes, performing similar roles, exist in many other different organisms, including humans. Indeed, it is now thought that more than 60 percent of the genes involved in human diseases may have counterparts in the fly.

An important breakthrough for manipulating the genome was made in 1982 by Spradling and Rubin. They developed a method for making transgenic flies by means of transposable element vectors. They used this method to achieve the first rescue of a mutant phenotype in an animal by gene transfer. New technologies are also being brought to bear on the study of *Drosophila melanogaster*. Since 1999, the genome sequence of *Drosophila melanogaster* has been available, and researchers are using functional genomics to investigate global patterns of gene and protein expression. The genome sequences of several other *Drosophila* species have now become available, which opens up new opportunities for functional genomic studies, looking at gene and protein expression on a large scale. Such experiments can produce huge amounts of data, difficult to interpret, organize, and store.

The considerable amount of information about *Drosophila melanogaster* accumulated in several Internet databases are our rationale for a bibliometric study. Bibliometrics studies the quantitative aspects of science information. A precursor of this methodology was De Solla Price (1963, 1965), whose work has been broadly promoted by Garfield (1955, 1979a, 1979b, 2004), Narin (1972, 1994, 1995, 1997), and, more recently, Leydesdorff (2005, 2007). Bibliometric studies are conducted to evaluate the amount and evolution of the scientific production among countries, institutions, research units, and scientists in major fields. Bibliometrics has had a major boom in recent decades due to the increasing digitalization, information systematization, and production of a large number and variety of databases of scientific literature that have worldwide electronic access

(Science Citation Index (SCI), Pub Med, Scopus, Google Scholar, among others) (Hood and Wilson, 2003).

The present bibliometric analysis seeks to investigate the rise and development of scientific research with *Drosophila melanogaster* from 1900 to 2008. We analyze the scientific literature with emphasis on (1) papers: temporal trends, document type, language, most frequent topics and their development, and most relevant papers from citation indicators; (2) researchers: most productive and most frequent institutions of residence and countries; (3) journals: core journals, subjects, and impact factors.

Methodology and Sources

The bibliographic search covered papers published during 1900-2008. The search was performed using the SCI, (Thomson Reuters 2008a, 2008b; http://thomsonreuters.com/products_services/science/science_products/a-z/science_citation_index) and the Pub Med database (http://www.ncbi.nlm.nih.gov/sites/entrez). SCI was started by the Institute for Scientific Information (ISI) in 1963. It is now owned by Thomson Reuters and is available online through the Web of Science database. Pub Med Central, which started in 2000, includes articles and peer-reviewed manuscripts dating back to mid the 1800s or early 1900s for some journals. These databases include many journals, provide a citation index, and the results of the queries are comparative concerning mainstream papers in scientific research. Pub Med has detailed document identification by the keywords listed in the medical subject headings (MeSH) thesaurus. We accessed the SCI until 2008, in order to find out where research in *Drosophila* has been done. We accessed data on documents with the word *Drosophila* in the title of the paper, because we were interested only in documents with their main interest in *Drosophila melanogaster*. All records were retrieved for each database and were systematized in a database; then the data sets were validated and normalized, and a quantitative analysis for each category was done: document, author, affiliation institution, country, journal, subject area (from SCI), and MeSH headings and qualifiers (from Pub Med). The 50 and the 10 most cited papers from SCI were identified. Journals were processed by subject (*sensu* SCI). Impact Factors (IF) were obtained from Journal Citation Report 2008, and core journals were identified with Bradford`s method (Bradford, 1948; Van Raan, 2000). The same method was used for each of ten additional biological models: *Escherichia coli*, *Saccharomyces cereviseae*, *Arabidopsis thaliana*, *Zea mays*, *Neurospora crassa*, *Dictyostelium discoideum*, *Chlamydomonas reinhardtii*, *Caenorhabditis elegans*, *Schizosaccharomyces pombe*, and *Danio rerio*. All the information was organized with scientific and historical points of view.

