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JoAnn Hilmas

Walter Fluegel
University of Minnesota, Duluth

Dictyostelium Discoideum's 35-year Contribution to Growth of Biology: A Bibliometric Analysis

JoANN HILMAS* and WALTER FLUEGEL**

ABSTRACT – *Biological Abstracts* is a sufficiently adequate bibliometric tool for the analysis of the accumulated literature of certain organisms. *Dictyostelium discoideum* (Cellular slime mold) titles are scarce, yet literature growth parallels some of the same growth patterns as the whole of science. Relatively few (5 percent) biologists produce most (55 percent) of the literature on this organism. American authors predominate. The literature is grouped into various categories such as aggregation, cytology, growth, and genetics with the molecular-physiological works surpassing all other categories combined in the last 5 years (66 percent). Although the literature is scattered worldwide, most articles are found in relatively few journals. *Biological Bulletin* was the steady "home" for information for 22 years with 15 articles and the *Journal of Bacteriology* accumulated 16 articles in the last 4 years of the survey. The analysis begins with Raper's discovery description of *D. discoideum* in 1935 and ends with 1970.

The history of biology is usually about biologists and their ideas but not about the organisms which are the raw material of biology. Perhaps specific organisms might tell us about the unfolding of knowledge, the scientists who had an interest in them, the fads in research, the unique features of particular organisms which stimulated the curiosity of scientists or something about the journals that house the information.

One can look at a phylum (Schopf, 1967) or a single species as has been done in this paper. Each paper or article about an organism contributes small fragments to science history, yet this history is scattered worldwide in many journals. Biological Abstracts (BA) is a repository for condensed fragments of this history. This paper describes how BA can be used as a first approximation bibliometric tool to understand the flow of biological history by analysing one organism at a time. Reviews or monographs cannot be used for the thrust presented here because review writers could ignore certain authors, or be biased or very specialized.

A cellular slime mold, *D. discoideum,* has been chosen as a model species for discussion. It was discovered in 1933 by Kenneth B. Raper several years after the founding of BA in 1926.

D. discoideum is an amoeba which feeds on bacteria in organic soil. It multiplies by binary fission, thus producing numerous independent amoeboid cells. When the food source is consumed in the area of feeding, certain cells produce the chemical, acrasin, which attracts other cells (chemotaxis) which in turn become producers of acrasin. Thus, centers of aggregation are formed. Eventually, each aggregation becomes a multicellular structure (pseudoplasmodium), resembling a miniature bullet. The pseudoplasmodium migrate sembling a miniature bullet. The pseudoplasmodium migrates towards light and undergoes certain morphogenic changes. A stalk is formed by some of the cells, thus elevating the remaining mass. When stalk formation stops, non-stalk cells become spores in a spore head. Elevated above the substratum, spores are subject to dispersal by rain and flowing water or carried on insect bodies. On a favorable substrate spores will germinate, releasing an amoeba to renew the cycle.

JoANN HILMAS was graduated from the University of Minnesota, Duluth, in 1973 and is teaching mathematics and physical education in Cambridge, Minnesota.

**WALTER FLUEGEL is an assistant professor of Biology at the University of Minnesota, Duluth.

The Species Name is the First Step.

Each organism listed in BA is found in the index of earlier editions and in a computer print-out retrieval system of later editions. A simple tabulation of entries under the species name reveals the growth of literature under that name and the future work load for the investigator. Each abstract is either noted for specific information or copied, cut out, and taped to a card for future sorting. The discrete bits of information available from each abstract entry are title, author(s), journal, pages, date of publication, place of investigation or country, and the abstract with its key words.

The study includes all publications from 1935 to 1970 and totaled 182 cards. Several types of derived information become available when cards are sorted.