Results

Papers

The total number of publications with *Drosophila* in the title was 48,981 in the SCI and 36,486 in Pub Med (Figure 1). The first paper registered was published in 1905 by Carpenter. Almost 77% of the documents retrieved are articles the majority (95%) published in English. The comparison of *Drosophila melanogaster* with other biological models is interesting: *Zea mays* and *Chlamydomonas reinhardtii* show a reasonably stable publication trend (after 1970). From approximately 1980 on, *Arabidopsis thaliana* and *Caenorhabditis elegans* exhibit exponential growth, while *Neurospora crassa* and *Dictyostelium discoideum* decrease. *Escherichia coli* is the most extensively used model organism for genetics research; from 1950 till 2007, nearly twice as many articles are published as for *Drosophila* (Figures 2 and 3).

There are 115 different subject categories in the SCI. The most frequently topics are: Genetics and heredity (37%), Biochemistry and molecular biology (22%), Cell biology (17%), and Developmental biology (13%). The temporal trends for the nine most frequent subjects are shown in Figures 4 and 5. Keywords were defined as MeSH terms assigned by PubMed documents by a team of indexers. In the indexing process a variable number of terms is assigned to each article. The MeSH terms (headings and qualifiers) used by PubMed experts to classify the articles selected for this study included more than 500 terms. The most frequent MeSH subjects from documents extracted from Pub Med are shown in Table 1. Considering MeSH qualifiers there were as many as 75 terms, 20 of them are included in Table 2.

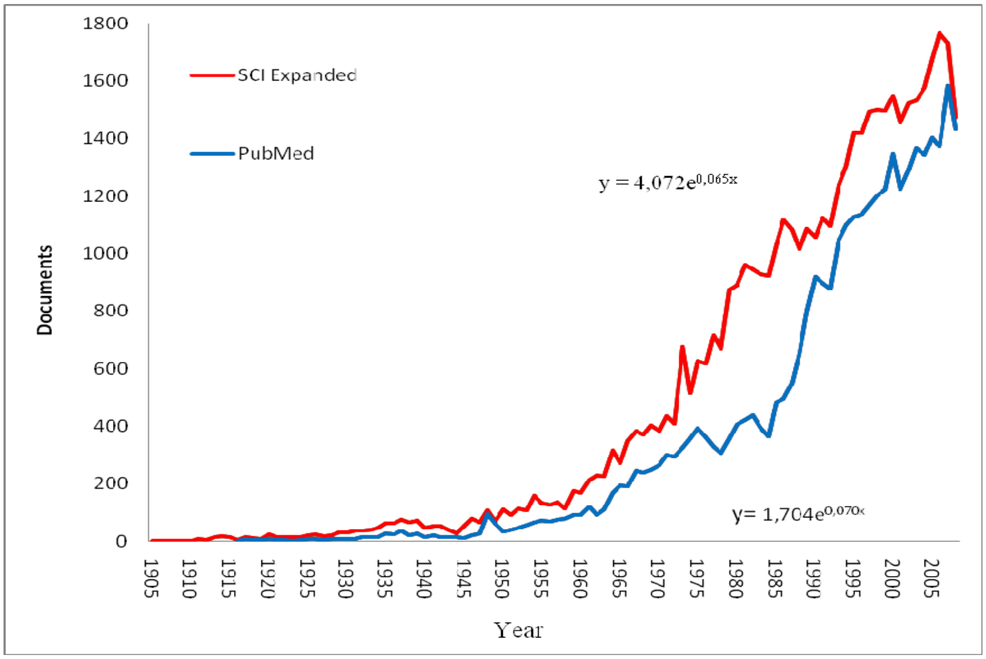

Figure 1. Temporal trend in global *Drosophila* publications, 1905-2008 (from WoS and Pub Med).

Researchers

45,415 author names were found. Table 3 shows the 34 most prolific, each with more than 100 published articles and jointly accounting for 9% of all the papers. 55.8% of all the papers had at least one North American author. There were 119 affiliation countries, 32 (2.6%) of which include each more than 100 papers, and jointly accounting for 97% of all papers. The 10 countries with the highest number of publications are shown in Table 4. The United States of America (USA) was the country most represented (43.91%). After USA the most productive countries with more or less each one with 5% of the total were France, England, Japan, and Germany. Jointly, these four countries account for 21% of the publications. There were 501 different institutions, such as universities, departments, and corporations. The 50 most highly represented are shown in Table 5. The most productive institutions are the Russian Academy of Sciences (1,385 papers), the Centre National de la Recherche Scientifique (CNRS in France) with 1,132, and Harvard University with 1,100 publications. Harvard included authors of 5 (10%) of the most cited documents. Taking together all the institutions by country the North American institutions account for 23.75% of all published papers.

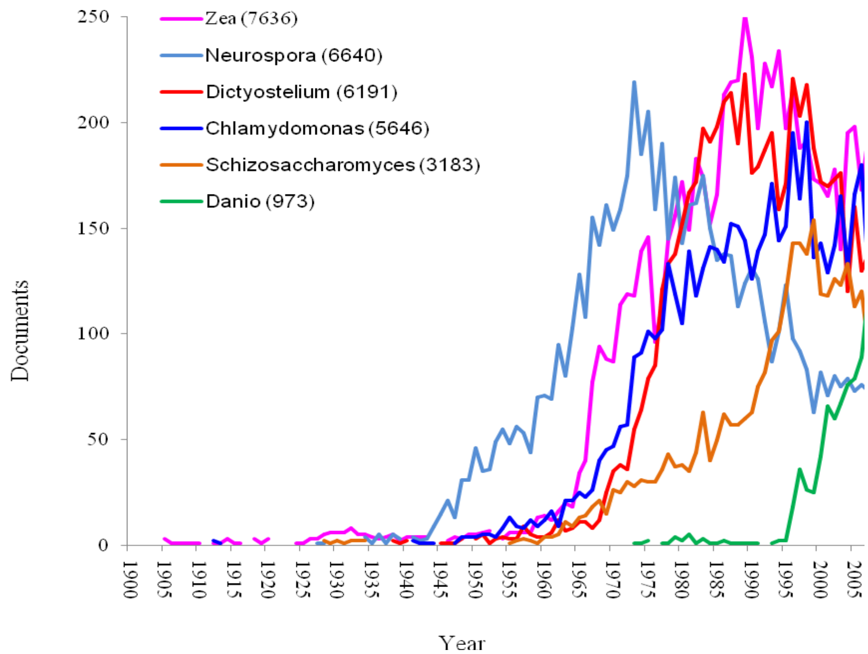

Figure 2. Temporal trend and total number of publications in *Drosophila* and four other biological models.