A. **Growth of literature:** Card sorting in five-year classes shows the growth of *D. discoideum* literature or scholarly work (figure 1). Half the titles accumulated between 1935 and 1964, a period of 29 years, whereas the other half occurred explosively in the six years between 1964 and 1970. Raper (personal communication) estimates that the literature doubled again from 1970-1975. Note: BA is now stored in a computer for access under species, author or other key word retrieval codes. Recently - March 1978 - the computer had 410 titles for the years 1975-1978.

B. **Authors and productivity**: There were 121 different authors, singly or in combination, who were interested in *D. discoideum* but only a few authors were major contributors (Table 1). Productivity in this context means all BA entries whether they were titles of books, abstracts of talks, or research articles because each entry is an indication of scholarly work. Table 1 also gives an index of whether the researcher worked alone or with others.

Kenneth Raper and J.T. Bonner are the two biologists who span the longest time of investigation. A preliminary survey of *D. discoideum* titles attributed to these researchers showed wide gaps over the years. However, a back-check of BA was re-examined through the author index and compared with publication lists graciously supplied by these two authors.

Three points were observed immediately: (1) that Bonner and Raper were very productive biologists (figure 2); (2) that BA did indeed record most output from these two authors, and (3) there should not be too heavy reliance upon using species name to the exclusion of other names or concepts in such studies.

Table 1 — Productivity Index for Investigators*
of *Dictyostelium discoideum*

Name†	Total	Alone	With Others	Index: Alone Total	Per Year	Work Span Year	% of Total+
Sussman	28	6	22	.21	1.65	53/70	15.
Wright	21	2	19	.09	2.62	61/69	11.
Bonner	19	7	12	.37	.73	44/70	10.5
Raper	13	5	8	.38	.39	36/69	7.2
Gregg	10	5	5	.50	.55	50/68	5.5
Konijn	10	5	5	.50	1.43	62/69	5.5

* Those having 10 or more entries recorded in BA.
† Maurice Sussman, Barbara E. Wright, John T. Bonner, Kenneth B. Raper, James H. Gregg, Theo M. Konijn.
+ Based upon all 121 authors producing 182 abstracts. About 5% of the scholars influenced or were responsible for 54.8% of the BA entries. However, based upon works done alone, they constitute 16.5% of all BA entries. A subjective analysis shows increasing frequency of multiple authorships from the discovery of *D. discoideum* to 1970.

C. Journals used: *D. discoideum* information was published in 55 journals. Some journals were favorites (figure 3). About 10 percent of the journals publishing anything on *D. discoideum* published 36 percent of the literature on the organism up to 1970.

D. Subject matter: Without the original article one must use the abstracts or title to discern research trends (Table 2). Judgements in this report were subjective and very general.

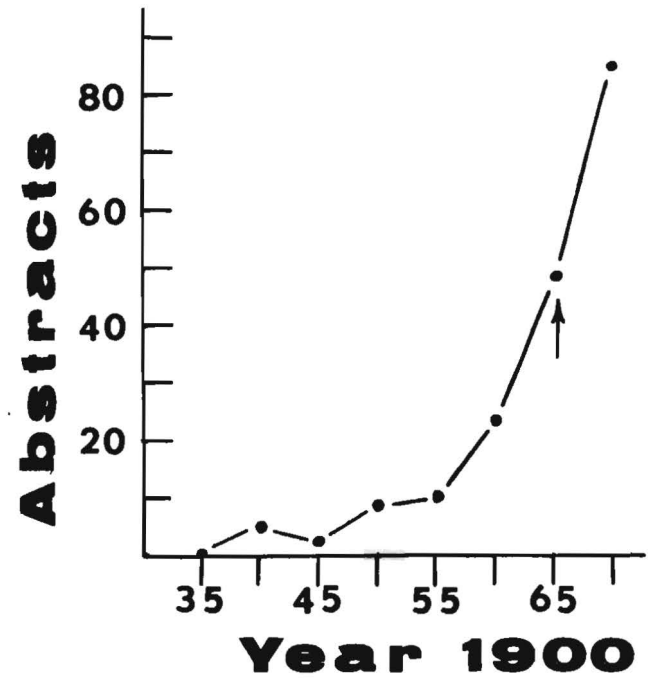
Why BA Is Preferred.