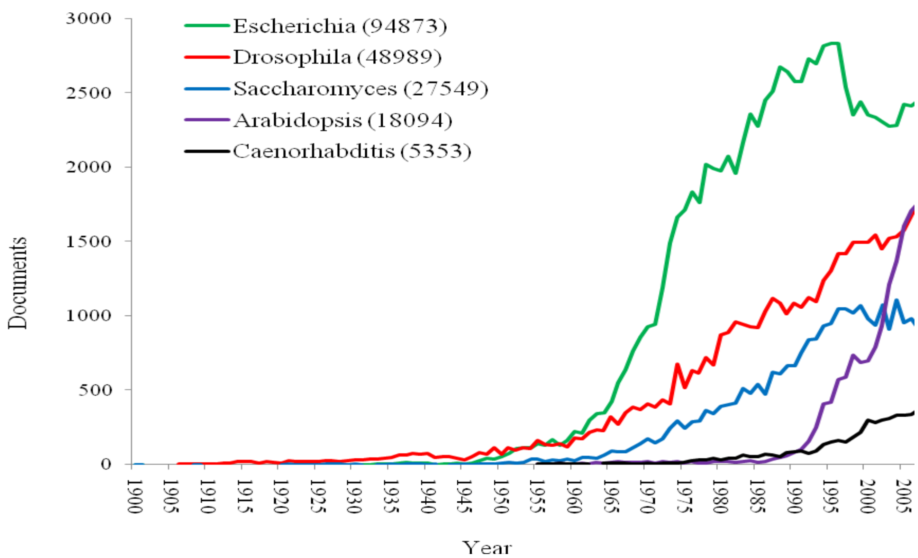

Figure 3. Temporal trend and total number of publications in six biological models.

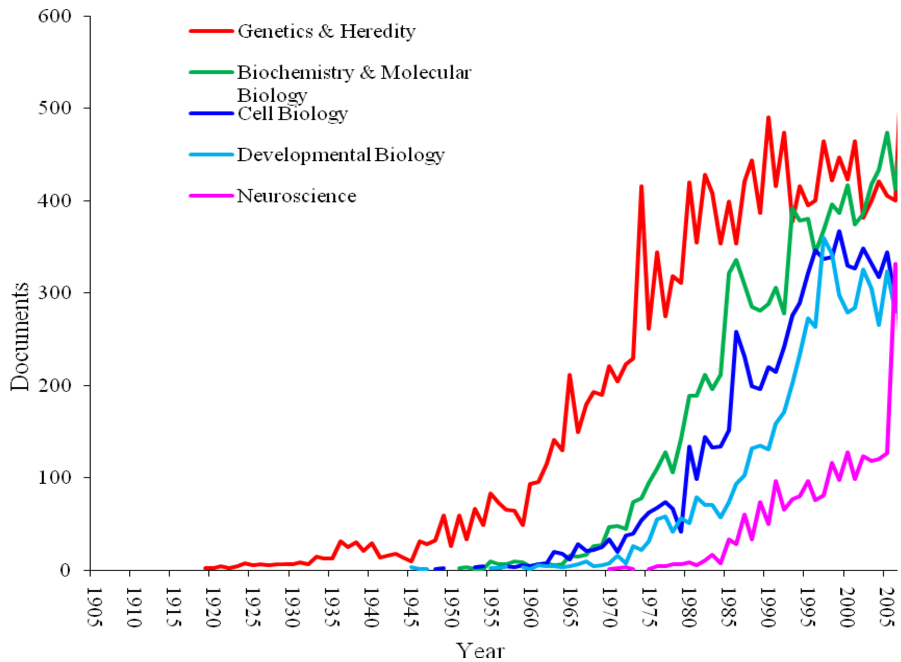

Figure 4. Temporal trends of *Drosophila* research for the most frequent subject.

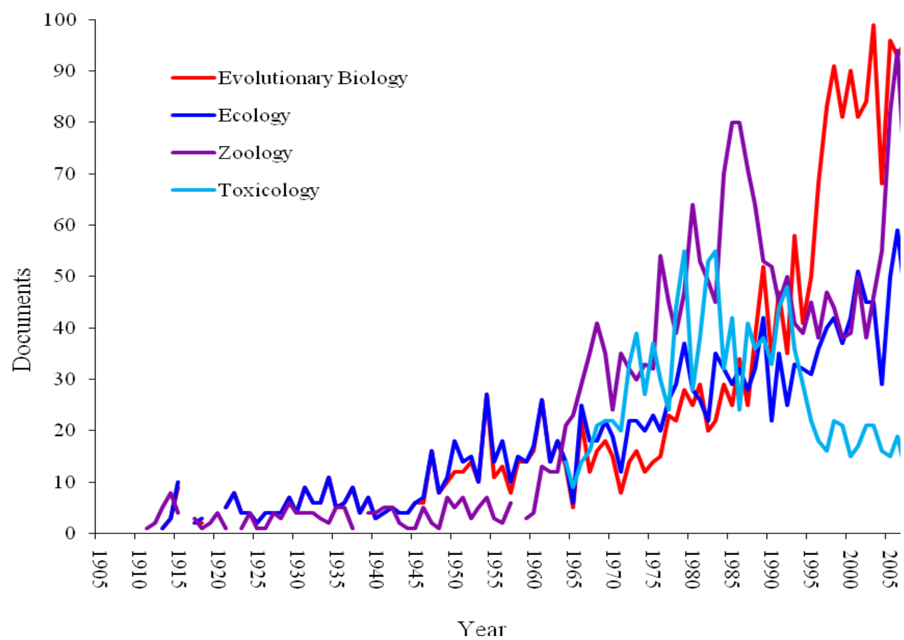

Figure 5. Temporal trends of *Drosophila* research for four additional subjects.

Journals

A total of 1,648 journal names were obtained, 60 of them (3.6%) published 66.6% of the articles about *Drosophila* (Table 9). *Genetics* has the majority publications about *Drosophila*, with nearly 10% of the total. *Cell* and *Nature* have the highest impact (Figure 6).

Table 1. Mesh headings (50 of 501 shown).

MeSH Headings	Record Count	% of 34,300
Animals	31,837	92.82
Drosophila melanogaster	18,425	53.72
Drosophila	14,984	43.69
Drosophila proteins	10,201	29.74
Female	9,614	28.03
Male	8,548	24.92
Mutation	7,931	23.12
Molecular sequence data	6,838	19.94
Base sequence	5,319	15.51
Amino acid sequence	5,049	14.72
Genes insect	4,184	12.20
Phenotype	3,517	10.25
Transcription factors	3,381	9.86
Gene expression regulation, and development	3,358	9.79
Larva	3,309	9.65
DNA	2,832	8.26
Chromosome mapping	2,778	8.10
DNA-binding proteins	2,687	7.83
Transcription	2,654	7.74
Genetic cloning	2,626	7.66
Signal transduction	2,419	7.05
Gene expression regulation	2,374	6.92
Humans	2,366	6.90
Chromosomes	2,344	6.83
Embryo, nonmammalian	2,277	6.64
RNA, messenger	2,261	6.59
Insect proteins	2,204	6.43
Genes	2,185	6.37
Sequence homology, amino acid	2,150	6.27
Alleles	2,036	5.94
Animals, genetically modified	1,952	5.69
Crosses, genetic	1,818	5.30
Species specificity	1,798	5.24
Nuclear proteins	1,784	5.20
DNA transposable elements	1,637	4.77
Wing	1,490	4.34
Membrane proteins	1,488	4.34
Gene expression	1,459	4.25
Genes, lethal	1,390	4.05
Cell differentiation	1,362	3.97
Genetic variation	1,355	3.95
Neurons	1,327	3.87
Morphogenesis	1,314	3.83
In situ hybridization	1,286	3.75
Time factors	1,255	3.66
Homeodomain proteins	1,237	3.61
X chromosome	1,192	3.48
Cell line	1,176	3.43
Genotype	1,159	3.38

Table 2. Mesh qualifiers (20 of 75 shown).

MeSH Qualifier	Record Count	% of 34,300
Genetics	23,265	67.83
Metabolism	13,586	39.61
Physiology	11,655	33.98
Embryology	6,843	19.95
Cytology	4,685	13.66
Growth and development	4,177	12.18
Chemistry	3,712	10.82
Pharmacology	3,414	9.95
Enzymology	3,246	9.46
Drug effects	2,931	8.55
Ultrastructure	2,859	8.34
Analysis	2,574	7.50
Biosynthesis	2,361	6.88
Isolation and purification	1,524	4.44
Anatomy and histology	1,408	4.11
Methods	1,201	3.50
Radiation effects	1,163	3.39
Immunology	944	2.75
Toxicity	648	1.89
Classification	618	1.80

Table 4. Countries (shown 10 of 119).