Will the saving of time by using BA sacrifice knowledge obtained by any other method? As a first approximation, card sorting lends itself well to future in-depth studies with computer analysis. Since the computer storage goes back only to 1970, extensive work must be done for more popular species, e.g. *Drosophila melanogaster.* It is now possible to collect all the printed material on *D. discoideum* for reading and analysis. But Menard (1971) points out the futility of reading everything in a rapidly growing subfield of a science. Fortunately, abstracts can be read for key words or phrases.

Change in emphasis of research from descriptive to the experimental or molecular-physiological approaches was observed in *D. discoideum* (Table 2). This also is noted in the type of journal selected for publication (figure 3). If abstracts are a true reflection of the articles, then BA is preferred as more convenient because it saves time. One can ask why the research took the route it did; however, the original research and interviews with the biologists themselves are necessary. As Price (1963) and other references point out, 90 percent of all the scientists who ever lived are still alive, and thus available to be interviewed. The detailed account of the cellular slime molds research is beyond the scope of this report. Among other things it involves the search for the identity of acrasin and the cytochemistry of changes as the amoebae become stalk or spore cells. It is noted investigators went into molecular biology. Was this following, or influenced by the main trend in all of biology? (Menard, 1971) Is the descriptive phase exhausted? Raper and his student (Cavender and Raper, 1968) demonstrate it is not. Steyskal (1965) demonstrates that the descriptive phase is not exhausted with respect to other organisms.

Conrad (1957) suggests that BA abstracted 45 percent of the world's literature during 1930 but only 17 percent by 1954, as the literature avalanche and financial problems caused BA to fall behind. In 1957 the estimate was 25 percent. In terms of research categories (Table 2), would the percentages change very much as BA abstracted more or less of the world's literature?

FIGURE 1. — Growth of *D. discoideum* scholarly works. Totals for five-year classes. After 1955 the growth doubles in six years. Arrow shows where half the growth has occurred.



What would change is the total number of publications used to construct the growth curve of *D. discoideum* abstracts (figure 1), productivity concepts (Table 1), and favorite journals (figure 3). However, the biologists who have had the most interest in *D. discoideum* are largely Americans or produced their work from American research centers. Of the Americans, only a handful have contributed to most of the literature up to 1970 (Table 1). Carried further, Bonner's and Raper's own lists compared to BA give assurance that BA is fairly complete with respect to *D. discoideum* research or titles. The literature citations for *D. discoideum* may be relatively complete. Would it be for other organisms?

FIGURE 2. – Scholarly works of Kenneth B. Raper (R) and J. T. Bonner (B) starting from the first publication on *D. discoideum*. Code letters indicate *D. discoideum(o), Cellular* slime mold (S), other organisms (O), essays (E), and books (B). Research papers done with students, fellows or post-doctorates (X, Bonner only).

Most of the other organisms (O) of K.B. Raper include his works on fungi such as *Penicillium and Aspergillus.*

Book reviews or lectures are not included.

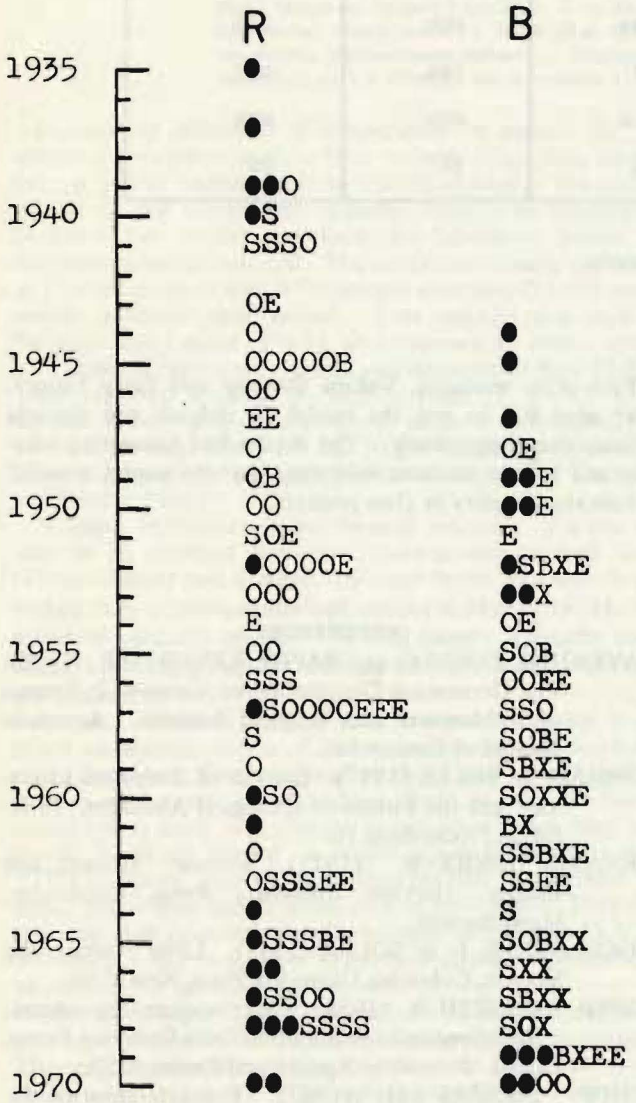
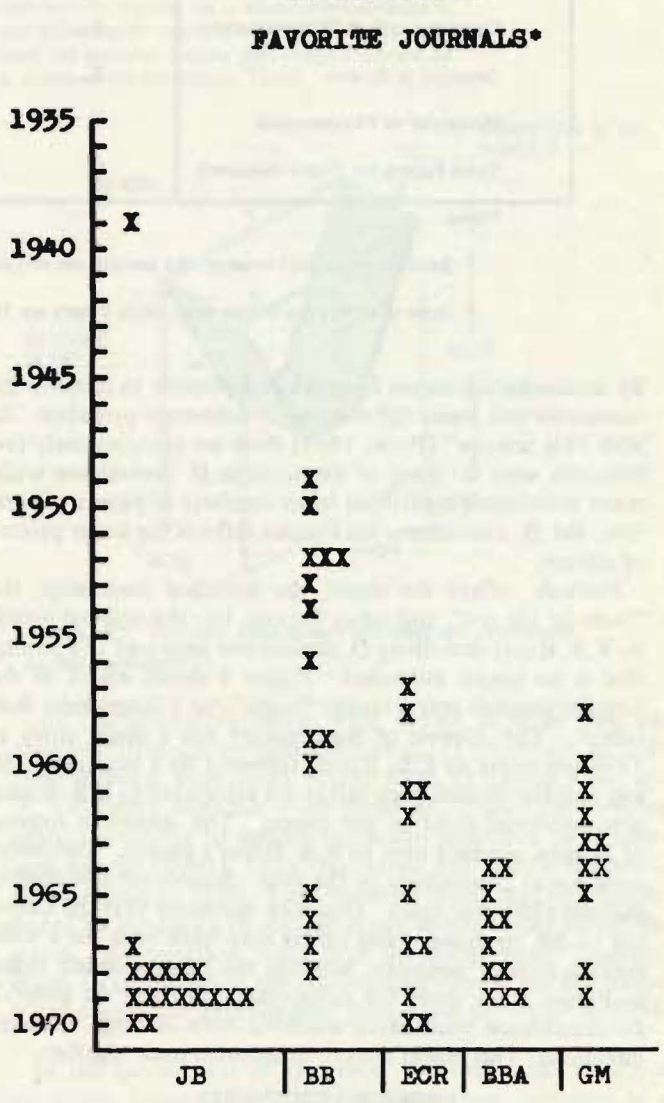


FIGURE 3. – Distribution of journals publishing more than 10 articles on *D. discoideum*. Founding date included to indicate relative need to publish information for specific areas of biology.