Country/Territory	Record Count	% of 48,981
USA	21,508	43.91
France	2,845	5.81
England	2,778	5.67
Japan	2,454	5.01
Germany	2,410	4.92
Canada	1,549	3.16
Spain	1,527	3.12
Switzerland	1,348	2.75
USSR	1,119	2.28
Australia	1,031	2.10

Table 3. The 34 most prolific researchers in *Drosophila*, each with 100 or more papers, as retrieved from the Web of Science.

Researcher	Documents (48,981)
Rubin, GM	220
David, JR	203
Dobzhansky, T	185
Perrimon, N	184
Hall, JC	170
Mukai, T	164
Zhimulev, IF	160
Jan, YN	155
Gehring, WJ	149
Jackle, H	148
Ayala, FJ	143
Hoffman, AA	139
Jan, LY	131
Bownes, M	126
Parsons, PA	126
Partridge, L	126
Ashburner, M	123
Green, MM	122
Belyaeva, ES	122
Glover, DM	119
Levine, M	115
Mahowald, AP	115
King, RC	111
Singh, BN	111
Elgin, SCR	110
Wurgler, FE	110
Korochkin, LI	109
Hartl, DL	109
Georgiev, PG	106
Kaufman, TC	103
Wu, CF	103
Rosbash, M	101
Ehrman, L	101
Mackay, TFC	101

Discussion

This study has shown that the temporal scientific production in *Drosophila melanogaster* research is fairly similar and with similar exponential growth in both SCI and Pub Med. The study included all peer-reviewed papers with an abstract and excluded review, meeting abstracts, notes, letters, proceedings papers, and editorial material. The great majority of papers retrieved are written in English. As pointed out, genetics and heredity, biochemistry, molecular biology, and cell biology are the leading research subjects in SCI. The most cited paper, providing the complete sequence of the euchromatic region of the *Drosophila melanogaster* genome was published in *Science* in 2000, with 2,751 citations at the time of the survey.

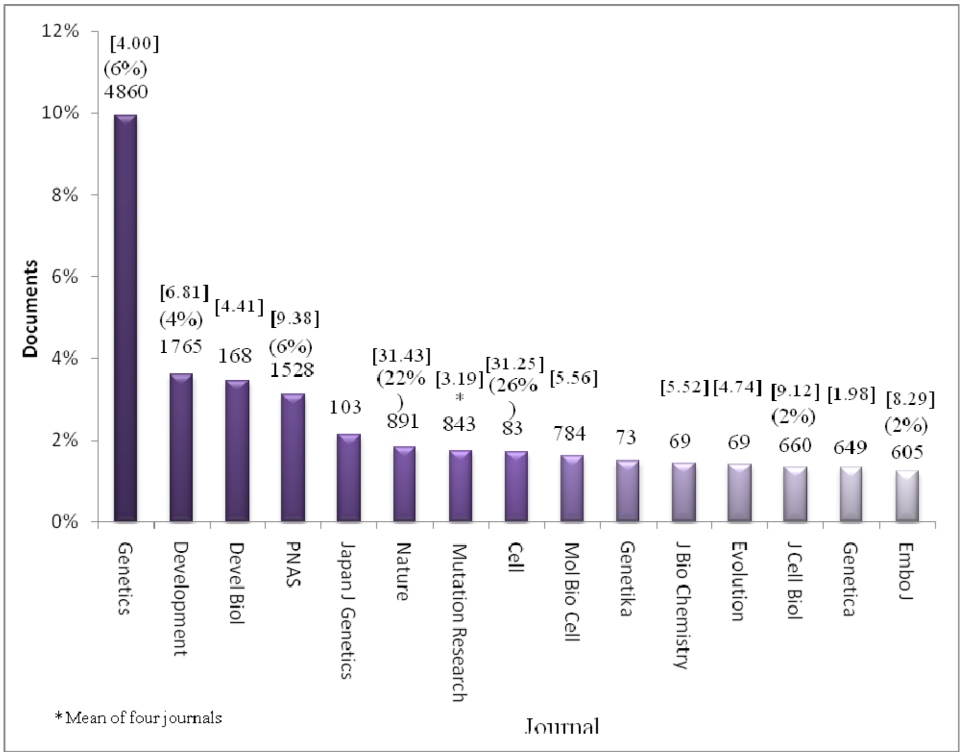

Figure 6. The 15 most productive journals, [impact factor], (% most cited papers), total documents.

The information obtained in this study from a systematic analysis of bibliometric data goes beyond the mere counting of citations. It also takes into account the keywords used in the MeSH – headings and qualifiers – thesaurus as well as different journals and their ranking of topics necessary to establish the dynamics of a scientific field. One factor contributing to the extensive research with *Drosophila melanogaster* may have been the free flow of materials and ideas among its researchers (Prigent and Rajpuroit, 2007). Morgan's style of research and leadership was distinctively focused on an experimental, rather than a descriptive approach to science. Once a critical mass of *Drosophila* researchers was working at different institutions in the USA (Cold Spring Harbor, University of Illinois, and University of Texas, among others), Europe (Kaiser Wilhelm Institute of Berlin), Russia, and Japan by the 1930s, an increase in the number of papers was reported in 1939 by Muller (Kohler, 1964). Another factor that contributed to the extensive use of *Drosophila* was the fact that genetics approaches dominated the first 40 years of research in *Drosophila melanogaster*. After 1950 *Drosophila* researchers realized that genetics approaches could be used to explore other scientific fields in addition to heredity. Thus, from 1950 to 2007 several research subjects, such as Biochemistry, Molecular Biology, Cell Biology, and Developmental Biology, were cultivated and an exponential increase of publications occurred. A decrease is observed in 2008. The decrease observed maybe due to random variation and/or the usual delay in the indexation process.

The most productive and highly cited *Drosophila* scientists are almost exclusively from USA and Western Europe. Among European countries the analysis shows France and England ranking in the first two places; Germany is in the middle; Spain, Switzerland, and the USSR in the bottom. These data are quite different from those in Muller (1939), where although USA and Europe were

Table 5. Institutions 50 of 501.

Institution	Documents	Country
Russian Aca Sci	1,385	Russia
CNRS, France	1,132	France
Harvard	1,110	USA
Washington	850	USA
Cambridge	810	England
Berkeley	799	USA
Paris	656	France
Yale	650	USA
San Francisco	605	USA
Stanford	598	USA
North Carolina	591	US.A
Wisconsin	552	USA
Zurich	548	Switzerland
Texas	528	USA
Max Planck	526	Germany
Pennsylvania	518	USA
Irvine	510	USA
Cornell	505	USA
Davis	492	USA
Edinburgh	485	Scotland
Arizona	481	USA
Caltech	428	USA
Barcelona	416	Spain
Chicago	414	USA
San Diego	410	USA
Los Angeles	408	USA
Indiana	406	USA
Johns Hopkins	391	USA
Columbia	388	USA
Madrid	386	Spain
Princeton	383	USA
European Mol Bio Lab	376	France
MIT	368	USA
Brandeis	361	USA
Tokyo	336	Japan
Duke	334	USA
Leiden	330	Netherlands
Baylor	326	USA
Basel	314	Switzerland
California	289	USA
Illinois	280	USA
Iowa	273	USA
Toronto	270	Canada
Minnesota	270	USA
Carnegie	269	USA
Utah	259	USA
MRC	259	England
Rochester	256	USA
British Columbia	245	Canada
U. Cologne	238	Germany

ranking with the highest scientific production (1,024 and 821 papers, respectively) a fine analysis showed that Russia (408) and Germany (149) were in the first and second places among European countries. From 1905 to 2008 virtually all European countries published papers with the word *Drosophila* in the title. Large countries such as England, Germany, Italy, and France published the highest number of papers. Among non-European countries, Japan was at the top following the United States. Concerning Iberoamerican countries, Spain produced five times more papers than Brazil, while Chile, Portugal, Argentina, and Mexico all together account for one third of those published in Spain.