JB Journal of Bacteriology (1916) - 17 articles
BB Biological Bulletin (1900) - 15
ECR Experimental Cell Research (1950) - 11
BBA Biochemistry Biophysics ACTA (1947) - 11
GM Journal of General Microbiology (1947) - 11



Cautionary Suggestions.

Figure 2 suggests this study may have been too limited by being restricted to one species. Bonner, for example, used the species name in only half his titles, yet *D. discoideum* was used as an experimental organism on other occasions. Raper used the species name roughly one-third of the time. This compilation relied too much upon title writers, species index, and key word writers for BA. Back-checking using prolific workers proved necessary. For figure 2 the authors were interested in the biologists who had an interest in *D. discoideum* and hence can justify inclusion of related organisms or organisms traditionally placed in general terms such as slime molds, (other examples: planaria or dolphin).

As a first estimate then, restriction to one species at a time does have advantages. For more detailed analysis from BA, the complex of organisms should be queried for no other reason than that the biologists might have been interested in related organisms as Figure 2 suggests. Schopf (1967) includes a whole phylum, but the authors of this discussion thought this approach too broad, especially in short term study or for class use.

Perhaps computer sorting could explore more parameters. Would more biologists be thus identified? Is there another cellular slime mold that has more advantages for lab work than *D. discoideum?* The unique features of *D. discoideum* for laboratory work are the separate, clear distinctions between each stage in the life cycle: cell, aggregation, pseudoplasmodium, migration, stalk formation, spores, germination. Other species of cellular slime molds have overlaps which complicate study of each stage.

BA is a neutral recorder of interested biologists. It does not deliberately exclude authors, as might a biased reviewer.

Table 2 – General Trends in Investigation of *D. discoideum*

Major Areas or Chief Emphasis	Percentage* of Total Papers Published in Years Indicated			
	1935-1945	1946-1955	1956-1965	1965-1970 +
Culture and Growth	50%	11%	7%	9%
Aggregation and Fruiting	75%	61%	35%	35%
Cytology or Cell Differentiation	0	28%	16%	20%
Genetics or Strains	0	0	14%	10%
Molecular or Physiological	0	11%	49%	66%
Total Papers for Years Indicated	8	18	71	85

Notes

* Because of subject overlap, the percentage will go beyond 100%.

† Note that this is a 5-year span while others are 10.

By accumulating names from BA it is possible to identify the luminaries and lesser lights without deliberate prejudice. As with "big science" (Price, 1963) there are comparatively few scientists who do most of the work in *D. discoideum* while many individuals contribute lesser numbers of papers. Therefore, the *D. discoideum* microcosm reflects the larger picture of science.

Journals reflect the times, the intended readership, the "state of the art", and other factors, but the original article by K.B. Raper describing *D. discoideum* appeared in a journal that is no longer published. Figure 3 shows which of the popular journals was a steady "home" for a longer time than others. The *Journal of Bacteriology* has a single entry in 1939 belonging to K.B. Raper, followed by a large gap. The gap and the sudden high influx are attributed to K.B. Raper, who produced eight of the papers. The *American Journal of Botany* received nine of K.B. Raper's papers. Curiously, none has *D. discoideum* in the title. Bonner used *Biological Bulletin* (BB) five times. One may speculate that the longer use of BB by Bonner and others may have been for a wide general biology audience, whereas the other journals listed in Figure 3 are more for molecular biologists. In general, *D. discoideum* researchers scattered their findings in many directions. This report tries to bring them back together.

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Two other students, Valorie Sweeny and Terry Zenner, later used BA to test the model for dolphin and planaria information, respectively. The results had interesting parallels and unique features indicating that the model is useful in historical inquiry or class projects.

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