The journal Impact Factor (IF) is calculated by the Institute of Scientific Information (ISI) as the average number of citations that a paper published in that journal receives in the two years following publication (Garfield 2006). Some journals in our survey are multidisciplinary, such as *Nature* and *Science* covering all scientific fields. Their social function in the scientific community is to provide communications about major discoveries whose details are often published in a more standard central journal of the discipline (Gingras 2010). *Nature* and *Science* have the highest count of IF, while the disciplinary journals have a lower IF. The difference, however, does not imply anything about the research quality. Among the 50 most cited papers the ranking of core journals are *Cell, Nature,* and *Science,* while for all published papers with *Drosophila* in the title *Genetics* is the top journal, as shown in this study.

The interpretation of the results of this global bibliometric analysis should take into account a number of potential limitations. The most remarkable is that we have chosen for the study only papers with the word *Drosophila* in the title. Moreover, both databases are biased in favor of English language journals: Japanese, Russian, Spanish, and Portuguese, among others have not been taken into account in this study. Another limitation of this bibliometric analysis - which affects all bibliometric studies - is represented by the intrinsic inaccuracy in the IF index as a measure of the quality of scientific production. The IF is an index that does not necessarily reflect the quality of a single paper; instead, it is a journal average value that may be severely conditioned by the ups and downs of scientific interests (Garfield, 2006).

This report represents the first effort to explore the global scientific production employing *Drosophila melanogaster* as an experimental model organism. It provides quantitative information about the growth of *Drosophila* research and, through the use of MeSH headings and qualifiers, a ranking of the most successful topics and temporal trends. We have shown that there are temporal trends with respect to research subject as well as to model organisms and prevailing methodologies: toxicology, cell biology, and descriptive developmental research are decreasing, while evolutionary biology, biochemistry, and molecular biology are increasing. The most frequent terms in *Drosophila* research have genetics, heredity, or a molecular connotation.

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Availability of the University of Texas Publications Dealing with *Drosophila*

Marshall R. Wheeler

From 1940 to 1972 many research articles were published by the University Press in the series, "Studies in the Genetics of *Drosophila*" with J.T. Patterson as editor and later (from 1957-1972) with M.R. Wheeler as editor. In 1960 the series title was changed to "Studies in Genetics." There were also a few special issues. Many of these are now out of print (OOP); all known copies of the remaining issues have been made available by Dr. Wheeler. The copies are available from the office of the Editor, *Drosophila Information Service*; contact Dr. James N. Thompson, jr., (jthompson@ou.edu) for details.

Some issues were given titles and subtitles, but the Publication Number (*e.g.*, UTP 4213) is the best reference. This is the complete list of all the publications:

1940: UTP 4032 (OOP). 1942: UTP 4213 (OOP). 1942: UTP 4228 (OOP). 1943: UTP 4313, "Drosophilidae of the Southwest" (OOP). 1944: UTP 4445, with "Drosophilidae of Mexico" (OOP). 1947: UTP 4720, "Isolating Mechanisms" (OOP). 1949: UTP 4920 (OOP). 1952: UTP 5204 (25 copies). 1954: UTP 5422 (OOP). 1957: UTP 5721 (45 copies). 1959: UTP 5914, "Biological Contributions." Dr. Patterson's 80th birthday issue (59 copies). 1960: UTP 6014 (16 copies). 1962: UTP 6205 (63 copies). 1966: UTP 6615, Morgan Centennial Issue (28 copies). 1968: UTP 6818 (24 copies). 1969: UTP 6918, W.S. Stone Memorial Issue (12 copies). 1971: UTP 7103 (22 copies). Final volume, 1972: UTP 7213 (29 copies).

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